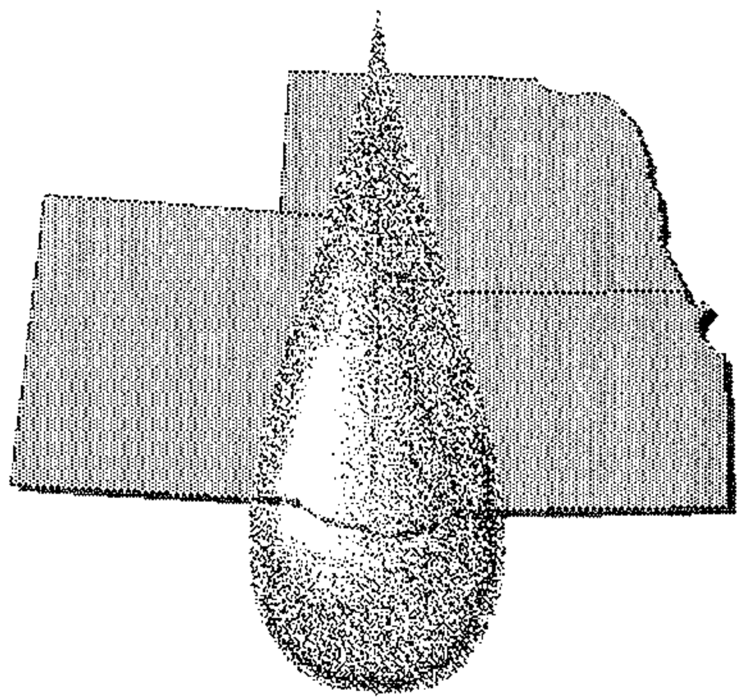
Central Plains Irrigation Short Course & Exposition

Proceedings



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COMPUTING FIELD LOSSES FOR FURROW IRRIGATION

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The goal of every irrigator should be to apply the right amount of water as uniformly as possible to meet the crop needs. To do the job right, irrigators need to take into account how much water is applied during irrigation and where the water goes (uniformity). Achieving a uniform water application is not easy when using furrow irrigation. However, with a better understanding of how irrigation system management affects water distribution and a willingness to make management changes, the uniformity and efficiency of most systems can be improved. This paper outlines the use of the "*cutoff ratio*" and how irrigators can use this management parameter to evaluate irrigation system performance.

CUTOFF RATIO

Soil texture, slope, and surface conditions (whether the furrow is smooth or rough, wet or dry) all influence how quickly water advances down the furrow. The speed of advance is directly related to how uniformly irrigation water is distributed within the soil profile. Prior to all irrigations soil surface conditions should be evaluated and the set size and corresponding stream size chosen accordingly. Having too many furrows running will slow the water's advance rate, resulting in excessive deep percolation at the head of the field, Figure 1a. Using a small set (relatively few gates open) results in a quicker, more suitable advance time and a more even, uniform, infiltration profile, Figure 1b. However, small sets coupled with a long set time may cause excessive runoff. So what is the correct compromise between runoff and deep percolation that will result in the highest system efficiency? The *cutoff ratio* is a management parameter that helps surface irrigators determine the proper balance and evaluate system performance.

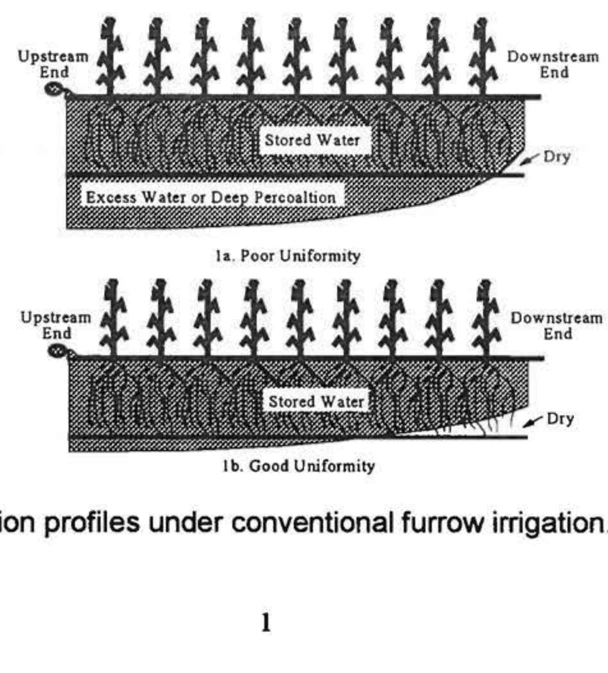

Figure 1. Infiltration profiles under conventional furrow irrigation.

The *cutoff ratio* is defined as:

$$CR = \frac{t_L}{t_{co}}$$

where: CR = cutoff ratio,
t_L = advance time to the end of the field, and
t_{co} = set time.

In general, low *cutoff ratios* result in large amounts of runoff, but good uniformity. While high *cutoff ratios* result in small amounts of runoff, but poor distribution. The *cutoff ratio* that provides the maximum irrigation efficiency is dependent both on soil characteristics and irrigation system configuration. Table 1 shows recommended *cutoff ratios* for three broad soil textural classes and several different irrigation system configurations. In Table 1, *Open Reuse System* refers to a system where the runoff from one field is applied to an adjacent field; *Closed Reuse System* refers to a system where runoff water is reapplied to the same field.

Table 1. Recommended cutoff ratios to achieve maximum efficiency.

	Clayey	Silty or Loamy	Sandy
No Reuse	0.90	0.70	0.50
Open Reuse System	0.70	0.50	0.35
Closed Reuse System	0.50	0.40	0.20
Blocked ends (low slope, 0.1%	0.95	0.85	0.70
Blocked ends (moderate slope, 0.5%	0.95	0.80	0.65

Researchers in Nebraska have developed relationships between the *cutoff ratio* and a set of irrigation performance parameters that can be used to predict infiltration depth and evaluate irrigation field losses like runoff and deep percolation:

$$R_i = Infiltration\,Ratio = \frac{Infiltration\,depth\,exceeded\,in\,90\%\,of\,\,field}{Gross\,depth\,applied}$$

$$R_p = Deep\,Percolation\,Ratio = \frac{Depth\,of\,\,percolation}{Gross\,depth\,applied}$$

$$R_r = Runoff\,\,Ratio = \frac{Depth\,of\,\,runoff}{Gross\,depth\,applied}$$

Table 2 contains values for these performance ratios for three broad soil textural classes and a range of cutoff ratios. The values presented assume a cutoff time (t_{co}) of 12 hours, a time of recession equal to 1 hour, and that the infiltrated depth occurs at $^9/_{10}$ of the furrow length.

Table 2. Furrow irrigation performance ratios*: R_i – ifiltration, R_p – deep percolation, and R_r. – runoff.

Cutoff	Clayey			Silty or Loamy			Sandy		
Ratio	R_i	R_p	R_r	R_i	R_p	R_r	R_i	R_p	R_r
0.1	0.188	0.001	0.811	0.315	0.002	0.683	0.495	0.005	0.500
0.2	0.316	0.006	0.679	0.454	0.015	0.532	0.613	0.030	0.358
0.3	0.421	0.015	0.565	0.549	0.035	0.417	0.677	0.063	0.263
0.4	0.511	0.028	0.462	0.617	0.061	0.323	0.709	0.102	0.192
0.5	0.586	0.046	0.369	0.664	0.094	0.245	0.720	0.147	0.137
0.6	0.648	0.069	0.284	0.691	0.134	0.178	0.714	0.198	0.094
0.7	0.696	0.099	0.207	0.700	0.182	0.122	0.692	0.255	0.060
0.8	0.727	0.138	0.138	0.691	0.239	0.075	0.67	0.318	0.034
0.9	0.737	0.190	0.077	0.662	0.308	0.038	0.608	0.388	0.016
1.0	0.720	0.260	0.027	0.608	0.392	0.011	0.545	0.260	0.001

*Preliminary Data

The following example demonstrates the application of these performance ratios.

Example:

Let's choose one of the recommended cutoff ratios given in Table 1, *CR = 0.4* (silty or loamy soil with a closed recovery system), and a gross irrigation application of 5 inches. Using the performance ratios find; the infiltrated depth at x_f = 0.9 (x_f is ratio of position along the furrow to total furrow length), depth lost to deep percolation, depth of runoff, and application efficiency.

From Table 2: $R_i = 0.617$
$R_p = 0.061$
$R_r = 0.323$

$$Infiltration\, depth\, exceeded\, in\, 90\%\, of\;\, field = 5\, inches\, x\, 0.664 = 3.3\, inches$$

$$Depth\, of\;\, percolation = 5\, inches\, x\, 0.094 = 0.5\, inches$$

$$Depth\, of\;\, runoff = 5\, inches\, x\, 0.245 = 1.2\, inches$$

For a closed runoff recovery system, application efficiency is calculated using:

$$AE = Application\,Efficiency = \left[\frac{1 - R_r - R_p}{1 - R_r R_T}\right] x100$$

where: R_T = return ratio (efficiency of the recovery system)
= volume applied from the recovery system divided by the volume of runoff
= 0.85 (assumed)

$$AE = \left[\frac{1 - 0.323 - 0.061}{1 - (0.323\,x\,0.85)}\right] x100 = 85\%$$

This example illustrates a system operating at maximum efficiency. For this efficiency to be attained the infiltration depth exceeded in 90% of the field (R_i) must be less than the available storage capacity in the soil profile. If R_i exceeds available storage capacity, the field has been uniformly over-irrigated and the calculated application efficiency is no longer valid. If the irrigator is not able to increase the available storage, perhaps the profile could be dried-down further before irrigation occurs, then other practices that reduce infiltration depths, such as every-other-furrow irrigation or shorter set times, must be considered.

RULES-of-THUMB

The way that runoff is managed greatly affects the amount of water lost to deep percolation, and the uniformity of water distribution along the row. When *cutoff ratio* guidelines are properly used deep percolation decreases and uniformity improves. In an effort to encourage wider adoption of the *cutoff ratio* concept, practical "rules-of-thumb", that generally adhere to the recommended *ratios* shown in Table 1, were developed. The two rules-of-thumb are the less-than-half rule and the three-quarters-plus rule. These general guidelines are broadly applied to two categories of systems, those with runoff reuse and those without runoff reuse.

Systems with Runoff Reuse

When runoff is reused, apply the less-than-half rule to obtain uniform application: the average furrow advance time should be less than half of the total set time. The exception is the first irrigation of the year when advance should take closer to 60-65% of the total irrigation time. This rule will be easier to follow as the season progresses and advance times quicken, as furrows tend to smooth out. If the irrigator normally uses 12-hour sets, shorter set times should generally be used during the first irrigation, to avoid uniformly over-irrigating the whole field.

Systems without reuse of runoff

If there is no reuse system, apply the three-quarters-plus rule to estimate the advance time: water should get to the end of the field in about three fourths of the total irrigation set time. This rule applied throughout the growing season, both for early season and later irrigations. For example: if you run 12-hour irrigations, your set size should be adjusted so that water reaches the end of the field in an average of 9 hours. Although a 9-hour advance time follows the three-quarters plus rule, a 12-hour set time may still result in poor irrigation uniformity and efficiency. For the first irrigation of the season when the root zone is shallow, 12-hour sets are likely too long on 1/4 mile rows.

Blocking the lower end of the field is one method that is sometimes used to retain water that would otherwise be runoff. The practice of blocking furrow ends often results in excessive deep percolation, especially at the downstream end of the field. If blocked-end furrows are used, apply the three-quarters-plus advance time rule discussed earlier. By properly managing blocked-end furrow irrigation, deep percolation cannot be eliminated, but it can be minimized.

SUMMARY

The goal of every irrigator should be to apply the right amount of water as uniformly as possible to meet the crop needs. With a better understanding of how irrigation system management affects water distribution and a willingness to make management changes, the uniformity and efficiency of most surface irrigation systems can be improved. This paper presented some generalized irrigation management rules-of-thumb that if properly applied will improve irrigation system performance. Application of the *cutoff ratio* concept to evaluate irrigation performance was also illustrated. More detailed *cutoff ratio* resources are available through Nebraska Cooperative Extension.

DESIGN AND MANAGEMENT CONSIDERATIONS FOR SUBSURFACE DRIP IRRIGATION SYSTEMS

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INTRODUCTION

Every project must have a goal. This goal should be solidly grounded with a purpose. It makes little sense to achieve a goal if the purpose has not been satisfied. If the goal of the irrigator is to develop and operate a successful subsurface drip irrigation (SDI) system, what is the purpose? Water conservation and water quality protection have often been cited as possible purposes to consider SDI. If so, it is imperative that the SDI system be designed and operated in a manner that there is a realistic hope to satisfy those purposes. It should also be noted that an improperly designed SDI system is less forgiving than an improperly designed center pivot sprinkler system. Water distribution problems may be difficult or impossible to correct for an improperly designed SDI system.

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HYDRAULIC DESIGN

Successful operation of a SDI system begins with a proper hydraulic design which satisfies constraints dictated by crop, soil type and characteristics, field size, shape, and topography, water source and supply. Disregarding design constraints will likely result in a system that is costly in both time and money to operate and will likely increase the chance of system failure. System failure might result in the loss of the total capital investment.

Crops and Soils Considerations

The crop and soil type will dictate SDI system capacity, dripline spacing, emitter spacing, and installation depth. The SDI system capacity must be able to satisfy the peak water requirement of the crop through the combination of the applied irrigation amount, precipitation, and stored soil water. The system capacity will influence the selection of the dripline flowrate and the zone size (area served by each submain). Improper selection of these items can result in more expensive systems to install and operate.

The dripline spacing is obviously an important factor in system cost, and economics suggest wider spacings. However, wide spacing will not uniformly supply crop water needs and will likely result in excess deep percolation on many soil types. The dripline spacing is dictated by the lateral extent of the crop root zone, lateral soil water redistribution, and in-season precipitation. Studies on silt loam soils in western Kansas conducted by Kansas State University have indicated that a 60-inch dripline spacing is optimal for a corn-row spacing of 30 inches. Soils that have a restrictive clay layer below the dripline installation depth would probably allow a wider dripline spacing without affecting crop yield. Wider spacings may also be allowable in areas of increased precipitation as the dependency of the crop on irrigation is decreased. The emitter spacing is dictated by the same factors affecting dripline spacing. However, generally, the emitter spacing is less than the dripline spacing. As a rule of thumb, dripline spacing is related to crop row spacing while emitter spacing is more closely related to crop plant spacing. One of the inherent advantages of a SDI system is the ability to irrigate only a fraction of the crop root zone. Careful attention to dripline spacing and emitter spacing are, therefore, key factors in achieving the purpose of water conservation and water quality protection.

The installation depth is also related to the crop and soil type. Deep installations reduce the potential for soil evaporation and also allow for a wider range of tillage practices. However, deep installations may limit the effectiveness of the SDI system for germination and may restrict availability of surface-applied nutrients. Acceptable results have been obtained with depths of approximately 18 inches in KSU studies in western Kansas on deep silt loam soils. Dripline should probably be installed above any restrictive clay layers that might exist in the soil. This would help increase lateral soil water redistribution.

Field Size, Shape, and Topography

The overall field size may be limited by the available water supply and capacity. The ability to economically adjust the size of the irrigated field to the available water supply is a distinct advantage of SDI systems compared to center pivot sprinklers. If sufficient water supply is available, the field size, shape, and topography, along with the dripline hydraulic characteristics, will dictate the number of zones. Minimizing the number of necessary zones will result in a more economical system to install and operate.

Whenever possible, dripline laterals should be installed downslope on slopes of less than 2%. On steeper terrain, the driplines should be made along the field contour and/or techniques for pressure control should be employed.

Dripline Hydraulic Characteristics

Pressure losses occur when water flows through a pipe due to friction. These friction losses are related to the velocity of water in the pipe, the pipe inside diameter and roughness, and the overall length. The emitter flowrate (Q) can generally be characterized by a simple power equation

$$Q = k\,H^{x}$$

where k is a constant depending upon the units of Q and H, H is the pressure and x is the emitter exponent. The value of x is typically between 0 and 1, although values outside the range are possible. For an ideal product, x equals 0, meaning that the flowrate of the emitter is independent of the pressure. This would allow for high uniformity on very long driplines, which would minimize cost. An emission product with an x of 0 is said to be fully pressure compensating. An x value of 1 is noncompensating, meaning any percentage change in pressure results in an equal percentage change in flowrate. Many lay-flat drip tape products have an emitter exponent of approximately 0.5. A 20% change in pressure along the dripline would result in a 10% change in flowrate if the exponent is 0.5. As a rule of thumb, flowrates should not change more than 10% along the dripline in a properly designed system. Most manufacturers can provide the emitter exponent for their product. Irrigators would be well advised to compare the emitter exponent among products and be wary of manufacturers that cannot provide this information.

Friction losses increase with length (Fig. 1). For this example, the dripline has a design flowrate of 0.25 gpm/100 ft. at 10 psi on a level slope. The variation in flows, Q_{var}, are 6, 16, and 29% for the 400, 600 and 800 ft. runs, respectively. Using general criteria for Q_{var}, these systems would be classified as desirable, acceptable, and not acceptable (Table 1).

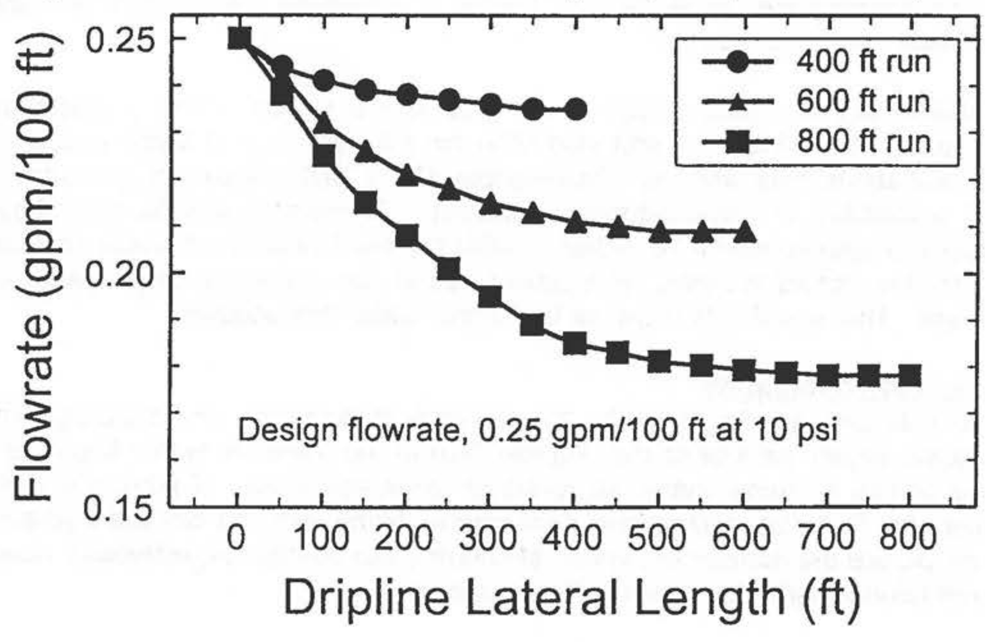

Figure 1. Calculated dripline flowrates on level slopes as affected by length of run.

Table 1. Dripline Uniformity Criteria

	Flow variation, Qvar = 100 x ((Qmax -Qmin)/Qmax)	
Desirable	< 10%	
Acceptable	10 - 20%	
Unacceptable	> 20%	
	Statistical Uniformity U_S	Emission Uniformity E_u
Excellent	95-100%	94-100%
Good	85-90%	81-87%
Fair	75-80%	68-75%
Poor	65-70%	56-62%
Unacceptable	< 60%	< 50%

Friction losses also increase with the velocity of water in the dripline. For a given inside diameter of line, friction losses will be greater for driplines with higher flowrates (Figure 2). Some designers prefer higher capacity driplines because they are less subject to plugging and allow more flexibility in scheduling irrigation. However, if larger-capacity driplines are chosen, the length of run may need to be reduced to maintain good uniformity. Additionally, the zone area may need to be reduced to keep the flowrate within the constraints of the water supply system. Decreasing the length of run or the zone area increases the cost of both installation and operation.

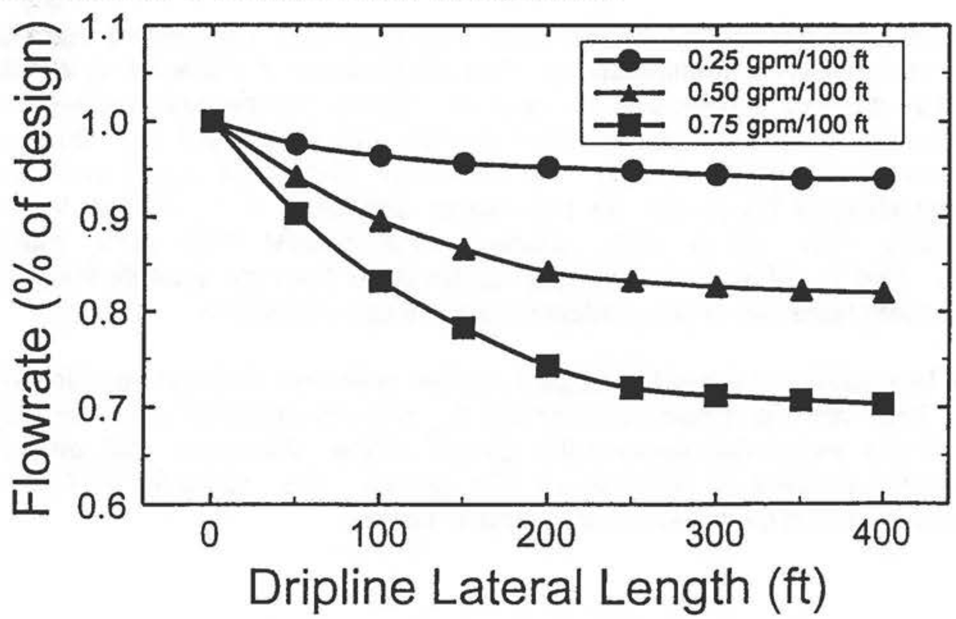

Figure 2. Calculated flowrates on level slopes as affected by dripline capacity.

The land slope can have either a positive or negative effect on the pressure distribution along the dripline lateral (Figure 3). Irrigating uphill will always result in increasing pressure losses along the lateral length. If the downhill slope is too large, the flowrate at the end of the line may be unacceptably high. In the example shown, the most optimum slope is either 0.5 or 1.0% downslope. Both slopes result in a flowrate variation of approximately 10% for the 600 ft. run.

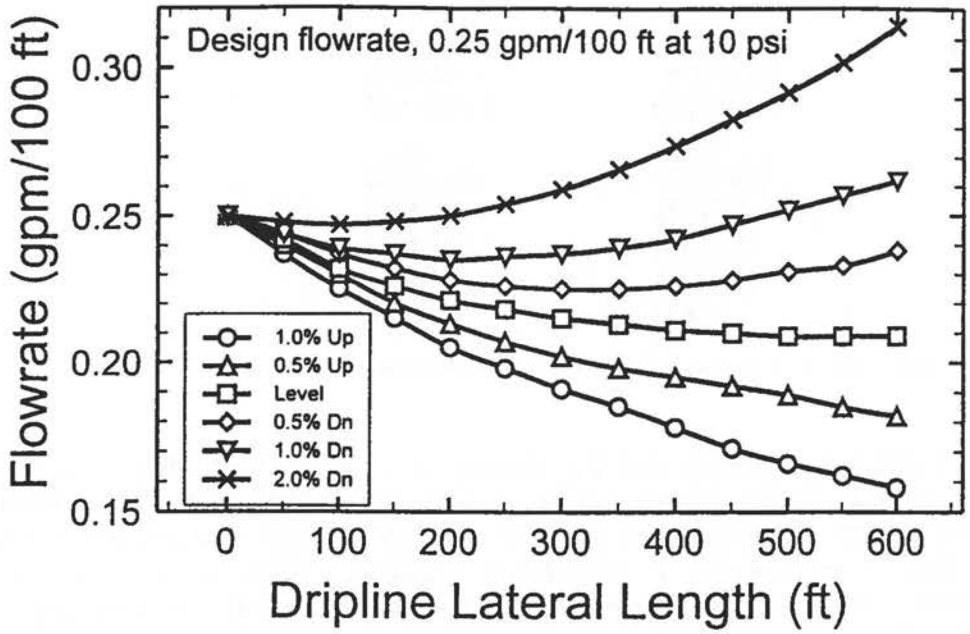

Figure 3. Calculated dripline flowrates as affected by slope.

The preceding discussion has only dealt with theoretical calculations that don't take into account the variability in manufacturing. The coefficient of manufacturing variation, C_V, is a statistical term used to describe this variation. Some dripline products are inherently difficult to manufacture with consistency and, therefore, may have a high C_V. Other products may suffer from poor quality control. The American Society of Agricultural Engineers (ASAE) has established C_V ranges for line-source driplines. A C_V of less than 10% is considered good; from 10 to 20%, average; and greater than 20%, marginal to unacceptable. The C_V of a product should be obtained from the manufacturer to aid in decisions regarding suitability of the product for a particular installation.

There are two additional terms to describe system uniformity that can be calculated for a SDI system. They are the emission uniformity E_u and the statistical uniformity U_s. The calculations of the terms lies beyond the scope of this discussion, but they may be encountered in the process of developing a SDI system. The criteria for evaluating these uniformities as developed by the ASAE are listed in Table 1.

FILTRATION, FLUSHING, AND WATER TREATMENT

Plugging of the dripline emitters is the major cause of system failure. Plugging can be caused by physical, chemical, or biological materials. The filtration system is one of the most important components of the SDI system. It's operation and maintenance must be well understood by the irrigator to help ensure the longevity of the SDI system. There are many different types of filtration systems. The type is dictated by the water source and also by emitter size. Improper filter selection can result in a SDI system which is difficult to maintain and a system prone to failure. The filtration system can be automated to flush at regular time intervals or at a set pressure differential.

Screen or sand media filters are used to remove the suspended solids such as silt, sand, and organic and inorganic debris. Surface water often requires more extensive filtration than groundwater, but filtration is required for all systems.

Chemical reactions in the water can cause precipitates, such as iron or calcium deposits to form inside the driplines. Plugging can be caused by either natural water conditions or by chemicals such as fertilizer added to the water. To avoid chemical clogging, the water must be analyzed to determine what chemicals are prevalent and which chemical additives should be avoided. Chemical water treatment may be required on a continuous or intermittent basis. Acids are sometimes used to prevent plugging and also to help renovate partially plugged driplines. The need for treatment is dictated by the water source and the emitter size. A thorough chemical analysis of the water source should be made prior to development of the SDI system.

Biological clogging problems may consist of slimes and algae. Some problems can be eliminated in the filtration process, but injection of chlorine into the driplines on a periodic basis is required to stop the biological activity. The source and composition of the water will determine, to a large extent, the need for chlorination.

A flushing system is recommended at the distal end of the dripline laterals to assist in removing sediment and other materials that may accumulate in the dripline during the season. This is in addition to a proper filtration system. A useful way to provide for flushing is to connect all the distal ends of the driplines in a zone to a common submain or header which is called the flushline. This allows the flushing to be accomplished at one point. Two other distinct advantages exist for this method. If a dripline becomes plugged or partially plugged, water can be provided below the plug by the interconnected flushline. Additionally, if a dripline break occurs, positive water pressure on both sides of the break will limit sediment intrusion into the line.

MANAGEMENT CONSIDERATIONS

A thorough discussion of the management for SDI systems lies beyond the scope of this paper. However, a brief discussion with regards to system longevity and also with regards to satisfying the stated purposes is in order.

Managing a SDI system is not necessarily more difficult than managing a furrow or sprinkler irrigation system, but it does require a different set of management procedures. Improper management of a SDI system can result in system failure, which might mean the loss of the total capital investment. Proper day-to-day management requires the operator to evaluate the performance of the components, to determine crop irrigation needs, and to make adjustments as needed. The performance of the SDI system components can be evaluated by monitoring the flowrate and pressures in each zone. Pressure gages should be installed on riser pipes from the submain and flushline at each of the four corners of the zone. Comparison of the flowrate and pressures from one irrigation event to the next can reveal any problems that are occurring. For instance, if the flowrate has increased and the pressure is lower, the irrigator needs to investigate for a possible leak in the system. Conversely, if the flowrate is lower and the pressure is higher, the irrigator needs to check the filtration system or look for possible plugging. Disregarding day-to-day management can result in problems such as poor water distribution, low crop yields, and even system failure.

SDI systems are typically managed to apply small amounts of water on a frequent basis to the crop. If properly managed, there are opportunities to save water and to provide a more consistent soil water environment for the crop. However, irrigation scheduling must be employed as some of the visual indicators of overirrigation, such as runoff, non longer exist with this type of irrigation. Overirrigation with a SDI system can lead to reduced yields because of aeration problems exacerbated by the higher irrigation frequency and also perhaps by the more concentrated crop root system. Overirrigation can dramatically increase deep percolation, which can increase groundwater contamination.

SDI systems are often used to provide all or a portion of the crop nutrient needs. The ability to spoon feed the crop its nutrients reduces the potential for groundwater contamination. However, fertigation is only recommended on SDI systems with good or excellent uniformity. Irrigation and nutrient amounts must be managed together to prevent leaching.

CONCLUDING STATEMENT

The initial investment costs for a SDI system are high. Efforts are justified to minimize, investment costs whenever possible and practical. However, if water conservation and water quality protection are important, proper design procedures must be employed. The SDI system must also be properly designed to ensure system longevity. Minimizing investment costs through cheaper designs can be a double-edged sword, as a cheaper system may increase operating costs and/or possibly increase the chance of system failure.

KSU RESEARCH FOR CORN PRODUCTION USING SDI

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ABSTRACT

Studies were initiated in 1989 at Kansas State University (KSU) to develop the methodology for successful application of subsurface drip irrigation (SDI) for corn production on the deep silt loam soils of western Kansas. Research efforts included evaluations of: the water requirement of subsurface drip-irrigated corn; the effect of SDI application frequency; irrigation uniformity for various length driplines; optimum dripline spacing and nitrogen management for subsurface drip-irrigated corn. SDI for row crops in the Central Great Plains is an emerging, but sound technology. Changing economic and environmental factors and/or resource constraints could result in increased adoption of this technology.

INTRODUCTION

The Ogallala or High Plains Aquifer is one of the largest freshwater sources of groundwater in the world. There is a large amount of irrigated crop production in the High Plains and as a result the aquifer is experiencing overdraft. Additional efforts are needed to develop improved water management techniques to conserve nonrenewable resources such as the Ogallala Aquifer. SDI is one technology that can make significant improvements in water management. However, it has traditionally been ignored as an irrigation method for crops such as corn because of high initial investment costs. Times change as well as the constraints under which irrigators operate. Economics, environmental issues and water resource constraints may dictate the adoption schedule of this irrigation method, but the methodology needs to be developed before the practice is adopted.

KSU has taken the initiative to determine the methodology for successful application of SDI for corn on the deep silt loam soils of western Kansas. This paper will summarize the engineering research efforts at KSU evaluating SDI for corn. The overall objectives of the research were to conserve water, to protect groundwater quality, and to develop sound methodologies for subsurface drip-irrigated corn. Research efforts have been broad, including evaluations of the water requirements of subsurface drip-irrigated corn, effects of SDI application frequency, irrigation uniformity for various length driplines, optimum dripline spacing and nitrogen management for subsurface drip-irrigated corn.

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PROCEDURES

This report summarizes several studies conducted at the KSU Northwest and Southwest Research-Extension Centers at Colby and Garden City, Kansas, respectively. A complete discussion of all the employed procedures lies beyond the scope of this paper. For further information about the procedures for a particular study the reader is referred to the accompanying reference papers when so listed. The following general procedures apply to all studies unless otherwise stated.

The two study sites were located on deep, well-drained, loessial silt loam soils. These medium-textured soils, typical of many western Kansas soils, hold approximately 18.9 inches of plant available soil water in the 8 ft profile at field capacity. Study areas were nearly level with land slope less than 0.5% at Colby and 0.15% at Garden City. The climate is semi-arid, with an average annual precipitation of 18 inches. Daily climatic data used in the studies were obtained from weather stations operated at each of the Centers.

The studies utilized SDI systems installed in 1989-90 (Lamm et al., 1990). The systems have dual-chamber drip tape installed at a depth of approximately 16-18 inches with a 5 ft spacing between dripline laterals. Emitter spacing was 12 inches and the dripline flowrate was 0.25 gpm/100 ft. The corn was planted so each dripline lateral is centered between two corn rows (Figure 1).

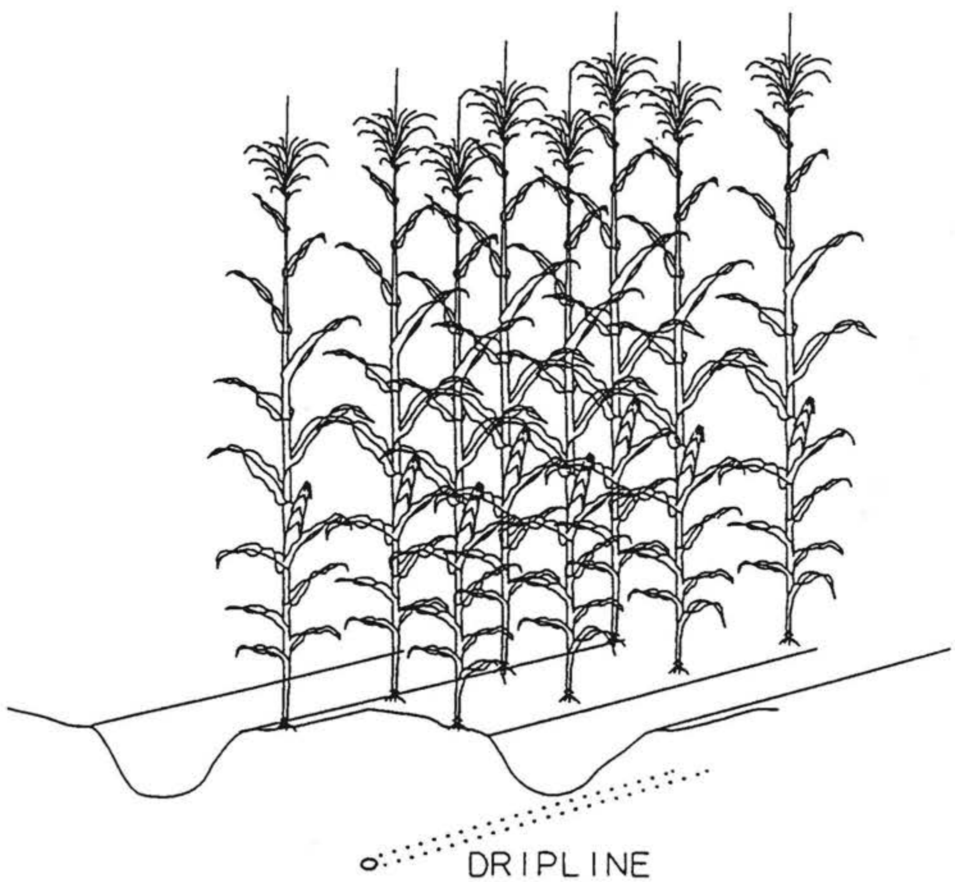

Figure 1. Arrangement of corn rows on permanent bed system in relation to the dripline.

A ridge-till system was used in corn production with two corn rows, 30 inches apart, grown on a 5 ft wide bed. Flat planting was used for the dripline spacing studies conducted at both locations. In these studies, it was not practical to match bed spacing to dripline spacing with the available tillage and harvesting equipment. Additionally at Garden City, corn rows were planted perpendicular to the driplines in the dripline spacing study. All corn was grown with conventional production practices for each location. Wheel traffic was confined to the furrows.

Reference evapotranspiration and actual evapotranspiration (AET) was calculated using a modified Penman combination equation similar to the procedures outlined by Kincaid and Heerman (1974). The specifics of the calculations are fully described by Lamm et al. (1995).

Irrigation was scheduled using a water budget to calculate the root zone depletion with precipitation and irrigation water amounts as deposits and calculated daily corn water use (AET) as a withdrawal. Modification of the individual treatment irrigation schedules to simulate the various regimes was accomplished by multiplying the calculated AET value by the respective regime fraction, such as, 0.75 for a treatment designed to replace 75% of AET. If the root-zone depletion became negative, it was reset to zero. Treatments were irrigated to replace 100% of their calculated root-zone depletion, when the depletion was within the range of 0.75 to 1.25 inches. Root zone depletion was assumed to be zero at crop emergence. Irrigation was metered separately onto each plot. Soil water amounts were monitored weekly in each plot with a neutron probe in 12 inch increments to a depth of 8 ft.

RESULTS AND DISCUSSION

Spacing and Length of the Driplines

Increasing the spacing and/or length of dripline laterals would be some of the most important factors in reducing the high investment costs of SDI. Soil type, dripline installation depth, crop type and the reliability and amount of in-season precipitation are major factors which determine the maximum spacing. Dripline size, emitter flowrate and spacing, and land slope are major hydraulic factors which determine acceptable length of run.

Two studies have been conducted in western Kansas to determine the optimum dripline spacing (installed at a depth of 16-18 inches) for corn production on deep, silt-loam soils. The Garden City study evaluated 4 spacings (2.5, 5, 7.5, and 10 ft) with corn planted in 30 inches rows perpendicular to the dripline lateral. At Colby, 3 spacings (5, 7.5, and 10 ft) were examined with corn planted in 30 inch rows parallel to the driplines. Average yields were similar between sites even though row orientation was different (Table 1).

Table 1. Corn yields obtained with various dripline spacing treatments under full and reduced irrigation at Garden City and Colby, Kansas, 1989-91.

Spacing Trt.	Irrigation Trt.	Dripline Ratio in relation to 1.52 m	Corn Yield (bu/a) Garden City 1989-91	Colby 1990-91
2.5 ft	Full Irrigation	2.00	230	----
5.0 ft	Full Irrigation	1.00	218	216
7.5 ft	Full Irrigation	0.67	208	204
7.5 ft	Reduced Irrigation (67%)	0.67	----	173
10.0 ft	Full Irrigation	0.50	194	194
10.0 ft	Reduced Irrigation (50%)	0.50	----	149

The highest average yield was obtained by the 2.5 ft dripline spacing at Garden City. However, the requirement of twice as much dripline (dripline ratio, 2.00) would be uneconomical for corn production as compared to the standard 5 ft dripline spacing. The results, when incorporated into an economic model, showed an advantage for the wider dripline spacings (7.5 and 10 ft) in some higher rainfall years. However, the standard 5 ft dripline spacing was best when averaged over all years for both sites.

Wider dripline spacings will not consistently (year-to-year) or uniformly (row-to-row) supply crop water needs. In 1990 at Colby, yields for the 5 and 7.5 ft dripline spacings were equal when full irrigation was applied, partially because soil water reserves were high at planting. In 1991, following a dry winter, yields for the wider 7.5 ft dripline spacing were reduced by 25 bu/a (Lamm et al., 1992). Similar results were reported by Spurgeon et al. (1991) at Garden City. The studies at Colby also sought to resolve whether equivalent amounts of water should be applied to the wider dripline spacings or whether irrigation should be reduced in relation to the dripline ratio. Yields were always lower for the corn rows furthest from the dripline in the wider dripline spacings regardless of which irrigation scheme was used (Figure 2). However in 1991, there was complete crop failure in the corn rows furthest from the dripline when irrigation was reduced in relation to the dripline ratio. Full irrigation on the wider dripline spacings at Colby resulted in excessive deep percolation (Darusman, 1994) and reduced overall water use efficiency (Lamm et al., 1992). Soils having a restrictive clay layer below the dripline installation depth might allow a wider spacing without affecting crop yield. Wider spacings may also be allowable in areas of increased precipitation as the dependency of the crop on irrigation is decreased (Powell and Wright, 1993). One of the inherent advantages of a SDI system is the ability to irrigate only a fraction of the crop root zone. Careful attention to proper dripline spacing is, therefore, a key factor in conserving water and protecting water quality.

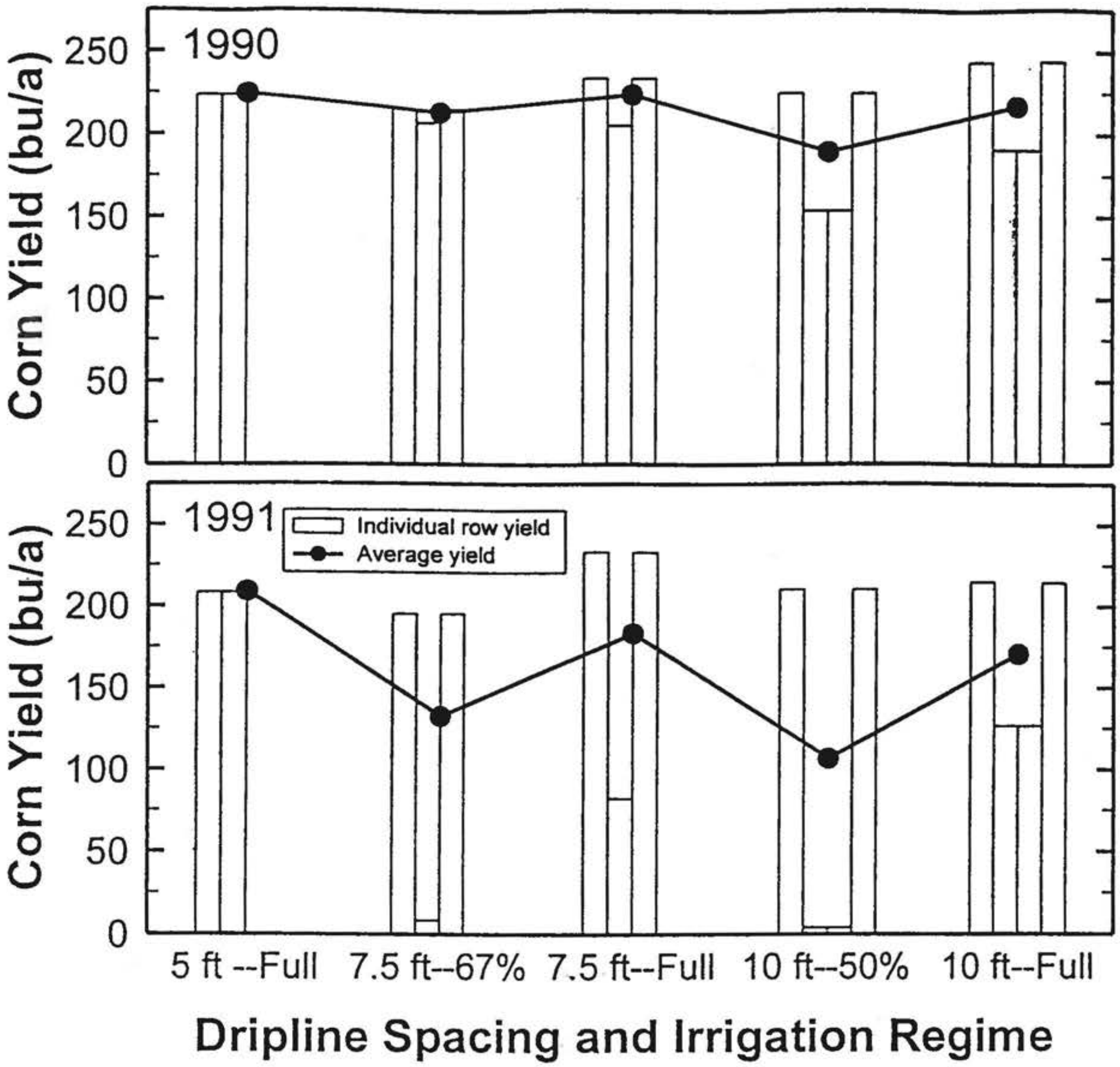

Figure 2. Corn yield as affected by dripline spacing and irrigation regime, Colby KS, 1990-91. Note: Bars represent the individual corn row yields between two adjacent driplines.

Studies conducted at Colby and Garden City, Kansas have indicated that lateral lengths as long as 660 ft are acceptable on slopes up to 0.5% for driplines with 0.625 inch inside diameter applying 0.25 gpm/100 ft for corn production on the deep silt loam soils (Makens et al., 1992). Calculations of the dripline hydraulics has indicated that a flow variation of approximately 17% exists between the water inlet and the terminal end of the dripline laterals for the 660 ft driplines when flowing upslope. However, corn yields were not significantly different at various distances along the lateral, even in 1991 when the study was deficit irrigated to replace only 75% of water use needs as estimated by a climatic- based ET model that has been used successfully for furrow and sprinkler irrigation. Overall yields were high, averaging 210 bu/a for the two locations during the two years of study. There also were no appreciable differences in water use or water use efficiency in either year. Corn is a relatively deep rooted crop and on these deep soils, can apparently buffer moderate water stress that might be caused by the flow variation.

Frequency of Subsurface Drip Irrigation

Typically, a smaller volume of soil is wetted with SDI as compared to other types of irrigation systems and as a result, crop rooting may be limited. Crops may benefit from frequent irrigation under this condition. However, in a study conducted at Garden City, Kansas, corn yields were excellent (190 to 200 bu/a) regardless of whether a frequency of 1, 3, 5, or 7 days was used for the SDI events (Caldwell et al., 1994). Higher irrigation water use efficiencies were obtained with the longer 7-day frequency because of improved storage of in-season precipitation and because of reduced drainage below the rootzone. The results indicate there is little need to perform frequent SDI events for fully-irrigated corn on the deep silt loam soils of western Kansas. There could be an advantage for more frequent irrigation events if the corn was deficit-irrigated or fertigated.

Water Requirement of Subsurface Drip-Irrigated Corn

Studies were conducted at Colby and Garden City, Kansas from 1989-1991 to determine the water requirement of subsurface drip-irrigated corn. Careful management of SDI systems reduced net irrigation needs by nearly 25%, while still maintaining top yields of 200 bu/a. The 25% reduction in irrigation needs translates into 35-55% savings when compared to sprinkler and furrow irrigation systems which typically are operating at 85 and 65% application efficiency. SDI technology can make significant improvements in water use efficiency through better management of the water balance components.

Corn yields at Colby were linearly related to calculated crop water use (Figure 3), producing 19.6 bu/a of grain for each mm of water used above a threshold of 12.9 inches (Lamm et al., 1995). The relationship between corn yields and irrigation is nonlinear (Figure 3) primarily because of greater drainage for the heavier irrigation amounts (Figure 4). The 25% reduction in net irrigation needs is primarily associated with the reduction in drainage, a non-beneficial component of the water balance (Figure 3 and 4).

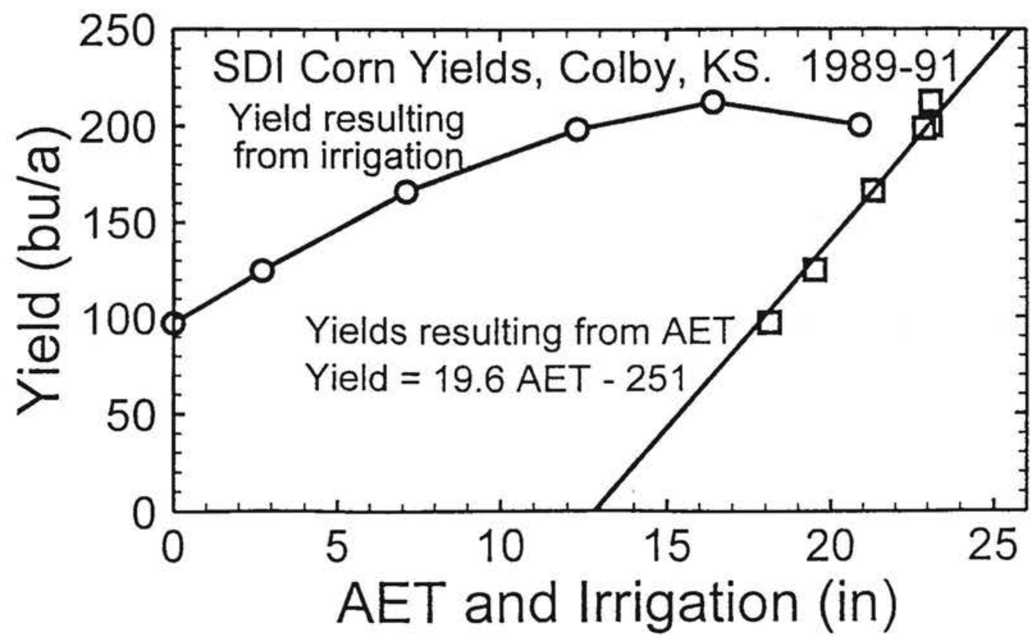

Figure 3. Corn yield as related to irrigation and calculated evapotranspiration (AET) in a SDI study, Colby, KS., 1989-1991.

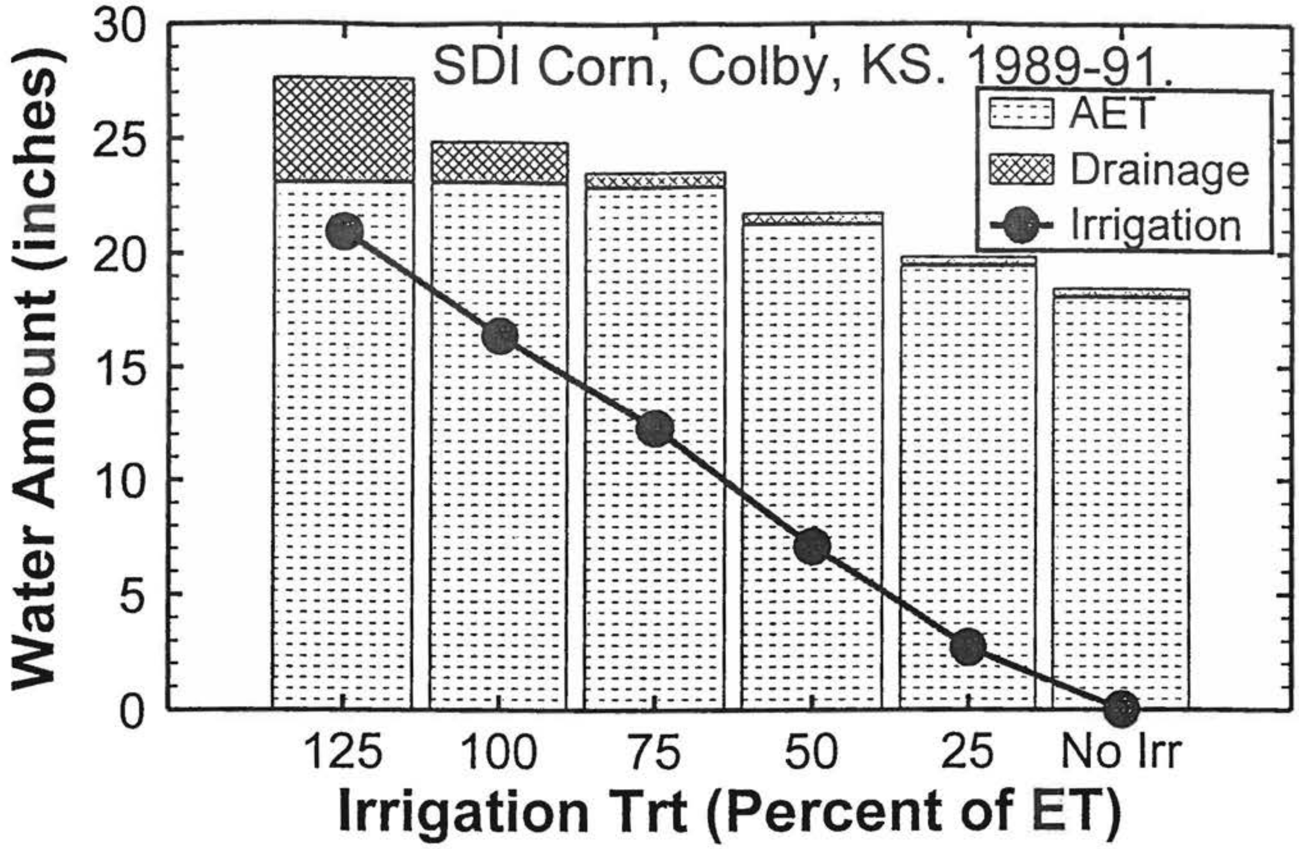

Figure 4. Calculated evapotranspiration (AET) and seasonal drainage as related to irrigation treatment in a SDI study, Colby, KS., 1989-1991.

Nitrogen Fertigation

Since properly designed SDI systems have a high degree of uniformity and can apply small frequent irrigation amounts, excellent opportunities exist to better manage nitrogen fertilization with these systems. Injecting small amounts of nitrogen solution into the irrigation water can spoonfeed the crop, while minimizing the pool of nitrogen in the soil that could be available for percolation into the groundwater.

In a study conducted at Colby, Kansas from 1990-91, there was no difference in corn yields between preplant surface-applied nitrogen and nitrogen injected into the driplines throughout the season. Corn yields averaged 225 to 250 bu/a for the fully irrigated and fertilized treatments. In both years, nearly all of the residual nitrate nitrogen measured after corn harvest was located in the upper 12 inches of the soil profile for the preplant surface-applied nitrogen treatments, regardless of irrigation level. In contrast, nitrate concentrations increased with increasing levels of nitrogen injected with SDI and migrated deeper in the soil profile with increased irrigation (Lamm and Manges, 1991). Nitrogen applied with SDI at a depth of 16-18 inches redistributed differently in the soil profile than surface-applied preplant nitrogen banded in the furrow (Figure 5). Since residual soil-nitrogen levels were higher where nitrogen was injected using SDI, it may be possible to obtain similar high corn yields using lower amounts of injected nitrogen.

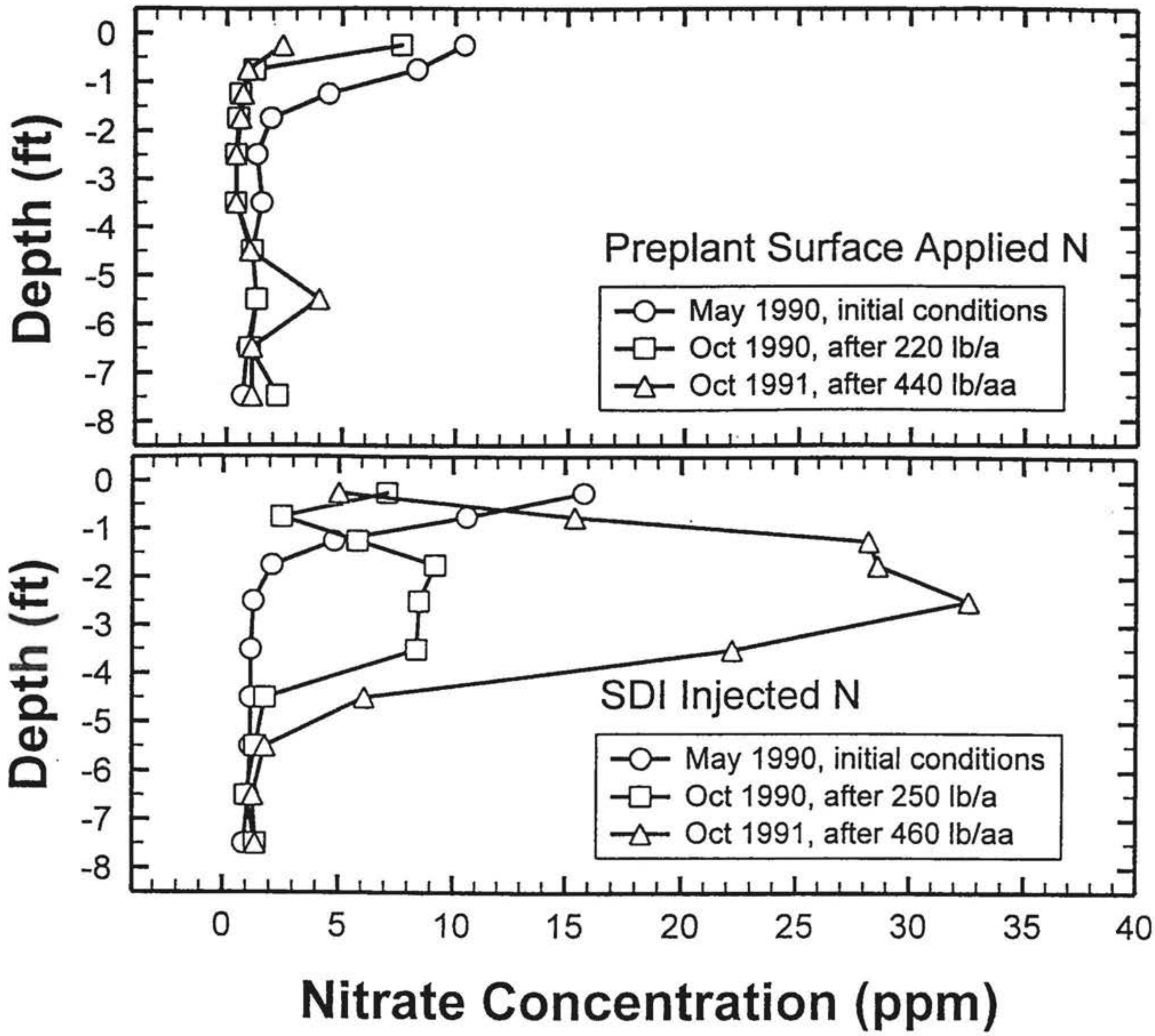

Figure 5. Nitrate concentrations in the soil profile for preplant surface-applied and SDI injected nitrogen treatments, Colby, Kansas, 1990-91. Data is for selected nitrogen fertilizer rate treatments with full irrigation (100% of AET).

CONCLUSIONS

SDI technology can be successfully applied for corn production on the deep silt loam soils of western Kansas. Soil, climate and topography factors indicate that successful designs can utilize 5 ft dripline spacings for lateral lengths of 660 ft. SDI application frequencies of 1-7 days did not affect yields of fully irrigated corn. The technology can reduce net irrigation needs by 25% while maintaining high corn yields. Potential exists for reduced application of nitrogen for corn production when injected with SDI. Nitrogen redistribution is different between surface applied nitrogen and nitrogen applied using SDI.

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This paper represents a non-SI (metric) unit version of a paper first presented at the Fifth International Microirrigation Congress, April 2-6, 1995, Orlando Florida. The original paper is entitled Corn Production Using Subsurface Drip Irrigation and is found on pages 388-394 of the proceedings of that conference. The proceedings is available from ASAE, 2950 Niles Road, St. Joseph, MI 49085-9659. Phone: 616-429-0300. Fax: 616-429-3852 Email: hq@asae.org

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FILTRATION AND MAINTENANCE CONSIDERATIONS FOR SDI SYSTEMS

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Introduction

All irrigation systems require proper maintenance and subsurface drip irrigation (SDI) systems are no exception. The major cause of failures in SDI and other microirrigation systems worldwide is clogging. The emitters in SDI systems are small, leaving a small margin for error, so it is important to understand the filtration and maintenance requirements of SDI systems and take a proactive approach to the prevention of clogging.

Fortunately, most SDI users in the Great Plains are pumping from high-quality groundwater, such as the Ogallala aquifer, reducing the potential for clogging. Even so, proper steps must be taken to prevent clogging and maintain effective SDI system operation. With proper precautions and maintenance, SDI also can be used with surface water and other, lower quality, waters.

Prevention of clogging and proper maintenance of the SDI system start before it is installed. Chemical and biological analysis of the irrigation water will indicate which preventative filtration measures may be required to prevent clogging. Dripline requirements may also play a role in the selection of filtration measures to employ. Proper placement and use of flow meters and pressure gauges are required to provide feedback to the system operator. Monitoring the flow meters and pressure gauges over time can reveal system performance anomalies that may require attention. Check valves, air vents, and vacuum relief valves may be required at various places in the system to prevent entry of chemically treated water into the water source and soil particles into the driplines. Also, flushlines are required to occasionally remove the material accumulated in the driplines.

Clogging hazards for SDI systems, regardless of the water source, fall into three general categories: physical, chemical, and biological. This paper will discuss prevention of clogging problems in these three categories with special emphasis on how they apply to SDI systems in the Great Plains.

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Physical clogging hazards

Physical clogging hazards are usually removed with screen filters. Sizing of screen filters is based on the maximum particle size allowable by the designed SDI system, quality of the irrigation water, the flow amount between required cleanings, and the allowable pressure drop across the filter. The maximum allowable particle size should be available from the dripline manufacturer. If not, a rule of thumb is to use 0.1 times the smallest diameter in the emitters used. A 200-mesh screen filter will remove the fine sand and anything larger, and is usually adequate for SDI systems in the Great Plains. Flow rates through screen filters should not exceed 200 gpm per square foot of effective filter area. The effective filter area is defined as the area of the openings in the filter screen. Screen filters should be cleaned (backflushed) when the pressure drop across the filter increases by 3 to 5 psi or as recommended by the filtration system manufacturer. Automatic flushing is available on some filtration systems.

Also available are self-cleaning screen filters called "spin filters." These are continuous-flushing units. They swirl the water inward. Filtered particles move to the bottom of the filter and eventually leave the bottom of the filter through an open hole. A small amount of water is continuously pushing the filtered particles out the bottom and is therefore lost from the irrigation systems.

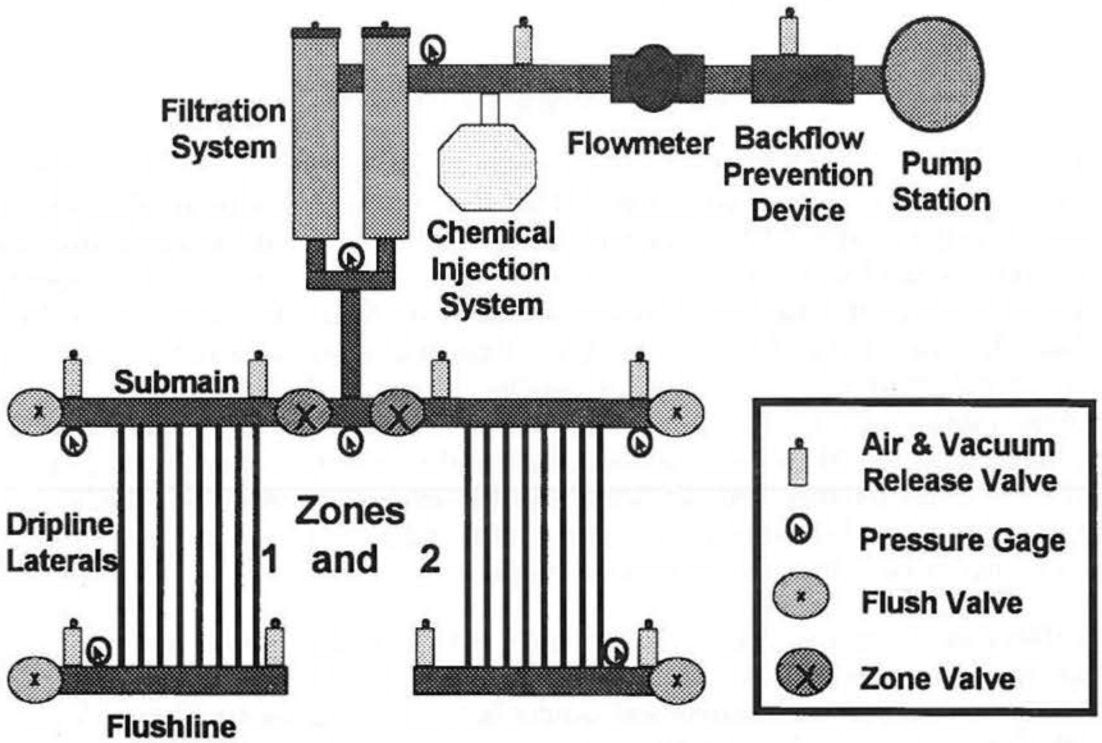

Figure 1. Schematic of a subsurface drip irrigation (SDI) system.

Table 1. Screen filter opening sizes.

Mesh	Inches	mm	Microns
40	0.017	0.425	425
100	0.006	0.150	150
150	0.004	0.105	105
200	0.003	0.075	75
270	0.002	0.053	53
400	0.0015	0.038	38

Table 2. Selected equivalent diameters.

Particle	Diameter, mm
Coarse sand	0.50 to 1.00
Fine sand	0.10 to 0.25
Silt	0.002 to 0.05
Clay	< 0.002
Bacteria	0.0004 to 0.002
Virus	< 0.0004

If large amounts of sand are in the water, a sand separator (also called a vortex sand separator or cyclone sand separator) may be required. Sand separators swirl the water and the centrifugal force separates the sand and other heavy particles from the water. If the amount of sand in the irrigation water is small, screen filtering will usually be adequate and a sand separator will not be required.

For surface water, other steps may be required. For water with a large silt concentration, a settling basin may be required to remove the silt. Also for surface waters, pre-screening of the water to remove debris such as but not limited to stalks, leaves, and other plant residue may be required. When surface water is used for SDI, more extensive filtration systems such as media filters may be desirable.

Biological clogging hazards

Sand media filters are usually used to filter organic materials. Particle size of the media is selected according to the desired degree of filtration. Flow rates for media filters should not exceed approximately 25 to 28 gpm per square foot of filter surface area. Lower flow rates should be used with water sources containing greater than 100 ppm of suspended material, to reduce the need for frequent backflushing. Media filters should be backflushed when the pressure drop reaches about 10 psi or as recommended by the filtration system manufacturer. Use of two filters in parallel allows backflushing of one filter while the other is actively filtering the water. Backflushing flow rates depend on the media size; lower flow rates should be used for finer filter media. Automatic flushing is generally required on media filtration systems. Some manufacturers recommend the use of a screen filter after the media filter to reduce the hazard of media clogging the SDI system should a catastrophic failure of the media filtration system occur.

Disk filters are sometimes used, also. They are a hybrid of screen filters and sand media filters. Water flows in microscopic grooves between disks that filter the particles. Disk filters separate during backflushing and require less water than media filters. However, backflushing pressure as high as 50 psi may be required, which may require use of a booster pump. A typical recommended flow rate for filtering groundwater with 200-mesh-equivalent disk filters is 50 gpm per square ft of filter area.

Table 3. Sand media size and screen mesh equivalent.

Sand No.	Effective Sand Size (in)	Screen Mesh Size
8	0.059	70
11	0.031	140
16	0.026	170
20	0.018	230
30	0.011	400

Chlorine injection is usually used to assure that any unfiltered biological material does not accumulate elsewhere in the SDI system. If the microbiological load of the irrigation water is high, a low concentration (1 to 2 ppm) of chlorine should be injected continuously. If the biological load is not particularly high, a single clogging problem is severe, or biological clogging problems are due to sources other than irrigation water, chlorine shock treatment may be desirable. A shock treatment uses concentration of 10 to 30 ppm. Frequency and duration of shock treatments are determined by the severity of the problem.

Chlorine gas is the most effective and least expensive chlorine source for injection but is hazardous and must be used with caution. Sodium hypochlorite (liquid bleach) is safer and easy to obtain and use. It degrades over time so it should not be stored for long periods before using. Calcium hypochlorite granules or tablets are more stable than bleach but more expensive.

Chemical clogging hazards

Two major chemical clogging hazards to SDI systems in the Great Plains are precipitation of calcium carbonate ($CaCO_3$) and formation of iron ochre (slime).

Precipitation of $CaCO_3$ can occur in one of two ways- evaporation of water, leaving the salts behind, or change of solubility due to change of solution characteristics (mainly temperature or pH). Evaporation isn't usually a problem in SDI systems, but chemistry changes can cause $CaCO_3$ precipitation. As water temperature rises, $CaCO_3$ solubility decreases and may precipitate. In SDI systems, the buried driplines don't get as hot as surface-installed drip irrigation lines, so temperature-induced $CaCO_3$ precipitation is not as great a problem. Increased pH also decreases $CaCO_3$ solubility, raising the potential for precipitation. A water analysis can be used to determine the predisposition of the water source to $CaCO_3$ precipitation. If precipitation is likely to occur, acid injection is used to lower pH and decrease the propensity for $CaCO_3$ precipitation. An acid formulation of nitrogen fertilizer can be used for pH control and nitrogen fertilization concurrently.

At very low concentrations, it may be possible to keep iron in solution by adding acid to lower the pH. Other concentrations will require more treatment, however. One hazard of iron is bacterial interaction with iron. Various bacteria can react with ferrous (+2 charge) iron through an oxidation process. The resulting ferric (+3 charge) iron is insoluble. The ferric iron eventually will be surrounded by filamentous bacteria, forming the slime (gel) that clogs emitters. Chlorination is used to oxidize the ferrous iron. The resultant ferric iron is filtered before it can reach and clog the emitters.

If the water pH is high, concurrent acidification and chlorination may be required. Injection points of the two materials into the water stream should be at least 2 to 3 feet apart. *Acid and chlorine should never be combined in the same container.*

Concluding Statements

When using SDI systems, it is important to prevent clogging problems before they occur so the benefits of SDI can be reaped for many years. The best prevention plan includes an effective filtration and water treatment strategy. Depending on the water source and its quality, various combinations of sand separation, screen filtration, sand media filtration, chlorination, and acid injection may be required. Filtration equipment may be the single item of greatest cost when installing the SDI system. Resist the temptation to "cut corners." Good filtration will pay for itself by avoiding the chemical treatments, labor, or extra effort that are otherwise required to fix a system damaged because it was not adequately maintained.

Despite our filtration efforts, some materials will not be removed and will find their way into the dripline. To prevent the accumulation of those materials in the dripline and the resultant emitter clogging, the driplines should be flushed occasionally. Flow meters and pressure gauges should be checked periodically to assure that the system is operating correctly. If measured flow rates and pressure distributions indicate problems in the system, some reconditioning may be possible with chemical injection (including chlorine shock treatments), flushing, and other steps.

Profit margins for crops typically grown in the Great Plains are not as high as the profit margins for fruits and vegetables traditionally grown with SDI systems. To make SDI systems in the Great Plains economically more viable, they must have a long life. Prevention of clogging is therefore critical to the successful and economical use of SDI in the Great Plains.

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ECONOMIC COMPARISON OF SDI AND CENTER PIVOTS FOR VARIOUS FIELD SIZES

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Subsurface drip irrigation (SDI) systems are feasible for some field crops and field arrangements using current levels of technology. Sprinkler irrigation systems have an economic advantage over SDI systems for the typical case where full-size center pivots can be used. However, center pivots lose important economies of scale as fixed investment costs are concentrated onto smaller acreages. Thus, the cost advantage for a center pivot system diminishes as field size is reduced.

This analysis assumes an existing flood-irrigated field with an existing well or water supply that is centrally located at the edge of the field. This flood-irrigation system is to be converted to either a center pivot or SDI system. The well is fully depreciated, but not in need of replacement. Investment cost estimates for alternative irrigation systems and estimated crop budgets for irrigated corn and summer fallow wheat in western Kansas are used to project annual profitability for the alternative irrigation and cropping systems. The objective is to compare center pivot and SDI system costs and net returns per acre for several field sizes.

FIELD INVESTMENT COSTS

Six field sizes were considered, starting with a standard quarter section (160 acres) on which a standard sized (125 acre) center pivot could be installed. The center pivot size was reduced in 25 acre increments from 125 acres down to 25 acres. The corresponding SDI field is assumed to be fully irrigated, whereas the center pivot field is assumed to have a combination of irrigated acres under the irrigated circle and non-irrigated acres on the center pivot corners. The exception is in the last comparison which assumes a typically shaped 80 acre field (a quarter section split into two equal rectangular parts) on which a standard sized center pivot could "windshield wipe" a semicircle of 64 acres, leaving 16 acres in dryland wheat-fallow rotation.

Investment costs and acreages used to compare the profitability of these two alternative irrigated cropping systems are shown in Table 1. Irrigation system investment costs were estimated using information from private industry and Kansas State University. In this analysis, the system life is projected to be 20 years for the center pivot and 10 years for of the SDI system. Additionally, all the components of each irrigation system are assumed to have no salvage value at the end of their projected life. Regular annual repair and maintenance expenses are assumed for each system. Per acre investment cost for center pivots increase as field size decreases in comparison to more stable SDI per acre investment costs. Figure 1 graphically illustrates the proportional cost reduction of a SDI system as compared to the less-adjustable cost structure of a center pivot. For example, as field size decreases by 50 percent, the SDI system cost also decreases by approximately 50 percent. In comparison, as field size decreases by 50 percent, the center pivot system cost is about 80 percent of the full sized system.

Table 1. Investment costs for various size center pivot and SDI systems.

	Center Pivot		**SDI**	**Center Pivot**		**SDI**	
Field Scenario	Irrigated Acres	Dryland Corners	Irrigated Acres	Total Cost $/Field*	Cost/Acre $/Acre	Total Cost $/Field**	Cost/Acre $/Ac
O	125	35	160	$40,782	$326	$86,210	$539
A	100	27	127	$37,948	$379	$72,258	$569
B	75	20	95	$34,527	$460	$54,388	$573
C	50	14	64	$29,909	$598	$34,836	$544
D	25	7	32	$24,459	$978	$21,251	$664
Wiper	64	16	80	$34,050	$532	$45,606	$570

* Includes underground pipe and electrical service & generator

** 5' dripline spacing

PROFITABILITY ANALYSIS

Partial budgeting was used to compare the profitability of the alternative irrigation and cropping systems. Unlike a whole-farm budget, a partial budget does not indicate whether the entire operation is profitable, but only if one enterprise or investment has a net returns advantage over another. Partial budgeting may not recognize all costs to the whole farm. For example, management of newly installed SDI systems may take more time than for the more familiar center pivot systems. The extra time is taken from other farm enterprises, which could affect their production efficiency and profitability. This is a SDI cost factor not accounted for in these partial budgets. Management of SDI systems is not necessarily more difficult than other irrigation systems, but does require a different set of management procedures.

CROP INCOME AND EXPENSES

The crop enterprises for the center pivot cropping system will be irrigated corn with dryland wheat-fallow on the nonirrigated corners. The SDI cropping system area will be in irrigated corn. The irrigation well capacity is assumed adequate for production of irrigated corn in all scenarios. Net revenue from the irrigated areas are projected assuming a corn yield of 190 bushels per acre, a price of $2.50 per bushel, average annual production flexibility contract (PFC) payments of $35 per acre, and production costs based on 1996 KSU Farm Management Guides. The net revenue from nonirrigated wheat acres is based on 40 bushel per acre yields, a price of $3.65 per bushel, PFC payments of $10 per acre, and 1996 KSU production cost estimates. Because land costs and management expenses over and above base labor expenses are not accounted for in these partial budgets, the net revenue projections represent per acre net returns to land and management for each irrigated cropping system.

Table 2 reflects the income and Table 3 shows line-by-line variable and fixed expenses for the baseline comparison of the quarter section (160 acre) field. In this analysis, SDI systems were assumed to have slightly less irrigation fuel and repair expenses due to lower pumping requirements. Center pivot irrigated corn was assumed to require 18 inches of applied water while SDI-irrigated corn was assumed to require 16 inches. Large differences exist in irrigation equipment depreciation and interest costs between alternative irrigation systems (Table 3).

Table 2. Crop revenue assumptions for SDI and center pivot systems.

Income	Corn-SDI	Corn-Pivot	Wheat
Crop yield (bu / acre)	190	190	40
Crop price ($ / bu)	$2.50	$2.50	$3.65
PFC payment ($ / acre)	$35	$35	$10
Total income ($ / acre)	$510	$510	$156

Crop production expenses do not vary on a per acre basis with changes in field size. Similarly, irrigation equipment depreciation and interest costs do not vary appreciably with field size for SDI on a per acre basis. However, drastic increases occur in irrigation equipment depreciation and interest costs on a per acre basis as field size decreases for center pivot systems. Table 4 summarizes these cost and return differences for all the field size scenarios for both SDI and center pivot systems.

Table 3. Corn and wheat-fallow expenses and net returns for SDI and center pivot on a per acre basis for a 160 acre field (base scenario O)

COST ITEMS	CROPPING SYSTEM ENTERPRISES		
	Corn - SDI	**Corn - Pivot**	**Wheat**
Variable costs			
Labor	$21.15	$21.15	$10.80
Seed	33.60	33.60	10.00
Herbicide	33.12	33.12	14.82
Insecticide	41.57	41.57	0.00
Fertilizer	46.20	46.20	15.20
Fuel & oil - crop	10.45	10.45	6.95
Fuel & oil - pumping	43.36	48.78	
Crop machinery repairs	23.20	23.20	10.92
Irrigation repairs and maintenance	4.80	5.40	
Crop insurance	6.75	6.75	4.89
Drying	19.00	19.00	0.00
Consulting	6.50	6.50	0.00
Miscellaneous	7.00	7.00	5.00
Interest on 1/2 variable costs	14.83	15.14	3.93
Total variable costs	**$311.53**	**$317.85**	**$82.51**
Fixed costs			
Depreciation	$15.34	$15.34	$12.35
Interest on machinery	15.93	15.93	12.83
Irrigation equipment depreciation	61.03	23.46	
Interest on irrigation equipment	29.44	18.81	
Insurance	2.06	1.53	0.48
Total fixed costs	**$123.80**	**$75.07**	**$25.65**
Total costs	**$435.33**	**$392.92**	**$108.16**
Net returns to land & management	**$74.67**	**$117.08**	**$47.84***

* Wheat-fallow rotation net returns are on an annual wheat acre basis. Annual net returns over all acres (wheat and fallow) are $23.92.

Projected center pivot cropping system income and expenses are less than for SDI cropping systems for all field-size scenarios. However, the differences in net returns (income minus expenses) for the two systems vary on a scenario by scenario basis. Center pivot systems have a $17 to $23 net returns advantage for larger size fields (95 to 160 acres). Returns for the two systems are essentially the same for the 64 acre scenario, but clearly favor SDI for smaller sized fields (32 acres). In comparing center pivot wiper and SDI systems on 80 acre tracts, the center pivot wiper cropping system (64 irrigated corn acres plus 16 dryland wheat-fallow acres) retains a small net return advantage ($12 per acre) over the SDI system with 80 acres of irrigated corn.

Table 4. Center pivot (CP) and SDI economic comparison across various field size scenarios.

Item	Base Scenario O		Scenario A		Scenario B		Scenario C		Scenario D		"Wiper" Scenario	
	160 acres		127 acres		95 acres		64 acres		32 acres		80 acres	
	Pivot	SDI	Pivot	SDI	Pivot	SDI	Pivot	SDI	Pivot	SDI	Pivot	SDI
Cropping system												
Irrigated acres	125 ac	160 ac	100 ac	127 ac	75 ac	95 ac	50 ac	64 ac	25 ac	32 ac	64 ac	80 ac
Non-irrigated acres	35 ac	0 ac	27 ac	0 ac	20 ac	0 ac	14 ac	0 ac	7 ac	0 ac	16 ac	0 ac
A. Crop income												
Irrigated corn	$63,750	$81,600	$51,000	$66,770	$38,250	$48,450	$25,500	$32,640	$12,750	$16,320	$32,640	$40,800
Dryland wheat	$2,730	---	$2,106	---	$1,560	---	$1,092	---	$546	---	$1,248	---
Total income	$66,480	$81,600	$53,106	$64,770	$39,810	$48,450	$26,592	$32,640	$13,296	$16,320	$33,888	$40,800
Income difference per acre (SDI – pivot)	***$94.50 /ac***		***$91.84 /ac***		***$90.95 /ac***		***$94.50 /ac***		***$94.50 /ac***		***$86.40 /ac***	
B. Crop costs												
Variable costs	$41,176	$49,845	$32,899	$39,565	$24,664	$29,596	$16,470	$19,938	$8,235	$9,969	$21,003	$24,923
Fixed costs	$9,833	$19,808	$8,399	$16,306	$6,918	$12,249	$5,327	$7,977	$3,638	$4,573	$6,359	$10,285
Land, mgmt costs	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total costs	$51,008	$69,633	$41,298	$55,871	$31,582	$41,844	$21,797	$27,915	$11,873	$14,542	$27,362	$35,208
Cost difference per acre (SDI – pivot)	***$116.53 /ac***		***$114.75 /ac***		***$108.03 /ac***		***$95.59 /ac***		***$83.42 /ac***		***$98.07 /ac***	
Variable cost	*$54 /ac*		*$52 /ac*		*$52 /ac*		*$54 /ac*		*$54 /ac*		*$49 /ac*	
Fixed cost	*$62 /ac*		*$62 /ac*		*$56 /ac*		*$41 /ac*		*$29 /ac*		*$49 /ac*	
C. Net Returns	$15,472	$11,947	$11,808	$8,899	$8,228	$6,606	$4,795	$4,725	$1,423	$1,778	$6,526	$5,592
Return difference												
Total (SDI – pivot)	*– $3,525*		*– $2,909*		*– $1,623*		*– $70*		*+ $286*		*– $934*	
per acre (SDI – pivot)	***– $22.07 /ac***		***– $22.90 /ac***		***– $17.08 /ac***		***– $1.09 /ac***		***+ $11.08 /ac***		***– $11.67 /ac***	

SENSITIVITY OF RESULTS TO CHANGES IN KEY FACTORS

A series of sensitivity analyses were conducted to determine how sensitive these results are to changes in certain key economic factors. These key factors are corn yield and price, irrigation system life, and SDI dripline costs. The sensitivity of projected net returns to these factors was determined for scenarios O (160 acres), D (32 acres), and the wiper scenario (80 acres). These scenarios were selected because they represent the extremes in field size (scenarios O and D) and a difference in center pivot point location and field shape (wiper scenario).

Sensitivity to Corn Yield and Price

Increases in corn yield and/or price will increase SDI net returns relative to those for the center pivot cropping system (Table 5). The trend is illustrated in Figure 2 for the full size field, scenario O. Figure 2 illustrates that at a corn price of $2.75 per bushel, SDI system net returns are competitive with center pivot cropping systems when corn yields exceed 210 bushels per acre. The wiper center pivot system remains more profitable in all cases except for high yield and price combinations. However, the differences in net returns between the systems are much less for the 80 acre wiper scenario than for the 160 acre full circle (base scenario O). In the small acreage scenario D, SDI has higher net returns in all cases except where both yields and prices are notably below the assumed averages in the preceding analysis. When corn prices and yields are low, center pivot cropping systems generally have a larger net return advantage. As corn prices and yields increase, SDI systems become more competitive economically.

Sensitivity to Irrigation System Life

Irrigation system life has a major effect on projected net returns (Table 6). Changes in the life of the SDI system from 5 to 10 to 15 years have a more dramatic effect on net returns than do changes in center pivot system life from 15 to 20 to 25 years. For example, in Base scenario O, the net returns advantage of a center pivot system with a life of 15 years over a SDI system with a life of 10 years is $18 per acre. The net returns advantage of center pivot systems in this scenario increases by $6 per acre to $22 if the center pivot has a 20 year life.

While a change in the life of a center pivot from 15 to 25 years increases projected net returns per acre from $6 to $21 per acre across the three field size scenarios considered here, an increase in SDI system life from 5 to 15 years increases projected net returns per acre from $71 to $89 per acre, or from at least 3 to 12 times the effect of a 10 year increase in center pivot life. The effect is most pronounced in scenario D where a

Table 5. Advantage of center pivot cropping systems over SDI as affected by yield and price (CP minus SDI cropping system returns per acre).

Base scenario O: (125 acre center pivot + 35 acre W-F) versus 160 acre SDI				
	Corn Cash Price			
Corn Yields	$2.25/bu	$2.50/bu*	$2.75/bu	$3.00/bu
160	$47	$38	$29	$20
175	$39	$30	$20	$11
190*	$32	$22*	$12	$1
205	$25	$14	$3	-$8
220	$18	$6	-$6	-$18
"Wiper" scenario: (64 acre center pivot + 16 acre W-F) versus 80 acre SDI				
Corn Yields	$2.25/bu	$2.50/bu*	$2.75/bu	$3.00/bu
160	$34	$26	$18	$10
175	$28	$19	$10	$1
190*	$21	$12*	$2	-$7
205	$15	$4	-$6	-$16
220	$8	-$3	-$14	-$25
Scenario D: (25 acre center pivot + 7 acre W-F) versus 32 acre SDI				
Corn Yields	$2.25/bu	$2.50/bu*	$2.75/bu	$3.00/bu
160	$13	$5	-$4	-$13
175	$6	-$3	-$13	-$22
190*	-$1	-$11*	-$21	-$32
205	-$8	-$19	-$30	-$41
220	-$15	-$27	-$39	-$51

* 190 bushel per acre irrigated corn yields and $2.50 cash price are the standard assumptions in the preceding analysis. The center pivot and SDI systems are assumed to have a life of 20 and 10 years, respectively.

change in SDI irrigation system life from 5 to 10 years while holding center pivot system life at 20 years causes a major change in the comparative net returns between the two systems. With a 5 year SDI system life in scenario D, the center pivot system has a $55 per acre net returns advantage over the SDI system. Conversely, if the SDI system has a 10 year life in this scenario, SDI has an $11 net returns advantage over the center pivot cropping system. SDI systems with a 15 year life clearly have a net returns advantage over center pivot cropping systems with a 25 year life for the wiper and 32 acre scenarios while net returns are nearly equal for the 160 acre scenario (Figure 3). SDI must have a system life approaching at least 10 years to be economically competitive with center pivot irrigation systems. Research SDI systems at Kansas State University Experiment Stations have been in use for up to nine years without any appreciable deterioration. Several commercial SDI systems in the southwestern United States have been in use for nearly 20 years. Evidence suggests that SDI systems with proper design and management should have good longevity.

Table 6. Advantage of center pivot cropping systems over SDI as affected by system life (CP minus SDI cropping system returns per acre)

Base scenario O: (125 acre center pivot + 35 acre W-F) versus 160 acre SDI			
	Center Pivot Life		
SDI System Life	15 years	20 years*	25 years
5 years	$72	$76	$78
10 years*	$18	$22*	$25
15 years	$0	$4	$7
20 years	-$9	-$5	-$2
"Wiper" scenario: (64 acre center pivot + 16 acre W-F) versus 80 acre SDI			
SDI System Life	15 years	20 years*	25 years
5 years	$62	$69	$73
10 years*	$5	*$12	$16
15 years	-$14	-$7	-$3
20 years	-$24	-$17	-$13
Scenario D: (25 acre center pivot + 7 acre W-F) versus 32 acre SDI			
SDI System Life	15 years	20 years*	25 years
5 years	$43	$55	$63
10 years*	-$24	-$11*	-$3
15 years	-$46	-$33	-$26
20 years	-$57	-$44	-$37

** 20 year center pivot life and 10 year SDI system life are standard assumptions in the preceding analysis. The corn yield is assumed to be 190 bushels per acre with a cash price of $2.50 per bushel.

Sensitivity to SDI Dripline Price

Dripline prices have a major impact on the total cost of SDI irrigation systems. Decreasing dripline prices increase the economic competitiveness of SDI. However, the selection of the most profitable irrigation system is not affected within the ranges of dripline prices and field-size scenarios considered (Figure 4). The center pivot system remained the most profitable system for scenario O and the wiper system across the range of dripline prices considered. Conversely, for scenario D the SDI cropping system remains most profitable system across the range of dripline prices considered except at the highest dripline price.

CONCLUSIONS

Several factors influence the relative profitability of center pivot and SDI cropping systems. According to the assumptions used in this analysis, center pivot cropping systems have higher estimated net returns than SDI cropping systems on standard quarter-section (160 acre) fields. As field size decreases, center pivot cropping system net returns eventually fall below those of SDI cropping systems. This occurs primarily because per acre investment costs for SDI remain relatively stable as field size declines, whereas center pivot irrigation system's per acre investment costs increase markedly.

SDI cropping system net returns are very sensitive to system longevity or life span. If a SDI system only lasts 5 years, it is noncompetitive in a net returns sense with center pivot cropping systems across all field-size scenarios. A SDI system with a 15-year life is economically competitive with center pivots on fields of less than full size (less than 160 acres), and even approaches economic competitiveness on full size fields.

Changes in corn yields and prices have a major effect on the projected net returns of these alternative cropping systems. Higher corn yields and prices favor fully irrigated SDI cropping systems. In this analysis corn yield and price changes generally do not affect the choice of irrigation systems across the different field-size scenarios for the range of corn yield and prices considered.

Any decrease in dripline prices results in improved SDI net returns relative to center pivot cropping systems. Still though, the selection of the most profitable irrigation and cropping system was not affected across the range of dripline prices or cropping system scenarios considered.

The results of this study are highly dependent on the assumptions made in calculating cropping system net returns for western Kansas. Producers considering an investment in either a center pivot or SDI cropping system should complete a partial budget analysis using information specific to their farm. These economic sensitivity analyses were performed by varying only one factor at a time. In practice, several factors may change simultaneously in a farm operation when a center pivot or SDI irrigation system investment is made. If these potential simultaneous factor changes are considered together, the relative profitability results may vary dramatically.

Future SDI applied research and extension efforts should focus on several areas. First, there is a need for more information on the longevity of SDI irrigation systems and on the costs of renovating them. Second, the potential water use efficiencies and uniform application benefits for SDI irrigation systems relative to center pivot irrigation systems needs further investigation. Third, the income tax management implications of alternative center pivot and SDI investments need to be accounted for in investment decisions. Because of higher system costs and associated tax deductions, SDI system investments would be expected to have an income tax management advantage over center pivot investments for comparable tracts of farmland. Fourth, an analysis is needed of how increased production risk and lower projected income for nonirrigated crop production influences a crop producer's willingness to select irrigation systems that provide higher proportions of irrigated production for a given piece of farmland. From a farm financial management perspective, potential implications of placing a center pivot or an SDI system on a furrow irrigated field may have land valuation and tax management impacts that should be understood. Finally, ongoing efforts are needed in the design and development of efficient, low cost center pivot and SDI irrigation and cropping systems.

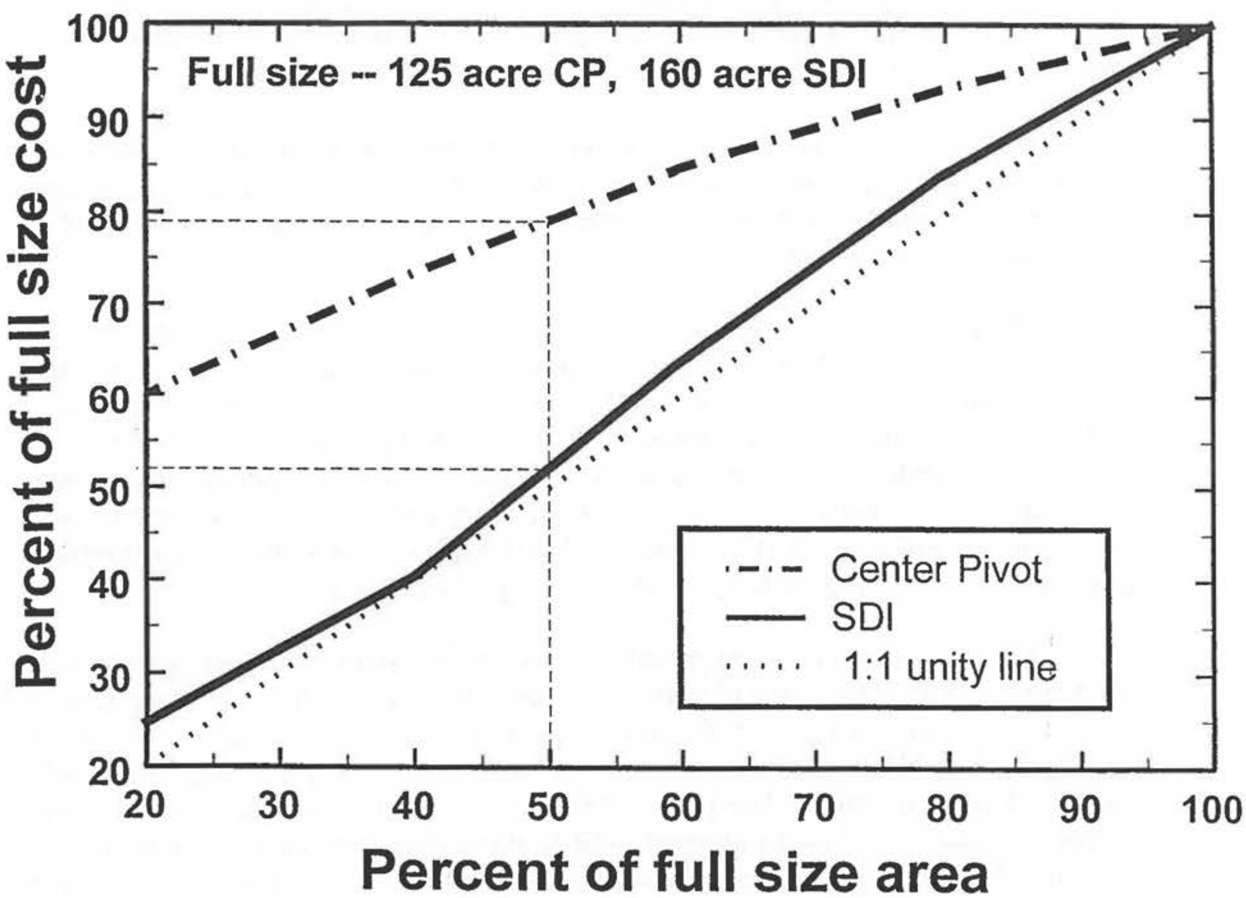

Figure 1. Investment Cost as Affected by System Size for Center Pivot and SDI Systems.

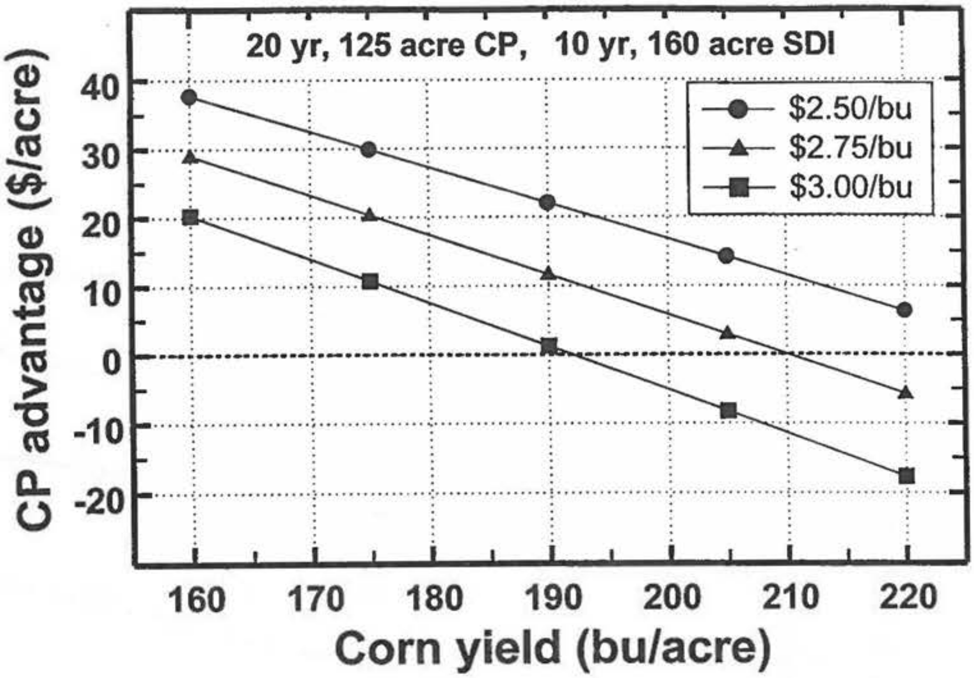

Figure 2. Net Returns Advantage of a Full Sized 125 Acre Center Pivot Cropping System over SDI as Affected by Corn Yield and Price.

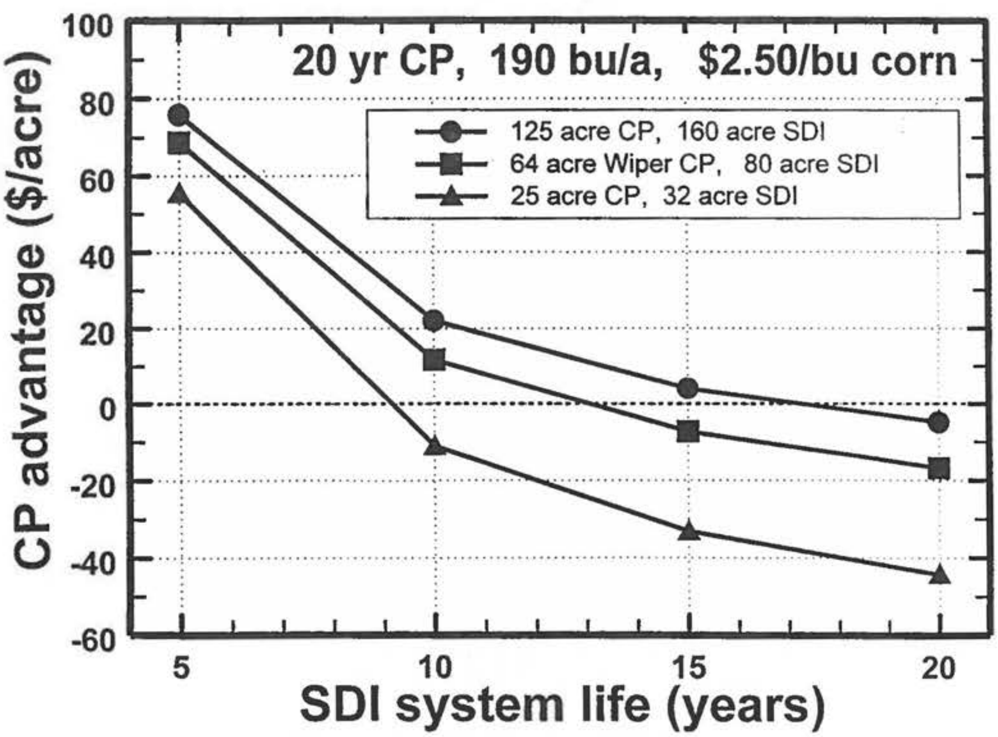

Figure 3. Net Returns Advantage of a Center Pivot Cropping System over SDI as Affected by System Size and SDI System Life.

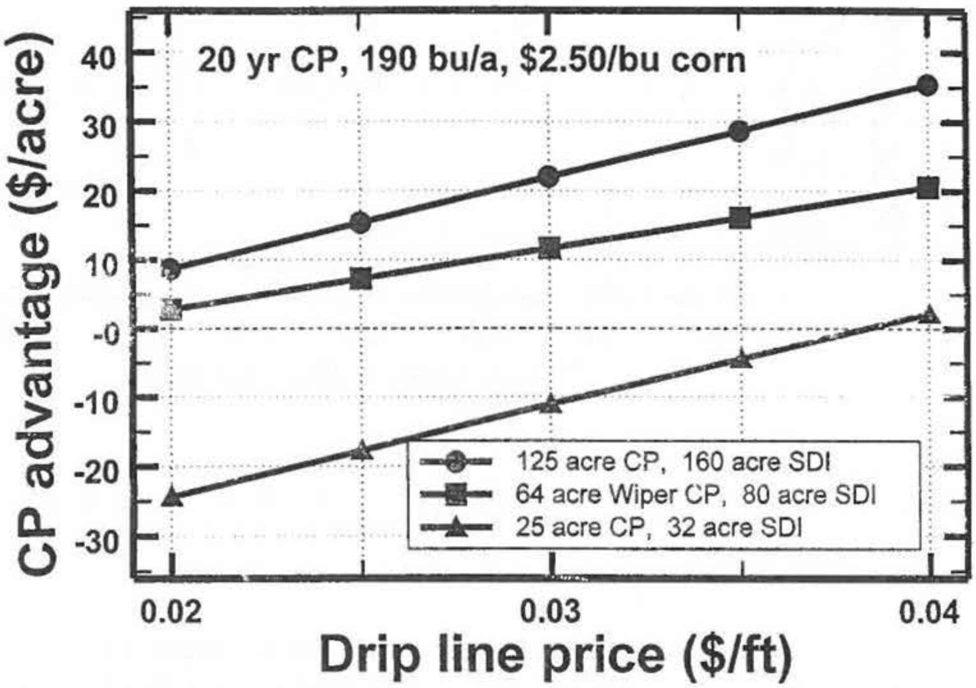

Figure 4. Net Returns Advantage of a Center Pivot Cropping System over SDI as Affected by System Size and SDI Dripline Price.

IN-CANOPY SPRINKLER APPLICATION FOR CORN: WHAT WORKS AND WHAT DOESN'T

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SUMMARY

In-canopy sprinkler application in fully developed corn after tasseling is affected by nozzle spacing, nozzle height, row orientation with respect to center pivot travel, and nozzle type. Incorrect combinations can lead to poor in-canopy uniformity. In general, as nozzle spacing increased from 5 to 10 ft, in-canopy uniformity decreased. The 4 ft nozzle height was worse than the 2 and 7 ft nozzle heights in terms of in-canopy uniformity. Circular (parallel to sprinkler travel) rows almost always have better in-canopy uniformity than straight (perpendicular to sprinkler travel) rows. Spinner nozzles had better in-canopy uniformity than plate nozzles at the 2 and 7 ft heights.

INTRODUCTION

In-canopy center pivot sprinkler irrigation is gaining popularity in much of the Great Plains region. Physical and institutional constraints have resulted in lower system capacities which has encouraged irrigators to get the maximum benefit from their water application. In-canopy sprinkler irrigation offers the potential of very high application efficiencies, because of lower evaporation losses from both in-flight and canopy evaporation. However, uniformity of applied irrigation can be greatly affected by canopy distortion of the sprinkler pattern. This may not be a significant concern if the pattern is still symmetrical and if all plants have equal opportunity to the water. Some irrigators are experimenting with wide-spaced in-canopy sprinklers for irrigation of corn. The advantages of the wider spacing is reduced investment costs. However, there is little research information available on the effectiveness of this strategy. The height of the sprinklers also has a direct bearing on the magnitude of the distortion. Redistribution of the applied water within the crop canopy is also affected by the orientation of the corn rows with respect to the center pivot sprinkler travel direction. Nozzle type (static plate vs. rotating plate) may also influence distribution of in-canopy sprinkler application. This report summarizes in-canopy sprinkler application research conducted in 1996 at the KSU Northwest Research Extension Center at Colby, Kansas. The results are from fully developed corn plants after tasseling. It should be noted that the canopy conditions roughly represent the last 30-40 days of the irrigation season at Colby. Therefore, the results do not represent the whole corn growing season, but do represent a time when irrigation needs are critical.

PROCEDURES

The study was conducted on a fully developed corn canopy from August 1-3, 1996 at the KSU Northwest Research-Extension Center at Colby, Kansas. Corn was planted in 30 inch rows at a plant population of 33,100 plants/acre (6.32-in spacing) in both circular and straight rows under a center pivot sprinkler irrigation system. This resulted in separate plot areas with rows parallel or perpendicular to the center pivot travel direction. The plot areas were centered at radii of 277, 327 and 377 ft on a two tower center pivot.

Throughfall is water that reaches the soil surface by *falling through* the leaves of the plant canopy. Stemflow is water that reaches the soil surface by *flowing* down the plant *stem*. Both components must be measured to get estimates of water distribution at the soil surface. Throughfall was measured in pans 16 inches long by 26 inches wide (30 inches between corn rows) and 4.5 inches in height. Throughfall was converted to an equivalent depth by dividing the measured amount by the pan area with appropriate conversion factors. Stemflow was measured with special collection units made from a 6 inch section of split 2 inch PVC pipe taped around the base of the corn stalks. Stemflow was converted to an equivalent depth by relating the measured amount to the land area represented by an individual plant (30 inch row spacing x plant spacing of 6.32 inches).

Trials were replicated at three radii (277, 327, or 377 ft) with a single nozzle at each location. Flowrates at the three radii were 5.08, 5.80 and 6.85 gpm using #30, #32 and #35 Nelson[1] nozzles with 10 psi pressure regulators. Treatments variables were nozzle height (2, 4 or 7 ft) and nozzle type (S-3000 spinner with purple D6-20 plates or D-3000 spray nozzle with blue deflection plate). Each height and nozzle type combination was replicated at each radii. The location of the throughfall and stemflow collection units are fixed at the three radii, so the replication is made by repeating irrigation events. The six events (2 plates and 3 heights) were conducted over a three day period. Stemflow and throughfall was also measured for a coincidental 1.2 inch rainfall event that occurred the evening of July, 31, 1996. Stemflow and throughfall was measured from a single nozzle at each of the three radii for the left half of each pattern for both parallel and perpendicular rows. Preliminary tests indicated a potential in-canopy wetted radius of 20 ft for the highest sprinkler height. Collection units were dispersed over the 20 ft distance with one throughfall pan for each interrow and one stemflow collection unit for each row. This translates into 54 stemflow and throughfall collection units each (3 radii x 2 row orientations x 9 row/interrow locations). Each throughfall pan was further divided into three equal size compartments (8.67 inches by 16 inches) to give better breakdown of water distribution. A single event could potentially consist of 162 measurements of throughfall and 54 measurements of stemflow, although distorted sprinkler patterns reduced some of the amounts to be measured to zero. The single nozzle arrangement was used to facilitate the use of superpositioning to "mirror" the amounts catched. This allowed the simulation of various nozzle spacings (i.e. 5, 7.5, and 10 ft). The center pivot sprinkler for these trials was operated at a speed that would apply 1.5 inches if all nozzles were operating on a 5-ft spacing. For this system, it is operating at a linear speed of 0.88 ft/minute for 3% of the 1 minute cycle at the 377 ft radius. This slow speed allows for larger measured sample and therefore more accuracy as measurement errors would constitute a smaller fraction of the sample. The applied amount does not affect the relative sprinkler water distribution pattern, only the magnitude of the amounts.

The collected data was analyzed using appropriate statistical procedures. The under-canopy water distribution was calculated for various simulated nozzle spacings. The unadjusted Christiansen Uniformity Coefficient was calculated for each treatment and row orientation as a index of performance. These are not truly the CU for these in-canopy systems because they are using "mirrored" data, but these values do serve as a relative index between the comparisons in this study.

RESULTS

Water application pattern as affected by row orientation and nozzle spacing

As outlined in the procedures, the concept of superposition was used to *mirror* the application from the single nozzle to get the resultant water pattern for nozzle spacings of 5, 7.5 and 10 ft.

Figure 1 shows the water application patterns at the ground surface from the Nelson Spinner nozzle applying water from a height of 2 ft for both the circular corn rows (parallel to center pivot sprinkler travel) and the straight corn rows (perpendicular to sprinkler travel). It is helpful to remember in interpreting the data, that a flatter pattern for a given nozzle spacing represents the best water distribution. For example, in Figure 1, the circular rows with the 5 ft nozzle spacing *(open circles in Fig 1.)* have a better water distribution pattern than the perpendicular rows with the 5 ft nozzle spacing *(open squares).* Application variation [A_{var} = 100 x ((Maximum amount -Minimum amount)/ Maximum amount)] was 20% for the circular parallel rows and 54% for the straight perpendicular rows. This is a considerable difference between the two row orientations. Normally for sprinkler applications on bare soils, it is considered desirable to limit the variation to less than 10% along the sprinkler lateral. However, there are other factors affecting distribution for in-canopy application and the 10% rule is probably not acceptable.

The differences in A_{var} for the two orientations with the 5 ft nozzle spacing is considerable, but it should be noted that it occurs over a distance less than 2.5 ft. In some cases, depending on field slope, soil type, tillage practices and residue levels, soil water infiltration differences may buffer out the water application differences over this <u>short</u> distance. Hart (1972) concluded from computer simulations that differences in irrigation water distribution occurring over a distance of approximately 3 ft were probably of little consequence and would be evened out through soil water redistribution. However, if chemigation (foliar or soil-applied chemicals) is a consideration, these differences might be very significant. If field characteristics encourage runoff or ponding in low areas, these differences would probably be unacceptable. Perfectly perpendicular rows only exist for two locations in a center pivot sprinkler field with straight rows, so for straight rows the application varies from parallel to perpendicular. In ridge-till situations when the rows are perpendicular, a large percentage of the center pivot capacity (GPM) is being applied to just a very few furrows in in-canopy application.

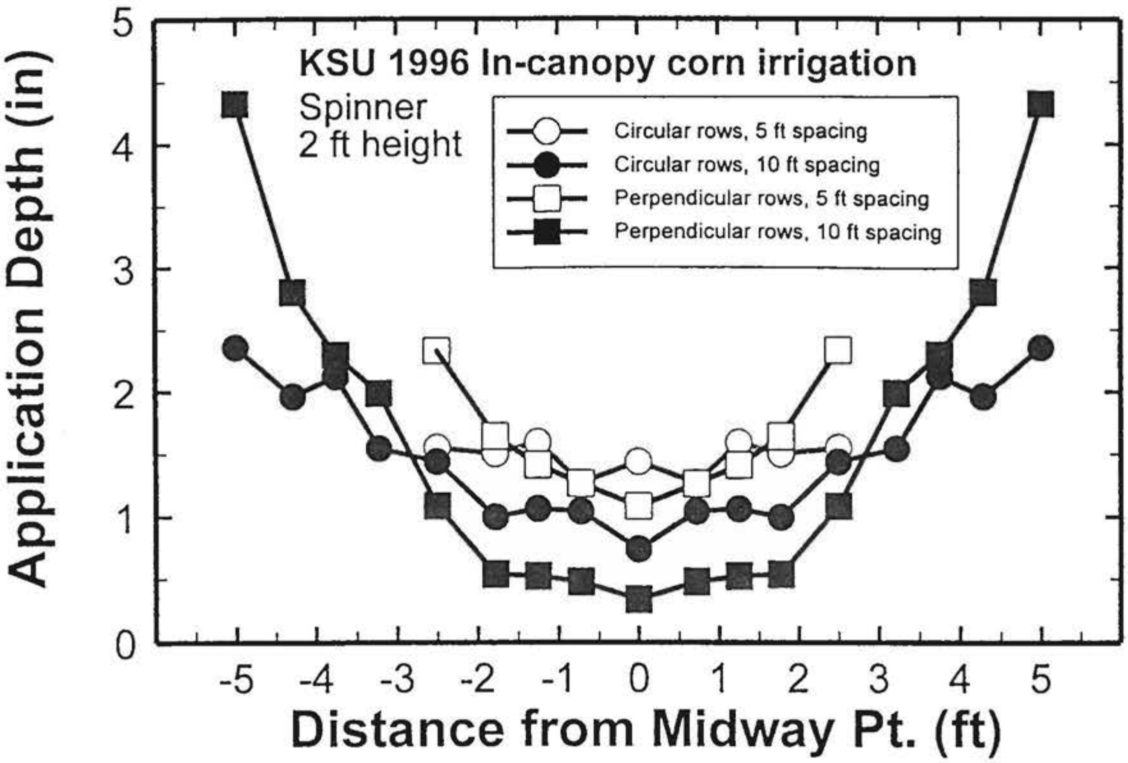

Figure 1. Water application pattern as affected by row orientation and nozzle spacing for spinner nozzles at the 2 ft height in a fully developed corn canopy after tasseling.

Figure 1 also shows the effect of wider nozzle spacings on the water distribution pattern. It is helpful to remember in interpreting this aspect of the data, that even if the magnitude of the variation in application amounts are similar that the shorter the trend line the better the potential distribution. For example, the circular rows with the 10 ft nozzle spacing has a somewhat similar A_{var} to the perpendicular rows with the 5 ft nozzle spacing (54% vs. 69%, respectively). However, for the 10 ft spacing, there is a trend of decreasing water application over a much longer distance, and so potentially larger areas would have incorrect application amounts (over or under application). The differences between A_{var} for the circular parallel and perpendicular rows for the 10 ft. nozzle spacing are 69 and 92%, respectively. It is highly probable that these amounts of application variation over the distance of 5 ft would lead to runoff or ponding in the locations with over application and crop water stress in the locations with under application.

Figures 2 and 3 show the water application patterns for circular parallel and straight perpendicular rows for all three simulated nozzle spacings, 5, 7.5 and 10 ft for the spinner nozzle at the 2 ft height. **Acceptable nozzle spacings/row orientation combinations for the spinner nozzle at 2 ft height are probably limited to 5 and 7.5 ft spacings with circular rows and to the 5 ft nozzle spacing with perpendicular rows. A_{var} for these combinations were 20, 44 and 54%, respectively. This conclusion assumes chemigation is not being used (applies only to 7.5 ft spacing or perpendicular rows) and that runoff is controlled to a small (2-10 ft radius) localized area with tillage management (furrow dams or implanted reservoirs) or by residue management.**

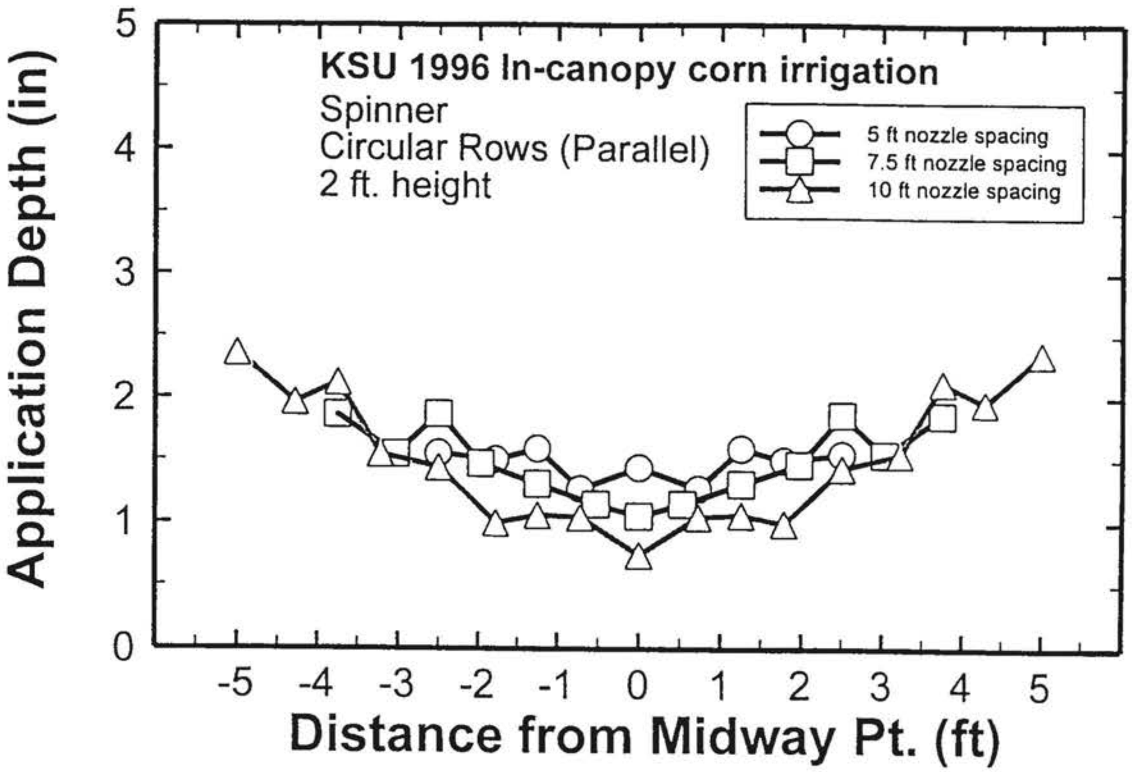

Figure 2. Water application pattern for circular parallel rows at various nozzle spacings for spinner nozzles at the 2 ft height in a fully developed corn canopy after tasseling.

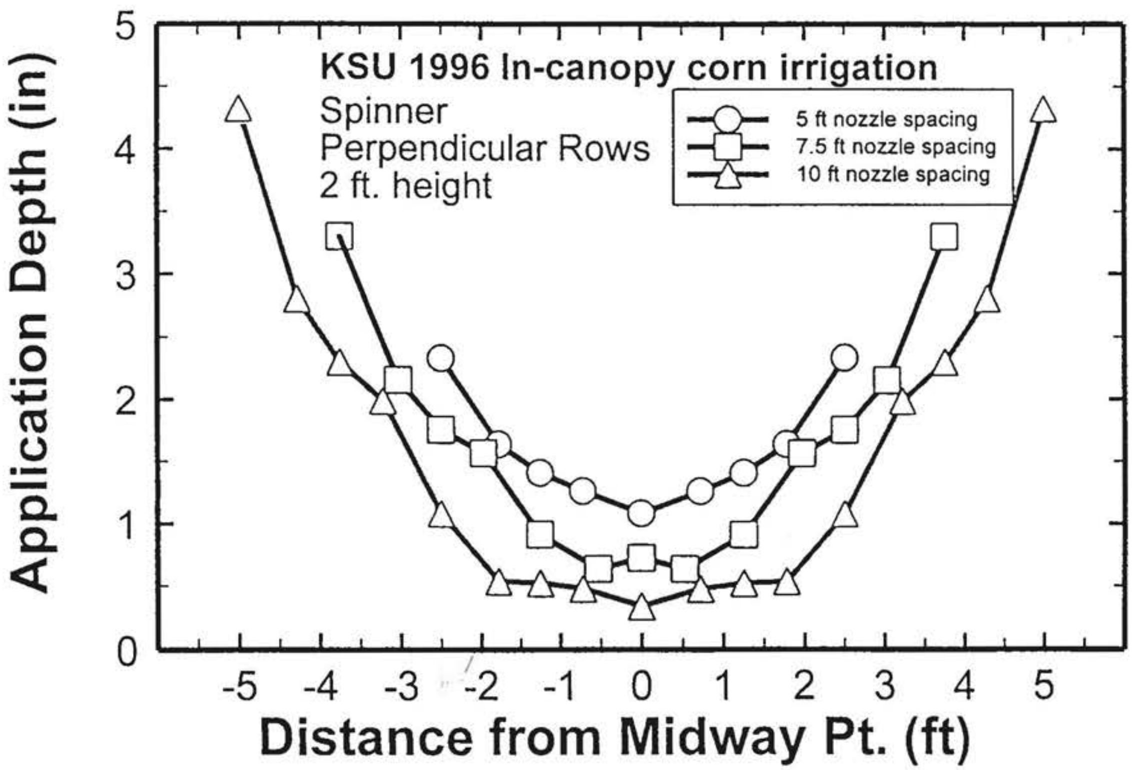

Figure 3. Water application pattern for straight perpendicular rows at various nozzle spacings for spinner nozzles at the 2 ft height in a fully developed corn canopy after tasseling.

In-canopy uniformity as affected by sprinkler height and nozzle type

Another way of characterizing the performance of in-canopy sprinkler distribution would be to calculate the Christiansen Uniformity Coefficient, CU. For those individuals that are very familiar with CU values, it should be re-noted that the in-canopy uniformity values expressed in this paper are not true CU values because they are using "mirrored" data, but they do serve as a relative index between the comparisons in this study. In addition, these values are not adjusted (using the techniques of Heerman and Hein, 1968) for the center pivot radius since they are over a very short distance. For these reasons, we will simply refer to the values in this paper as in-canopy uniformity, to distinguish them from true CUs.

Figure 4 shows the in-canopy uniformity for spinner nozzles at heights of 2, 4 or 7 ft at nozzle spacings of 5, 7.5 or 10 ft for both circular parallel and straight perpendicular rows. It can be seen that the 4 ft height is always the worst height for a given nozzle spacing and row orientation. This may not be surprising since this is about the corn ear height, an area of high leaf density at this portion of the season. Distortion of the sprinkler pattern is very high at the 4 ft height. For the circular parallel rows, the 2 ft height is better than the 7 ft height, but the opposite is true for the straight perpendicular rows. This may seem confusing. However, some previously unmentioned factors are beginning to have an influence. As the nozzle is raised in the canopy, the flowpath to the soil surface changes from almost equal amounts of stemflow and throughfall to larger amounts of stemflow. This is indicated by the *"spikes"* in the 4 and 7 ft height lines in Figure 5. The spikes correspond to the locations of the corn rows and are stemflow amounts. Because these spikes affect the in-canopy uniformity, the 7 ft height is worse than the 2 ft height for the circular rows. For the perpendicular rows, there are some spots in the center pivot travel that give a relatively straight path of throughfall that is not heavily distorted by the nearby plant row. The in-canopy uniformity at 7 ft can be better than at the 2 ft level for the straight perpendicular rows because of less distortion.

Figure 6 shows the effect of nozzle type, spinner or plate, as affected by nozzle spacing and height for circular parallel rows. Spinners have considerably better in-canopy uniformity than plates at the 2 ft height. This may not be surprising since the spinner has a rotating water impingement plate that has multiple angles for the diffused water. Conversely, the plate nozzle is static and has only one angle of water diffusion. In essence, the spinner nozzle allows for the searching of the crop canopy for holes to better diffuse the water. At the 4 ft level, the plate nozzle showed better in-canopy uniformity than the spinner nozzle. The reason for this is unknown. One possibility is that the plate nozzle may be diffusing water at a higher kinetic energy which may allow better penetration. Another possibility may be that the multiple diffusion angles of the spinner may be causing more partitioning of the sprinkler application into stemflow as the height is raised in the canopy (IE the spiking mentioned in the previous section). At the 7 ft height there was not great differences in in-canopy uniformity as affected by nozzle type but the spinner did have higher values.

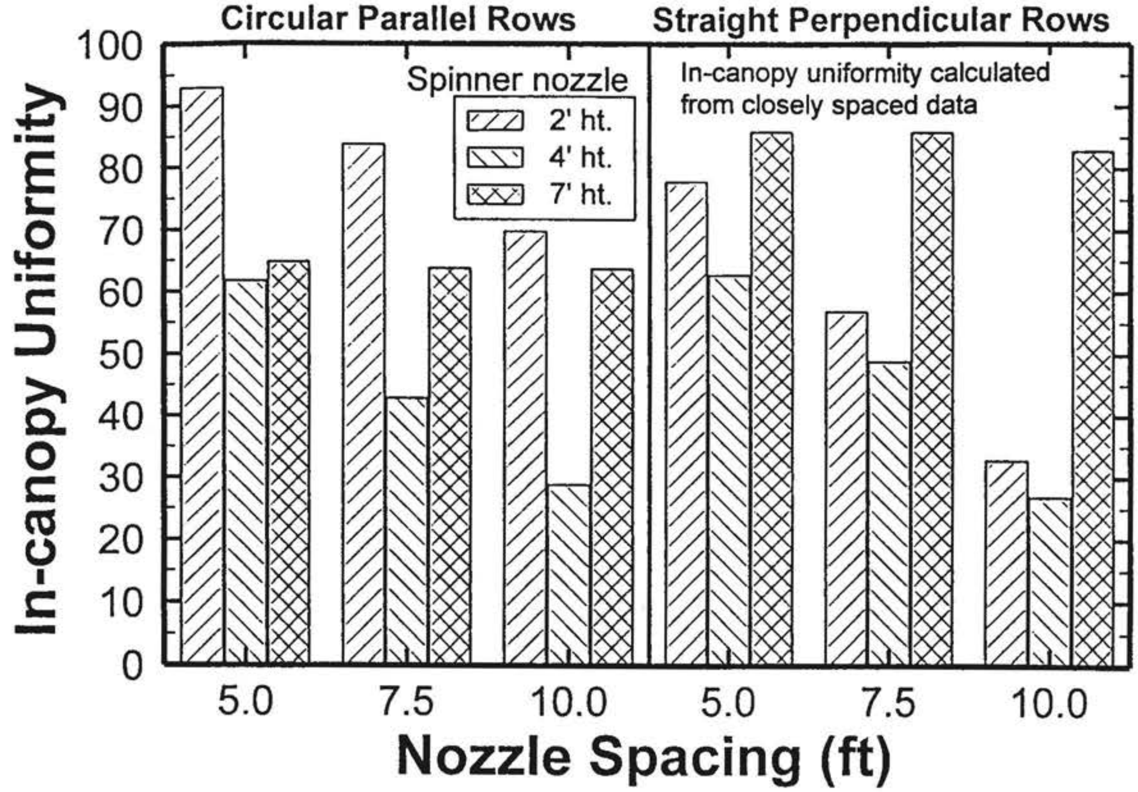

Figure 4. In-canopy uniformity as affected by nozzle spacing and row orientation for spinner nozzles at various heights in a fully developed corn canopy after tasseling. The uniformity between corn rows was calculated from closely spaced containers.

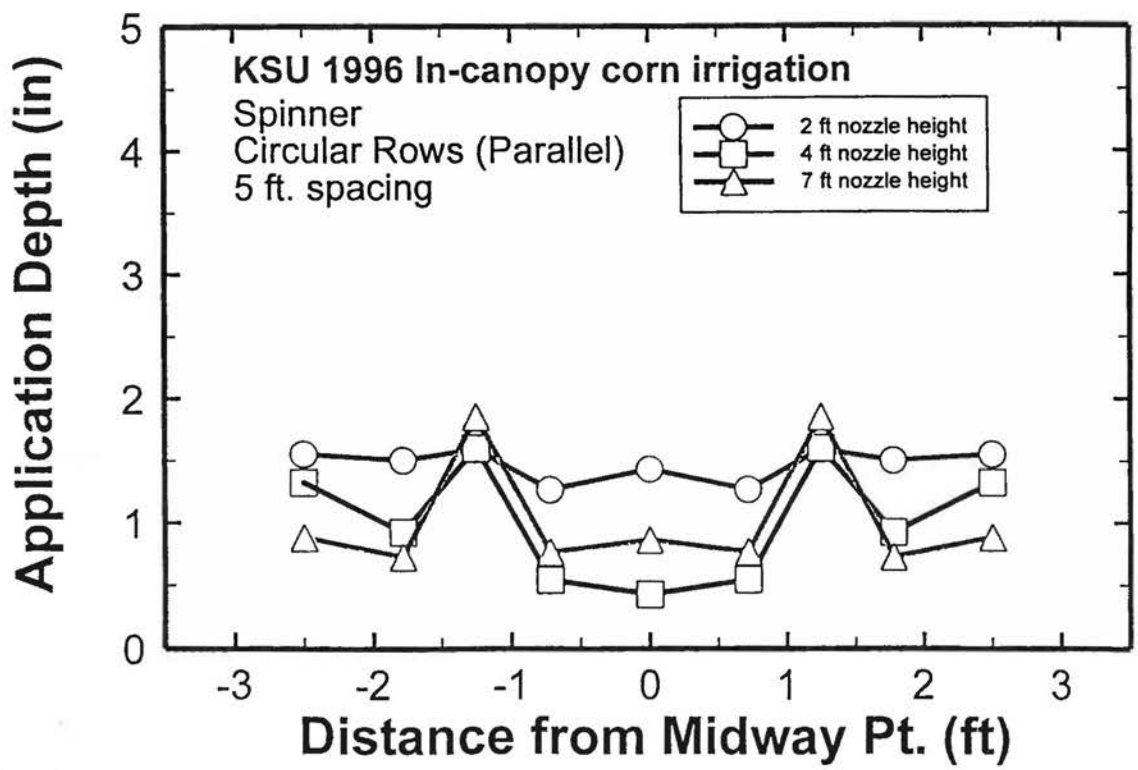

Figure 5. Water application patterns showing evidence of spiking due to stemflow increases as nozzle height increased from 2 to 4 to 7 ft in a fully developed corn canopy.

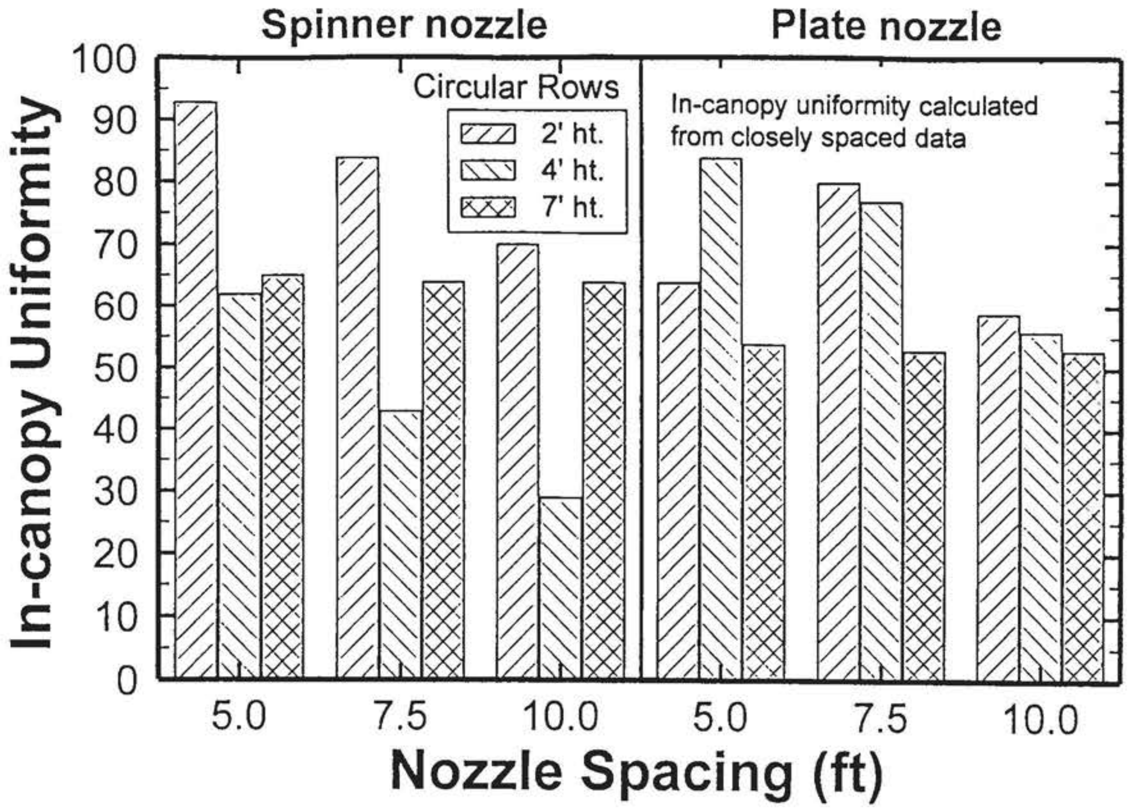

Figure 6. In-canopy uniformity as affected by nozzle spacing and nozzle type for circular parallel rows at various heights in a fully developed corn canopy after tasseling. The in-canopy uniformity between corn rows was calculated from closely spaced (6-9 inches apart) containers.

Table 1 shows some of the application characteristics for all the comparisons in this study. Examining this single rainfall event shows that even Mother Nature can present uniformity differences. The rain storm in this case was driven by a 17 mph (hourly average) wind from the East-Northeast. This resulted in nearly perpendicular application for the circular rows and nearly parallel application for the straight rows, resulting in in-canopy uniformities of 65 and 86%, respectively.

Summarizing this section, **the worst height in terms of in-canopy uniformity for a spinner nozzle is at 4 ft in a fully developed corn canopy. Row orientation makes a large difference in in-canopy uniformity at the 2 and 7 ft height. Spinners performed better than plates at the 2 and 7 ft heights. In-canopy uniformities as high as 93% are possible with circular rows using spinners with a 5 ft spacing.**

Table 1. Water pattern application characteristics for several in-canopy sprinkler comparisons.

Row Orientation	Nozzle type	Nozzle height (ft)	Nozzle spacing (ft)	Maximum amount (in)	Minimum amount (in)	Mean amount (in)	Standard Deviation (in)	Coefficient of Variation	In-canopy Uniformity	Avar
Parallel (C)	Rain	-	-	0.86	0.26	0.46	0.20	43	65	70
Perpendicular (S)	Rain	-	-	0.81	0.35	0.57	0.11	19	86	57
Parallel (C)	Spinner	2	5.0	1.59	1.27	1.47	0.12	8	93	20
Parallel (C)	Spinner	2	7.5	1.86	1.05	1.50	0.30	20	84	44
Parallel (C)	Spinner	2	10.0	2.36	0.74	1.52	0.53	35	70	69
Parallel (C)	Spinner	4	5.0	1.60	0.43	1.02	0.46	45	62	73
Parallel (C)	Spinner	4	7.5	1.92	0.30	1.06	0.68	65	43	84
Parallel (C)	Spinner	4	10.0	2.56	0.08	1.08	0.89	83	29	97
Parallel (C)	Spinner	7	5.0	1.86	0.73	1.04	0.47	45	65	61
Parallel (C)	Spinner	7	7.5	2.17	0.60	1.04	0.52	50	64	72
Parallel (C)	Spinner	7	10.0	2.18	0.55	1.05	0.51	48	64	75
Perpendicular (S)	Spinner	2	5.0	2.33	1.08	1.60	0.45	28	78	54
Perpendicular (S)	Spinner	2	7.5	3.30	0.64	1.64	0.91	55	57	81
Perpendicular (S)	Spinner	2	10.0	4.33	0.34	1.67	1.33	79	33	92
Perpendicular (S)	Spinner	4	5.0	2.41	0.76	1.36	0.65	47	63	69
Perpendicular (S)	Spinner	4	7.5	3.06	0.47	1.41	0.91	65	49	85
Perpendicular (S)	Spinner	4	10.0	4.07	0.10	1.44	1.29	90	27	98
Perpendicular (S)	Spinner	7	5.0	1.35	0.83	1.04	0.19	18	86	38
Perpendicular (S)	Spinner	7	7.5	1.37	0.75	1.04	0.20	19	86	46
Perpendicular (S)	Spinner	7	10.0	1.51	0.68	1.05	0.24	23	83	55
Parallel (C)	Plate	2	5.0	2.03	0.79	1.28	0.52	41	64	61
Parallel (C)	Plate	2	7.5	1.97	0.68	1.25	0.37	29	80	66
Parallel (C)	Plate	2	10.0	2.49	0.59	1.30	0.65	50	59	76
Parallel (C)	Plate	4	5.0	1.44	0.61	1.10	0.25	23	84	58
Parallel (C)	Plate	4	7.5	1.55	0.55	1.13	0.33	29	77	64
Parallel (C)	Plate	4	10.0	1.99	0.29	1.15	0.57	50	56	85
Parallel (C)	Plate	7	5.0	1.95	0.45	0.96	0.58	60	54	77
Parallel (C)	Plate	7	7.5	2.07	0.57	0.96	0.57	59	53	72
Parallel (C)	Plate	7	10.0	2.06	0.33	0.98	0.59	60	53	84
Perpendicular (S)	Plate	2	5.0	2.22	0.71	1.31	0.56	43	69	68
Perpendicular (S)	Plate	2	7.5	2.88	0.61	1.33	0.78	58	56	79
Perpendicular (S)	Plate	2	10.0	3.74	0.64	1.35	1.00	74	44	83
Perpendicular (S)	Plate	4	5.0	2.79	0.46	1.27	0.92	73	45	83
Perpendicular (S)	Plate	4	7.5	3.69	0.42	1.30	1.16	89	32	89
Perpendicular (S)	Plate	4	10.0	4.68	0.29	1.32	1.41	107	23	94
Perpendicular (S)	Plate	7	5.0	1.58	0.82	1.13	0.31	27	77	48
Perpendicular (S)	Plate	7	7.5	1.75	0.83	1.13	0.31	27	80	52
Perpendicular (S)	Plate	7	10.0	1.82	0.81	1.15	0.34	29	76	56

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Heerman D.F. and P.R. Hein. 1968. Performance characteristics of self-propelled center-pivot sprinkler irrigation systems. Transactions of the ASAE, 11(1):11-15.

1 The mention of trade names or commercial products does not constitute their endorsement or recommendation by the author or by the Kansas Agricultural Experiment Station.

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DETERMINING RUNOFF POTENTIAL

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INTRODUCTION

Sprinkler irrigation systems and specifically center pivots have been adapted to operate on many different soils, to traverse extremely variable terrain, and to provide water to meet a number of different management objectives. **The main goal for water application systems** is to apply water uniformly in sufficient quantities to meet crop water needs without generating runoff. As a buyer, you will be furnished with an array of different sprinkler types, many that are capable of performing adequately. However, you should make a selection based upon accurate field based information, system installation and operating costs, and careful consideration of the interaction between the water application system and field conditions. Only then will the system meet your expectations.

Water runoff is a problem often associated with sprinkler irrigation systems operated on sloping terrain. Fields with steep slopes typically have little soil surface storage to keep water where it is applied. A number of water quality and crop production problems are the direct result of surface runoff. Surface runoff can dislodge and transport soil particles, fertilizers and pesticides from their field positions causing degradation of surface and/or ground waters. Other potential problems associated with runoff include a lack of soil moisture in localized areas of the field, crop nutrient deficiencies, washed-out seeds or plants, and increased pumping costs.

Water Application Uniformity

We begin with the assumption that water is uniformly applied by the irrigation system. Nonuniform water distribution may contribute to runoff problems. Uniform water application requires that the correct sprinklers be at each position along the pivot lateral, that the pumping plant deliver water at the appropriate pressure and flow rate, and that the system is not operated under adverse atmospheric conditions. Another aspect of water application uniformity is the uniformity of infiltration. Even if water could be applied to the soil at 100% uniformity, runoff causes poor infiltration uniformity. Thus, the goal must be to consider how well the sprinkler package will match up with the field conditions.

It is safe to say that the uniformity of water application generally increases with a decrease in sprinkler spacing. This statement assumes that the operating characteristics of the sprinkler do not change. Narrowing the spacing results in more overlap among the water application patterns of individual sprinklers. A narrow spacing also makes it more difficult for wind to alter the overall system water application pattern.

Uniformity can also be influenced by field topography. In the absence of some sort of flow control, the topographic features of the field change the water pressure delivered to each sprinkler/nozzle location. Since each sprinkler has an orifice through which water is metered, alterring the pressure supplied to that orifice changes the sprinkler output. If the field is sloped uphill from the pivot point, sprinklers located at the highest elevation will be distributing less water than those close to the pivot pivot. For this reason, it is recommended that flow control devices be installed if the elevation difference results in a change of flow greater than about 10%. NebGuide G88-888, *Flow Control Devices for Center Pivot Irrigation Systems*, presents some considerations for different types of flow control devices.

Zero Runoff Goal

The zero runoff goal requires that the sprinkler package selected for the system be carefully matched to the field conditions and to the operators management scheme. Too often the desire to reduce pumping costs clouds over the issue of overall water application efficiency. Some systems like LEPA (Low Energy Precision Application) are designed so water does not immediately soak into the soil. However, proper LEPA designs also call for tillage practices that hold the water on the soil surface where it lands until it has time to infiltrate into the soil.

Water droplet impact should be considered with all sprinkler package selections. Each sprinkler will deliver water to the soil with a particular range of water droplet sizes and distribution of water droplets. In general, larger water droplets are concentrated toward the outside edge of the water application pattern and smaller droplets fall closer to the sprinkler\nozzle. It is the large water droplets that tend to be a concern. Large water droplets carry a substantial amount of energy that is transferred to the soil upon impact. The impact will tend to break down the soil clods causing the soil to consolidate. Eventually a thin crust will be formed on the surface that can reduce soil infiltration by up to 80% compared to soils protected by crop residues.

A computer program "CPNOZZLE", based on research conducted at Mead, NE, provides an opportunity to establish how well suited a sprinkler package is to a field's soils and slopes. The program is also useful in predicting how much the design or operation should be changed to eliminate a runoff problem. For example, if the normal operation is to apply 1.25 inches of water per revolution, the program can be used to see if runoff might occur and, if so, what application depth would be acceptable. If you are in the process of alterring the sprinkler package, the program can be used to select an appropriate system flow rate and sprinkler wetted diameter.

The program works by overlaying a soil infiltration rate curve with a water application pattern. Figure 1 shows an infiltration rate curve for a NRCS Intake Family of 0.5 and the water application pattern of a low pressure spray nozzle mounted at truss rod height. Beginning from the right hand side of the graph, the program mathematically compares the water application rate to the soil infiltration rate for each minute that water is applied to the field. For example, at 9 minutes after water application started, the water

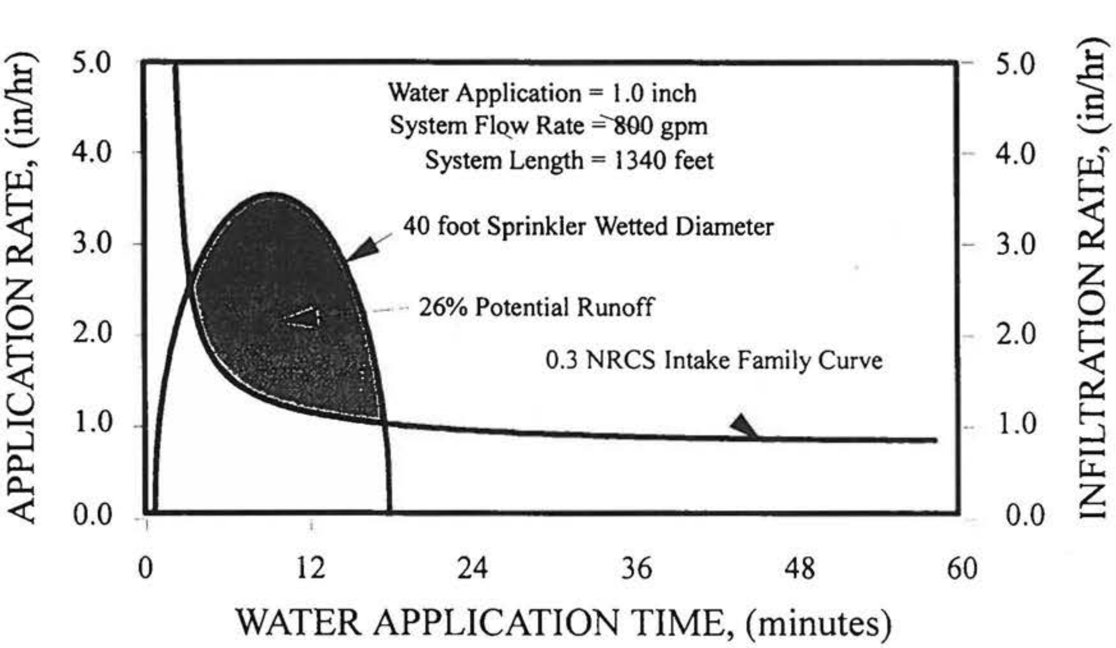

Figure 1. Estimated runoff for a 1340 foot center pivot supplied with 800 gpm and applying 1.0 inch of water using a nozzle package with a 40 foot wetted diameter.

application rate was 3.6 inches per hour and the soil infiltration rate was 1.2 inches per hour. Since the water application rate is greater than the infiltration rate, water will begin ponding on the soil surface. The program mathematically totals the amount of water that is applied in excess of the soil infiltration rate. When the program has compared the two curves for an entire water application pattern, the sum of the water applied in excess of the soil infiltration rate is the potential runoff signified by the shaded area in Figure 1.

Case Study

One way to demonstrate how the program might be used is to run through a series of examples changing only one of the data inputs. Let's assume that our base system has the characteristics given in Table Ia. Data entered in each column could influence runoff potential. Soil texture and intake family, defined by the Natural Resource Conservation Service (NRCS), determine how fast water will infiltrate into the soil. In this example, the field has a *silt loam* soil with an NRCS Intake Family designation of 0.3. *Slope*, or the change in elevation within the field, influences how much water will naturally puddle or be stored on the soil surface to infiltrate later, and how easily the water will flow to a lower part of the field. In this example, the field has a moderate *slope of 3-5 percent*.

The characteristics of center pivot influence how intensely water is applied to the soil. Lets use a system capacity of 800 gallons per minute, system length equal to 1340 feet, application depth of 1.0 inch per revolution, and a sprinkler head wetted diameter of 40 feet. The estimated runoff resulting from this field-system combination is 26 percent, which means 26 percent of the water pumped through the system may not infiltrate where it landed. The runoff moved to another part of the field or it left the field altogether. As a result, water application efficiency was reduced by 26 percent.

Each of the land surface factors and center pivot characteristics are varied individually in Tables Ib - Ig. These examples indicate how each factor influences overall runoff. All runoff data are reported as the percentage of applied water that did not infiltrate where landed.

Soil texture cannot be changed in a given field. It has a tremendous impact on runoff as given in Table Ib. A soil in intake family 0.1 (clay, silty clay or silty clay loam) has very slow infiltration and produces 44 percent runoff. However, a silt loam, very fine sandy loam, fine sandy loam or loamy fine sand in the 1.0 intake family can infiltrate all of the applied water from this system with no runoff.

Slope (or changes in field elevation) is usually an unchanged factor. Table Ic shows a field with a slope of 1-3 percent has 8 percent runoff while a slope greater than 5 percent has 35 percent runoff. The influence of land surface factors on runoff shows sprinkler packages must be designed for each field. Pressure on flow regulators can compensate for slope changes within the field and keep application uniform. However, steeper slopes will still produce more runoff than flatter slopes, even if water application is the same.

Irrigation system capacity influences application rate or intensity if other system characteristics are the same. Table Id shows the influence of changing system capacity on runoff. When system capacity drops to 700 gallons per minute, runoff is 22 percent. When system capacity increases to 900 gpm, runoff is 29 percent. Although not shown in Table I, runoff is greater near the outer end of the system than near the center. Outer spans have more area to water in the same amount of time, allowing less time for the water to infiltrate and increasing the potential for runoff.

Application amount of each irrigation also influences runoff. Table Ie shows that if the operator speeds up the pivot and puts on 0.75 inch instead of 1.0 inch, runoff is 16 percent. If the pivot is slowed to put on 1.25 inches, runoff is 33 percent. The practical limits for irrigation applications are normally 0.75-1.25 inches. Smaller applications are less efficient in delivering water to the crop; larger applications have the potential for more runoff.

Wetted diameter of the sprinkler pattern has a large influence on runoff, as shown in Table 1f. The wetted diameter is determined by the type of sprinkler device and operating pressure of the irrigation system. A maximum wetted diameter should be selected to produce little or no runoff. Eliminating runoff through sprinkler selection is usually more important than moving the sprinkler heads nearer or into the canopy to gain application efficiency.

Table Ig shows how changing more than one system characteristic affects runoff potential. Here the application depth ranged from 0.50 inch to 1.25 inches for a wetted diameter of 60 feet or 80 feet. Compared to the base system, increasing the wetted

Table I. **Examples of estimated potential runoff from center pivot irrigation systems with differing operating characteristics. Results from CPNOZZLE program.**

Soil Intake Family	Field Slope (%)	System Capacity (gpm)	System Length (feet)	Application Depth (inches)	Wetted Diameter (feet)	Estimated Runoff (%)
Table Ia.		**Base system characteristics.**				
0.3	3-5	800	1340	1.0	40	26
Table Ib.		**Influence of soil intake family (soil texture) on runoff.**				
0.1	3-5	800	1340	1.0	40	44
0.3	3-5	800	1340	1.0	40	11
0.5	3-5	800	1340	1.0	40	0
Table Ic.		**Influence of field slope.**				
0.3	0-1	800	1340	1.0	40	0
0.3	1-3	800	1340	1.0	40	8
0.3	>5	800	1340	1.0	40	35
Table Id.		**Influence of system capacity.**				
0.3	3-5	500	1340	1.0	40	14
0.3	3-5	700	1340	1.0	40	22
0.3	3-5	900	1340	1.0	40	29
Table Ie.		**Influence of application depth.**				
0.3	3-5	800	1340	0.50	40	3
0.3	3-5	800	1340	0.75	40	16
0.3	3-5	800	1340	1.25	40	33
Table If.		**Influence of wetted diameter.**				
0.3	3-5	800	1340	1.0	30	48
0.3	3-5	800	1340	1.0	60	15
0.3	3-5	800	1340	1.0	80	8
Table Ig.		**Influence of application depth and wetted diameter on runoff.**				
60 Foot Wetted Diameter						
0.3	3-5	800	1340	0.50	60	0
0.3	3-5	800	1340	0.75	60	7
0.3	3-5	800	1340	1.25	60	22
80 Foot Wetted Diameter						
0.3	3-5	800	1340	0.50	80	0
0.3	3-5	800	1340	0.75	80	2
0.3	3-5	800	1340	1.25	80	15
Table Ih.		**Influence of distance from the pivot point.**				
0.3	3-5	800	268	1.0	40	0
0.3	3-5	800	620	1.0	40	20
0.3	3-5	800	1072	1.0	40	33

diameter to 60 feet reduced runoff by about 11 percent. An increase in wetted diameter to 80 feet reduced overall runoff by about 17 percent of the applied water.

Tables Ia-Ig report weighted potential runoff or the amount of runoff based on how much of the irrigated area contributes to runoff. The CPNOZZLE program divides the system into 10 equal increments of the total system length and then calculates the weighted potential runoff. Table Ih shows how the potential for runoff changes based on position along the center pivot. Table Ia reports the weighted potential runoff of 26 percent for the entire system. Note the influence of the inside portion of the system on the overall value.

Water Application Efficiency

The LEPA system has been advertised as one method that can both uniformly apply water within the crop canopy and maintain a high application efficiency. Based on the success of the LEPA system, variations of in-canopy application have been tried in hopes of similar results. When only a part of the LEPA system is used, however, the potential for saving water may not the same. The application efficiency could be lower than above canopy packages and application uniformity may decrease resulting in increased water loss.

In a Nebraska study, runoff was measured from three different systems; a LEPA system with bubblers located at 18 inches, Spinners located 42 inches above the ground and Spinners located above the corn canopy. A comparison also was made between normal cultivation and furrow diking. Field slope varied between 1 - 3 percent. The results of these studies are shown in Figures 2 and 3. The LEPA system resulted in 15 - 25 percent runoff from both irrigation events. The Spinners located at 42 inch height had runoff of between 10 - 15 percent. Spinners above the canopy with furrow diking had the lowest runoff at approximately 8 percent.

The amount of runoff when 0.7 inch of water was applied and the Dammer-Diker[1] was used (Figure 3) decreased from 15 percent at 42 in height to 8 percent at truss rod height. A 1 - 2 percent savings in evaporation losses can be expected when sprinkler devices are moved from above to within the crop canopy.

Comparing the LEPA system with the above-canopy devices resulted in runoff being reduced from 20 percent to 8 percent. Based on Texas data, a 10 percent savings can be achieved when using a LEPA system, compared to using above-canopy devices. In this instance, trying to save 10 percent using LEPA reduced application efficiency by 12 percent due to runoff. In either case, the water runoff loss is unacceptable.

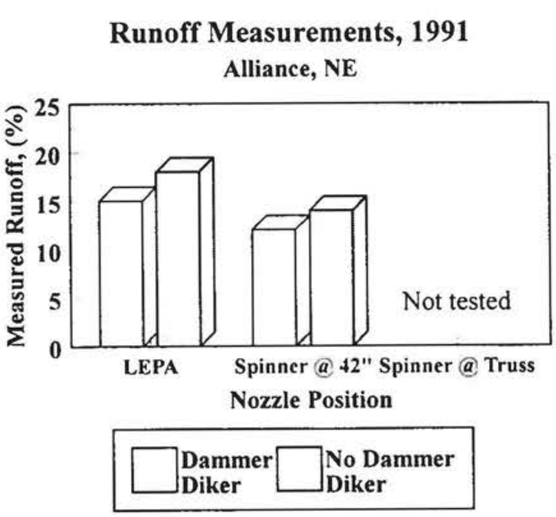

Figure 2. Percent runoff for LEPA system and Spinners at 42 inch height for a 1.0 inch application.

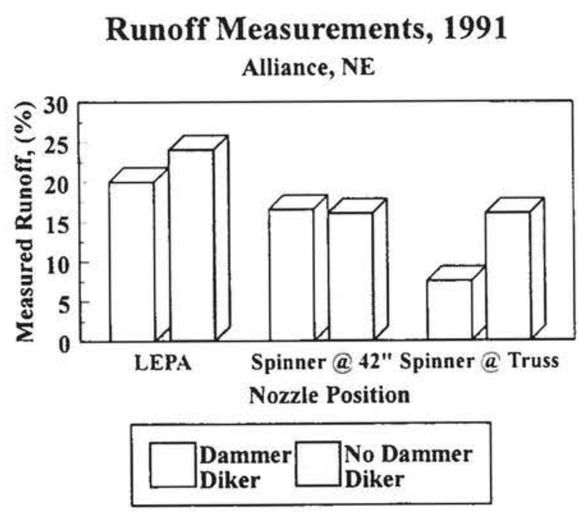

Figure 3. Percent runoff for LEPA system, Spinners at 42 inch height, and Spinners at truss rod height for a 0.7 inch application.

THE EFFECTS OF CONVERSION ON THE PUMPING PLANT[1]

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Every farmer needs to make a profit in order to continue farming. Traditionally, farming has not made a large return on investment, so when production costs rise in comparison to crop price and/or yield, profits can quickly turn into deficits. Irrigators are also subject to this economic reality, so they also need to evaluate the cost-effectiveness of production inputs. One component is irrigation fuel. The irrigator should know whether irrigation costs are reasonable and whether irrigation is paying its way.

The irrigation fuel or energy bill is composed of two parts. The first is related to pumping plant performance and the second to crop and irrigation management.

Total fuel bill = Pumping Cost/Volume X Volume Applied

Reducing the total volume applied reduces the fuel bill proportionately, so if the amount of water applied is minimized with good irritation scheduling and high application efficiency, the fuel bill will also be reduced by a similar amount. Good irrigation management practices and high system efficiency would minimize the total volume applied. These topics are the subject of other presentations.

The major factors that influence the pumping cost per volume are: pumping plant efficiency and TDH or total dynamic head, which is the total hydraulic resistance against which the pump must operate. Well efficiency is also a factor, but it is largely determined by design and construction factors that were used during the drilling and development processes. Many wells would produce a greater flow with less drawdown if the screen, gravel pack and development procedure had been better designed, but little can be done to improve the efficiency of a poorly constructed well.

Performance evaluations indicate that many irrigation pumping plants use more fuel than necessary if a properly sized, adjusted and maintained pumping plant were used. In Kansas, the average pumping plant uses about 40 percent more fuel than necessary. Obviously, some are much worse and others much better. Causes of excessive fuel use include:

1. Poor pump selection. Pumps are designed for a particular discharge, head and speed. If used outside a fairly narrow range in head, discharge and speed, the efficiency is apt to suffer. Some pumps were poor choices for the original condition, but changing conditions such as lower water levels or changes in pressure also cause pumps to operate inefficiently.
2. Pumps out of adjustment. Pumps need adjustment from time to time to compensate for wear.

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[1]Originally published and presented at the 1994 Central Plains Irrigation Short Course.

3. Worn-out pumps. Pumps also wear out with time and must be replaced.
4. Improperly sized engines or motors. Power plants must be matched to the pump for efficient operation. Engine or motor loads and speed are both important to obtain high efficiency.
5. Engines in need of maintenance and/or repair.
6. Improperly matched gear heads. Gear head pump drives must fit the load and speed requirements of the pump and engine.

Pumping plant performance evaluations can be obtained by hiring a consulting firm or contractor to take the measurements, but many farmers are reluctant to spend money to find out if something is wrong. Energy costs, however, can represent a significant portion of the production cost for a crop. The following will help an irrigator analyze irrigation fuel or energy bills to see if they are within reason considering the pumping conditions and price of fuel or energy.

Irrigation pumping energy requirements can be estimated using the Nebraska Performance Criteria shown in Table 1. The Nebraska criteria is a guideline for a performance of a properly designed and maintained pumping plant. Some pumping plants will exceed this criteria, but most will not.

If this estimate indicates low pumping plant efficiency, then hiring a firm to repair or replace the pumping plant may be justified. The irrigator needs to know 1) acres irrigated, 2) discharge rate, 3) total dynamic head, 4) total application depth, 5) total fuel bill, and 6) fuel price/unit in order to make such an estimate.

Step 1: Determine Water Horsepower

Water horsepower (WHP) is the amount of work done on the water and is calculated by
WHP = TDH (GPM)/3960
where:
GMP = discharge rate in gallons per minute
TDH = total dynamic head (in feet)
TDH is usually estimated by adding total pumping lift and pressure at the pump.
Since pressure is usually measured in PSI, convert PSI to feet by multiplying PSI x 2.31 (see conversions in Table 2).

Step 2: Calculate hours of pumping

Hr = D (Ac)/(GPM/450)
where:
Hr = Hours of pumping
D = Depth of applied irrigation water (inches)
Ac = Acres irrigated
GPM discharge rate in gallons/minutes
450 = Constant (see conversion in Table 2)

Step 3: Estimate hourly NPD fuel use

FU = WHP/NPC

where:

FU = Hourly fuel use using the Nebraska criteria

WHP = Water Horsepower from Step 1

NPC = Nebraska Performance Criteria (Table 1)

Step 4: Estimate seasonal NPC field cost

SFC = FU x H_R x Cost

where:

SFC = Seasonal Fuel Cost if the pumping plant was operating at NPC

H_R = Hours of operation from Step 2

Cost = $/Fuel Unit

Step 5: Determine excess fuel cost

EFC = AFC - SFC

where:

EFC = Excess Fuel Cost (in dollars)

AFC = Actual Fuel Cost (in dollars)

SFC = Estimated Seasonal Fuel Cost using NPC (in dollars)

Step 6: Calculate annualized repair cost

ARP = INVEST X CRF

where:

ARP = Annualized Repair Cost

INVEST = Investment required to repair or upgrade pumping plant

CRF = Capital Recovery Factor (Table 3)

The excess fuel cost may be thought of as the annual payment to cover the cost of a pumping plant upgrade or repair. Repair costs can be annualized by using capital recovery factors (CRF). If the annualized repair cost for the interest rate and return period selected is less than the excess fuel cost, the investment in repair is merited.

This procedure is an indicator of your total pumping plant performance. It does not indicate the source of the excessive fuel use, but pumping plant tests in Kansas have generally shown that poor performance is generally the fault of the pump. The low efficiency may be due to excessive pump clearance, worn impellers, or changes in pumping conditions since the pump was installed. However, engines and gear heads can also be problems.

Figure 1 provides an example farm problem and a place for you to fill in information from your farm. The example farm results in an annualized repair cost of $2,287. Since $2,287 is less than $3,385, the investment in repair of the pumping plant would be merited. The excess fuel use could be divided by the CRF (example $3,385/.3811 = $8,882) to indicate the amount you could afford to spend in upgrading the pumping plant.

The water power equation, shown in Step 1, establishes that the power needed to lift water is proportional to the amount and the total head requirement. Reducing either will reduce water horsepower requirements and therefore reduce fuel use. However, each pumping plant has given head-discharge point at which it will operate most efficiently. Once installed, changes in head on discharge requirements could result in a loss of pumping efficiency.

PUMP PERFORMANCE CURVE

A typical performance curve for a pump is shown in Figure 2. The curve can be confusing to read since it shows information on different impeller trim sizes. The total dynamic head is read from the left vertical axis. The pump capacity is read from the horizontal axis and pump efficiency is shown within the chart. Brake horsepower requirements are shown below the head-discharge curve. Brake horsepower is the actual amount of work performed on pumping the water at a given head and capacity plus the additional amount of work required due to pump inefficiency.

Head and Capacity Relationship

The most important part of the pump performance graph is the head-capacity curve which shows the relationship between the total dynamic head and the capacity for a given pump. A given pump can produce only a certain flow (capacity) for a given head, and vice versa. The example pump performance curve in Figure 2 shows that this pump with a 9-3/16 inch impeller trim (marked as curve A) can produce a total dynamic head of 60 feet and pump 300 gpm. If a given field needed 400 gpm of capacity, this pump could then generate only 50 feet of total head.

Most pumping plants have head requirements in excess of the capability of a single bowl or stage of a pump. Pressure or head increases are accomplished by combining stages of a given pump in series. Additional stages of the pump are added together until the total dynamic head requirements of the pumping system are met. Total dynamic head includes head requirements due to pumping lift, elevation changes, friction losses, and system operating pressure. So, if 250 feet of total dynamic head is required with a desired pumping rate of 400 gpm, then five stages of this pump would be required. Adding stages increases pressure, it does not increase capacity. If capacity were to be changed significantly, the selection of a different pump would be required.

Pumps are generally selected so that the operating pint on the performance curve is to the right of the peak efficiency point. Any declines in groundwater and normal wear processes would then to push the pump towards higher efficiency, resulting in better performance over a larger period of time than if the original selection was to the left of maximum efficiency.

Efficiency

The pump performance curve also gives information on pump efficiency. The efficiency curves intersect with the head-capacity curve and are labeled with percentages.

Each pump will have its own maximum efficiency point. Figure 2 shows this pump's maximum efficiency is 81 percent for operating conditions of approximately 380 gpm with an impeller trim A. When operating at 300 gpm and 60 feet of head, efficiency is approximately 78 percent. When operating at 50 feet of total head and 400 gpm efficiency is approximately 80.5 percent.

The pump performance curve also features an efficiency adjustment chart to account for changes in efficiency that occur as the number of stages change. Pump efficiency improves with additional stages since the friction losses that occur are shared. If only a single stage pump is used then the efficiency chart indicates the pump efficiency read from the chart should be reduced by 4 percent. When three stages are used, the readings can be taken directly from the chart. When six stages are used, chart readings can be increased by 1 percent. Some manufacturers record efficiency on the chart for single stage pumps and give increases with stages. Others do as shown in this example.

Brake Horsepower

The pump performance curve will give information on the brake horsepower required to operate a pump at a given point on the performance curve. The brake horsepower curves run across the bottom of the pump performance curve. Like the head-capacity curve, there is a brake horsepower curve for each different impeller trim. Continuing with the previous example, a pump with an impeller trim A operating at 50 feet of head and 400 gpm would require approximately 6.2 horsepower. The addition of stages increase horsepower by an equal amount.

Impeller Trims

Pump performance curves generally show performance for various impeller diameters or trims. Manufacturers will put several different trim curves on a pump performance curve to make pump specification easier, although this sometimes makes the pump performance curve more difficult to read.

Operating Speed

Occasionally manufacturers will provide pump performance curves that will show the effect of changing operating speed or rpm. Figure 3 shows the same 12-inch pump model with trim A operating at 1770, 1470, and 1170 rpm. The curved lines marked A in Figure 2 and 3 are identical. The general effect of reducing speed is a reduction of capacity and head. Pump efficiency can be unaffected with head and capacity changes if the new pumping conditions are proportional to the speed changes. However, most often a specific head or discharge is required which forces the pump to operate at some other point in the curve. This means efficiency will be changed.

The manufacturer cannot be expected to provide a performance curve for every conceivable operating speed and trim. The effect of speed and trim changes can be determined through the use of mathematical relationships, sometimes known as affinity laws. However since the trim of the pump cannot be easily altered after installation, only the affinity laws for speed will be discussed.

The affinity law associated with the rotational speed or rpm of a pump is that discharge is proportional to the ratio of rotational speed; head is proportional to the square of the rotational speed ratio and brake horsepower is proportional to the cube of the rotational speed ratio. These relationships can be stated mathematically as follows:

1) $\text{\textit{Final Discharge}} = \dfrac{\text{\textit{Final RPM}}}{\text{\textit{Initial RPM}}} \times \text{\textit{Initial Discharge}}$

2) $\text{\textit{Final Head}} = \left(\dfrac{\text{\textit{Final RPM}}}{\text{\textit{Initial RPM}}}\right)^{2} \times \text{\textit{Initial Head}}$

3) $\text{\textit{Final BHP}} = \left(\dfrac{\text{\textit{Final RPM}}}{\text{\textit{Initial RPM}}}\right)^{3} \times \text{\textit{Initial Head}}$

These relationships could be used to develop Figure 3 using information from Figure 2. For example, at a rated speed (1770 rpm) and impeller curve A, the pump curve shows 50 feet of head can be developed at a discharge of 400 gpm with a pump efficiency of 80.5 percent. Brake horse power requirements are 6.2 hp. If pump speed is slowed to 1470 rpm, what is the effect on pumping characteristics?

Solution:

Use equations 1, 2 and 3.

1) $\text{\textit{Final Discharge}} = \dfrac{1470}{1770} \times 400 = 291\ \text{\textit{gpm}}$

2. $\text{\textit{Final Head}} = \left(\dfrac{1470}{1770}\right)^{2} \times 50 = 34.5\ \text{\textit{feet}}$

3. $\text{\textit{Final BHP}} = \left(\dfrac{1470}{1770}\right)^{3} \times 6.2 = 3.4\ \text{\textit{hp}}$

The above results can be compared to values read from Figure 3 to see that the relationships are valid.

Engine Performance Curve

Engine performance curves can also be obtained. Anybody with a new pumping plant installation should request a copy of the performance curves for the pump and engine and be certain the gear head ratio is clearly marked on the unit and recorded with the performance curves. The irrigator is then in a much better position to evaluate the effects of system changes or water declines on pumping plant efficiency.

A typical engine performance curve or map is shown in Figure 4. The horizontal axis shows percent of rated engine speed. The left vertical axis is the percent of rated torque. The intersection of 100 percent rated torque and speed is the maximum rated power for the engine. In this example, 100, 75, 50 and 25 percent of rated power is plotted. On Figure 6, points A and B are plotted along the 50 percent rated power curve. This illustrates that the same power output can be achieved using various combinations of speed and torque. Imposed on the power curves are lines that are lines of equal fuel consumption. For a given engine, the lines would be labeled with values using units such as pounds of fuel per horsepower-hour, or gallons per horsepower - hour, kilograms per kilo watt-hour, or so forth. In this example, these values were replaced by percent of minimum fuel use. The point labeled, 100 percent, is the area of best fuel economy.

Effects of Rotational Speed Changes on Engine Performance

Examination of points A and B from Figure 4 illustrate that the engine at point A is operating at much better fuel economy than at point B. If this situation were a tractor, operator response would be to gear up and throttle down. With a fixed gear head, this would require changing of the gear head at considerable expense.

With pump and engine performance curves, the effect of changing pump speed to accommodate new pumping conditions with the same equipment may be estimated without extensive field testing or discovery of excessive fuel use during or after the irrigation season. Changing speed to accommodate changes in pumping conditions can result in pumping water at very low efficiency. Worst case situations result in decreased water availability and increased pumping costs, although occasionally some changes can improve pumping efficiency. However, since irrigation fuel costs can represent a significant production expense, any changes in operating conditions should be analyzed in order to make certain profitability is not sacrificed.

A series of pump tests were conducted in 1982 by the Northwest Kansas Groundwater Management District #4, Colby, Kansas. In Table 1, the results of two tests conducted on the same pumping plant at different pumping heads. The original pumping conditions were for low head conditions, which are reflected by the higher pump efficiency and overall performance rating. However, the pump efficiency was only 63 percent and the performance rating was 76 percent indicating either wear, misadjustment, or changed pumping conditions. Adding a sprinkler system and raising well head pressure from 2 psi to 68 psi drops pump efficiency to 51 percent and also lowers engine efficiency, making the overall performance rating only 53 percent. About twice as much fuel was being used as necessary for this pumping condition. Never-the-less the pump supplied adequate pressure and discharge so the pumping plant was not upgraded.

Figures 5 and 6 are actual pump performance curves of two pumps. They will help illustrate why sometimes it is necessary to upgrade the pumping plant with pressure and discharge changes. Assume original pumping conditions were 1100 gpm and 155 feet of TDH. Pump 1 (Figure 5) can provide 1100 gpm and 31 feet of head per stage. Therefore, 5 stages would provide the desired head at a pump efficiency of 78.5 percent. Pump 2 on trim 8.19 inches, provides 1100 gpm at 55 feet of head per stage, making a close fit with three stages and a pump efficiency of 82 percent.

If the producers wanted to switch from an 1100 gmp flood system to a 750 gpm pivot system with 35 psi pressure, would these pumps be able to perform adequately?

Thirty-five psi is about 81 feet of head. Pumping lift would be reduced some because of the reduced discharge, so lets say 70 feet of additional head is needed, making TDH = 155 + 70 = 225 Feet.

Pump 1 then needs to provide 225/5 = 45 feet of head per stage. Reading from the pump curve, this pump can provide only 275 gpm. In this case, a new pump would likely be the best course of action. Pump 2, at 750 gpm, can provide 68 feet of head per stage, so three stages can provide 204 feet of TDH. In this case, a slight increase in RPM will mean this pump can provide the new pumping conditions and at a pump efficiency of about 77 percent.

The formulas provided in the first part of this paper allow an individual to calculate the effect of changing head on fuel cost. Therefore, quick reference figure 7 shows pumping cost per ac-in for various fuel prices. Figure 8 shows hourly cost of operation for various water horsepower requirements.

SUMMARY

Reducing pressure can be a way of reducing pumping cost. However, pressure reduction on an existing pumping may also decrease efficiency and negate any fuel cost saving potential. Always consider and investigate the effect of changing head or pumping rate on pumping plant efficiency before making any permanent changes.

Acknowledgment: Some material is from the 1982 Irrigation Pumping Plant Performance Handbook, University Nebraska.

Table 1. Nebraska Performance Criteria for Pumping Plants

Energy Source	WHP-HRS per Unit of Fuel
Diesel	12.50 per gallon
Propane	6.89 per gallon
Natural Gas	61.7 per MCF
Electricity	0.885 per KWH (kilowatt-hour)

Table 2. Useful Irrigation Conversions

1 psi (pounds per square inch)
= 2.31 feet of head

1 acre-inch/hour
= 450 gallons/minute

Table 3. Selected Capital Recovery Factors (CRF)

Length of Load or Length of Useful Life Years	Annual Interest Rate (%) 5	7	10	12	15
2	.5378	.5531	.5712	.5917	.6151
3	.3672	.3811	.4021	.4163	.4380
4	.2820	.2820	.3155	.3292	.3503
5	.2310	.2310	.2638	.2774	.2983
7	.1728	.1728	.2054	.2191	.2404
10	.1295	.1295	.1627	.1770	.1993
15	.0963	.0963	.1315	.14	.1710

Table 4. Selected Pump Test Results from 1982
Pump Test Program (Northwest Kansas GMD #4).

Well Head Pressure PST	WHP	Measured HP °	Pump EFF %	Engine EFF %	Overall EFF %	Performance Rating % NPC*	Excess Fuel Use MCF/HR
2	35.2	55.8	63.1	21.8	13.8	75.8	0.164
68	38.0	75.0	50.7	19.1	9.7	53.3	0.487

Figure 1. Example Farm Problem and Form for your Farm

Acreage:	150 acres
Pumping Lift:	300 feet
System Pressure:	22 psi
System Discharge Rate:	1200 gpm
Total Irrigation Application:	24 inches/ acre
Fuel Type: Natural Gas Price:	$3.50/ MCF
NPC for Natural Gas:	61.7
Total Fuel Bill:	$11,500
Pump Repair Estimate:	$6,000
Desired CRF using 3 years and 7% interest From Table 3:	0.3811

Step 1: Determine Water Horsepower

WHP = (TDH x GPM)/3960
= ((300 + (22 x 2.31)) x 1200)/3960
= 106 WHP

Step 2: Calculate Hours of Pumping

HR = (Depth x Acreage)/(GPM/450)
= (24 x 150)/(1200/450)
= 1348 hrs.

Step 3: Estimate Hourly NPC Fuel Use

FU = WHP/NPC
= 106/61.7
= 1.72 MCF/Hr.

Step 4: Estimate Seasonal NPC Fuel Cost

SFC = FU x HR x Cost
= 1.72 x 1348 x 3.50
= $8,115

Step 5: Determine Excess Fuel Cost

EFC = AFC – SFC
= 11,500 – 8,115
= $3,385

Step 6: Calculate Annualized Repair Cost

ARC = REPAIR ESTIMATE x CRF
= 6,000 x 0.3811
= $2,287

Acreage:	________ acres
Pumping Lift:	________ feet
System Pressure:	________ psi
System Discharge Rate:	________ gpm
Total Irrigation Application:	______ inches/ acre
Fuel Type and Price:	__________ $/ unit
NPC for Natural Gas:	__________
Total Fuel Bill:	$__________
Pump Repair Estimate:	$________
Desired CRF using ___ years and ____% interest From Table 3:	________

Step 1: Determine Water Horsepower

WHP = (TDH x GPM)/3960
= ((____ ft + (____psi x 2.31))
x _____ gpm)/3960
= ________________ WHP

Step 2: Calculate Hours of Pumping

HR = (Depth x Acreage)/(GPM/450)
= (_____ inches x _____ acres)
/ (______ gpm/450)
= ________ hrs.

Step 3: Estimate Hourly NPC Fuel Use

FU = WHP/NPC
= _______/_______
= _______/Hr.

Step 4: Estimate Seasonal NPC Fuel Cost

SFC = FU x HR x Cost
= _______ x ______ x ______
= $__________

Step 5: Determine Excess Fuel Cost

EFC = AFC – SFC
= _________ – _________
= $__________

Step 6: Calculate Annualized Repair Cost

ARC = REPAIR ESTIMATE x CRF
= _________ x _________
= $______________

Figure 2: Example Performance Curve for a pump with various trims.

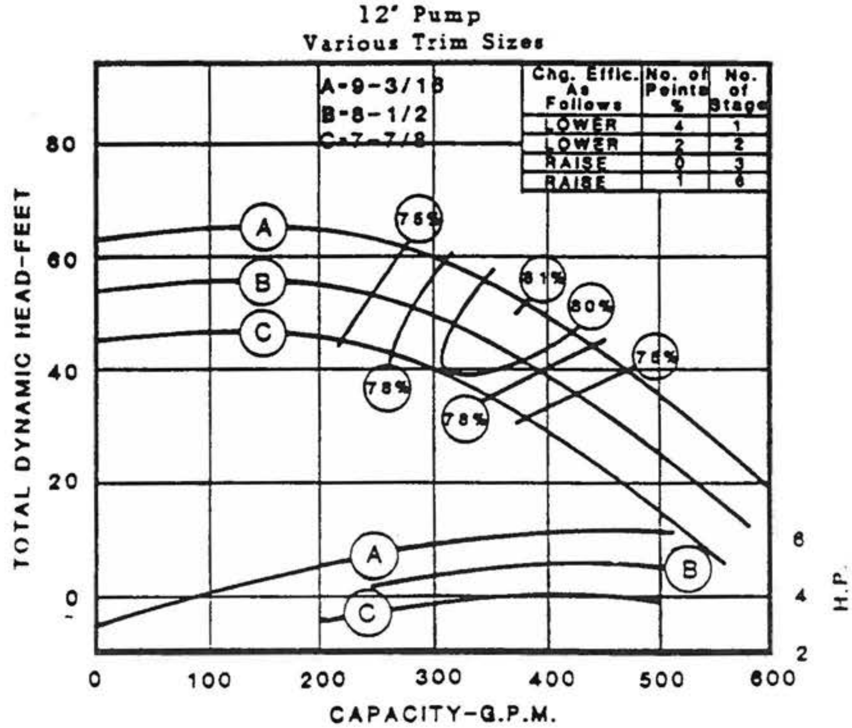


Figure 3: Example Performance Curve for a pump with various speeds.

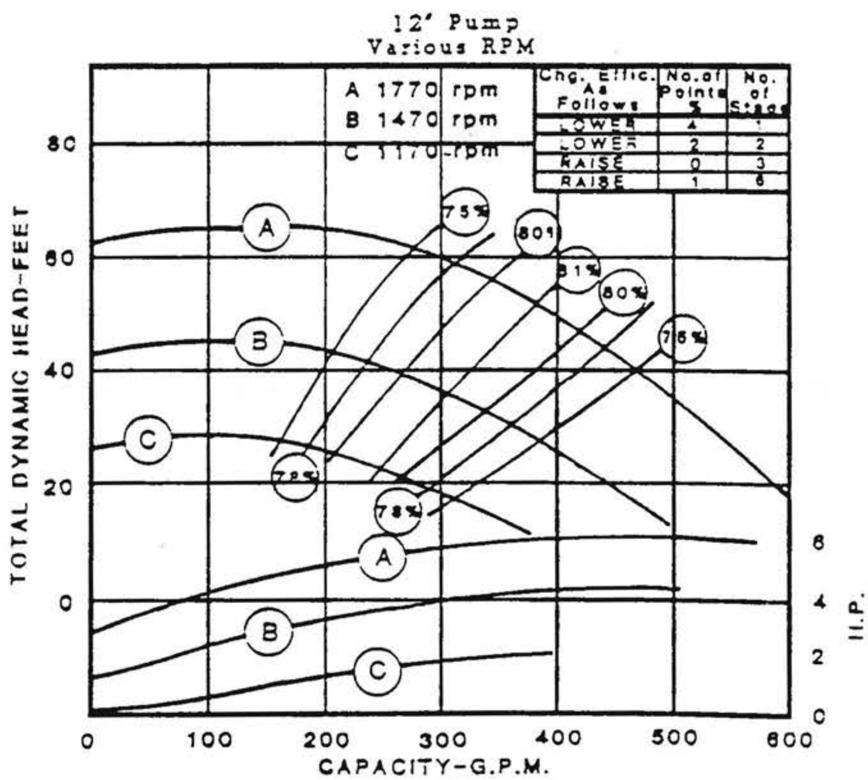


Figure 4: Example of an Engine Performance Curve.

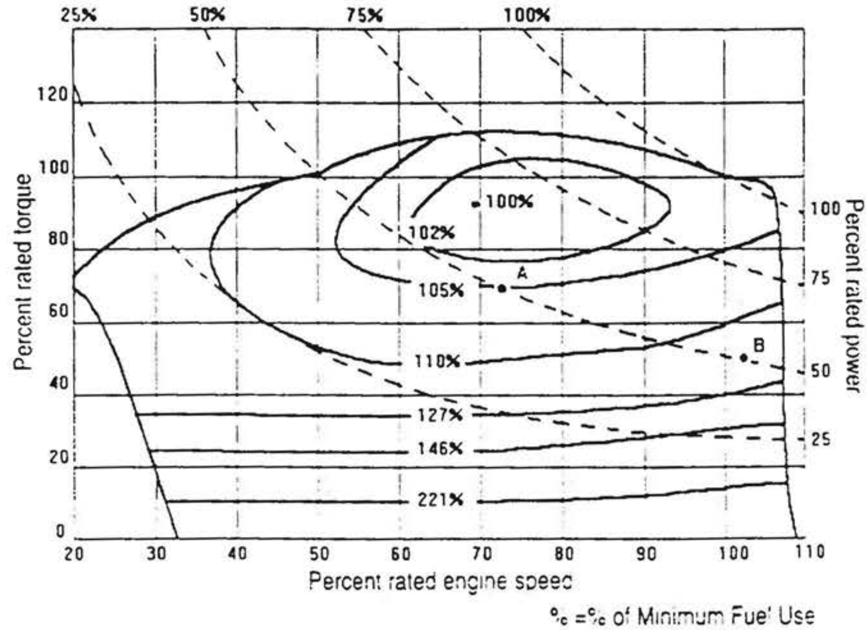


Figure 5: Example Pump Performance Curve

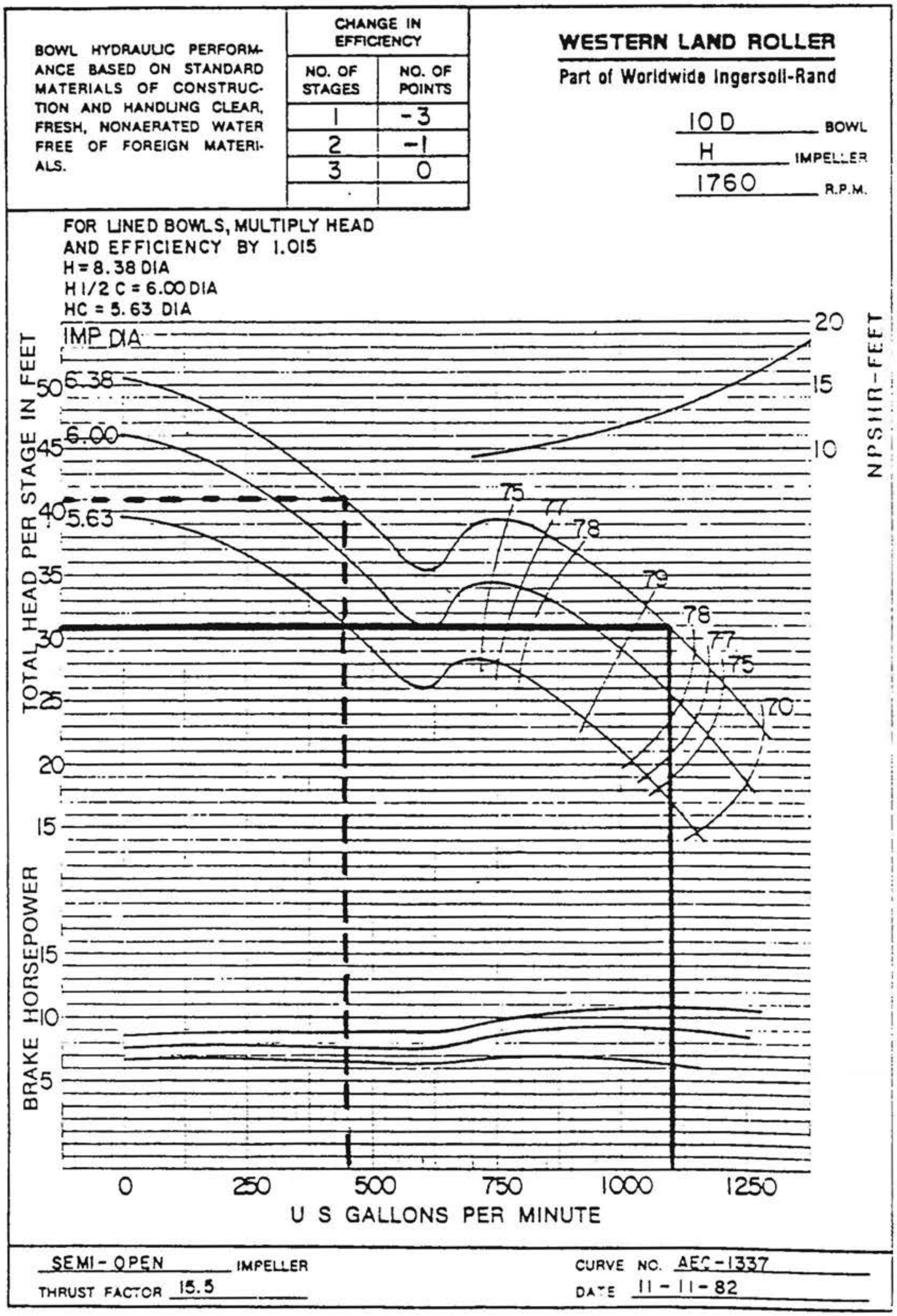
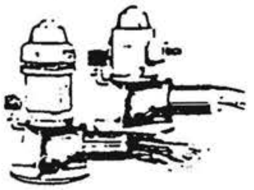


Figure 6: Example Pump Performance Curve



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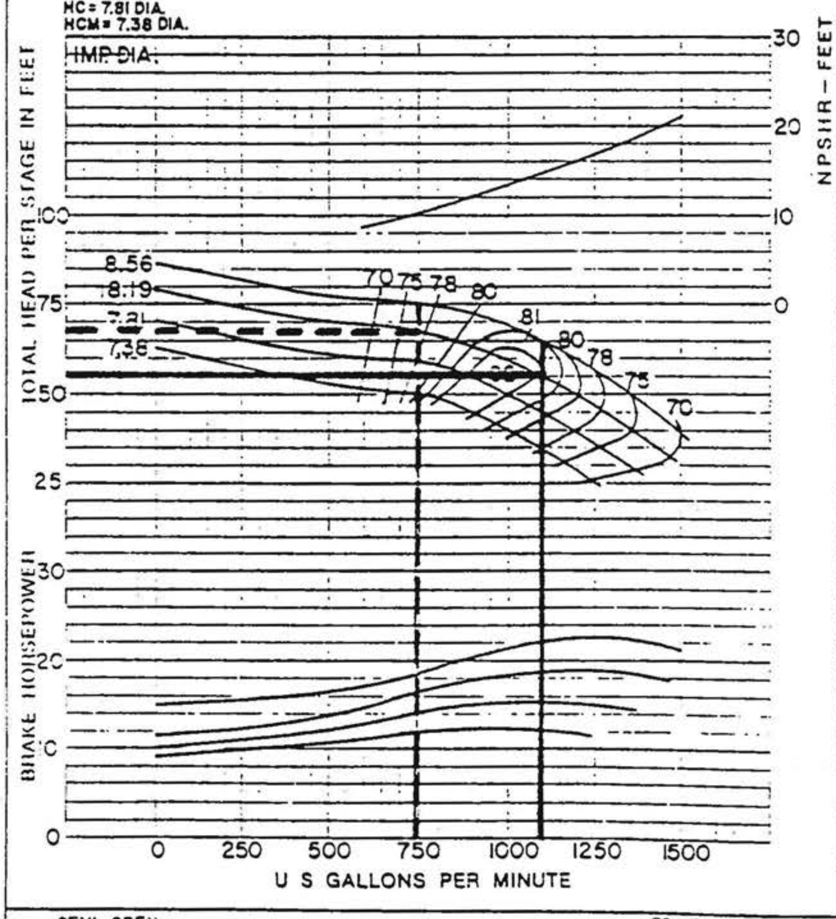

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Figure 7: Pumping Cost For Various Fuel Prices and Head Requirements.

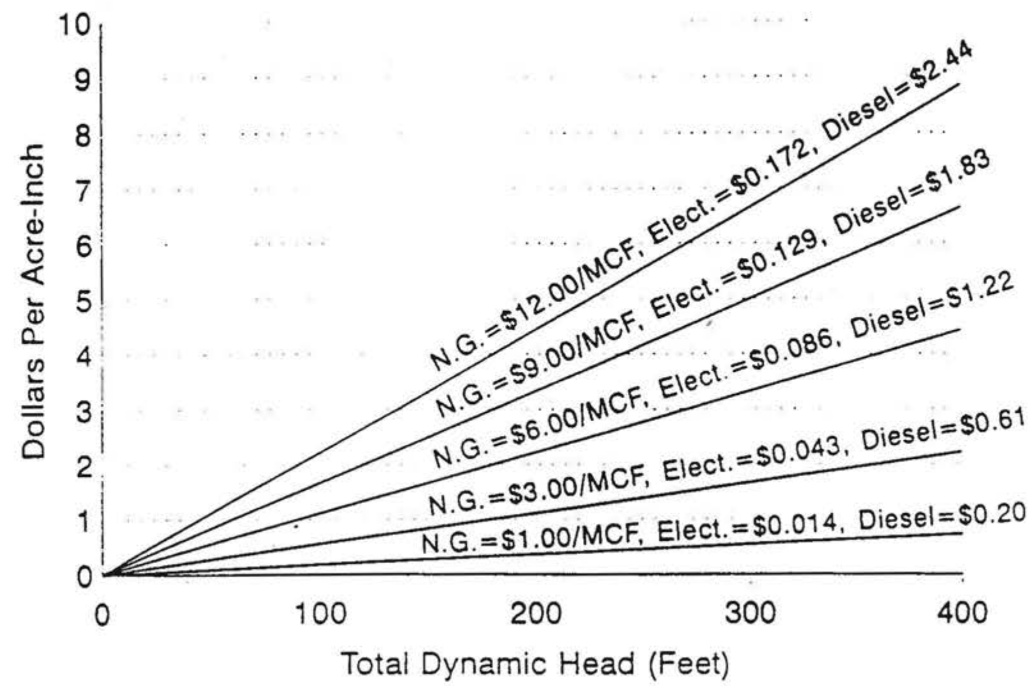
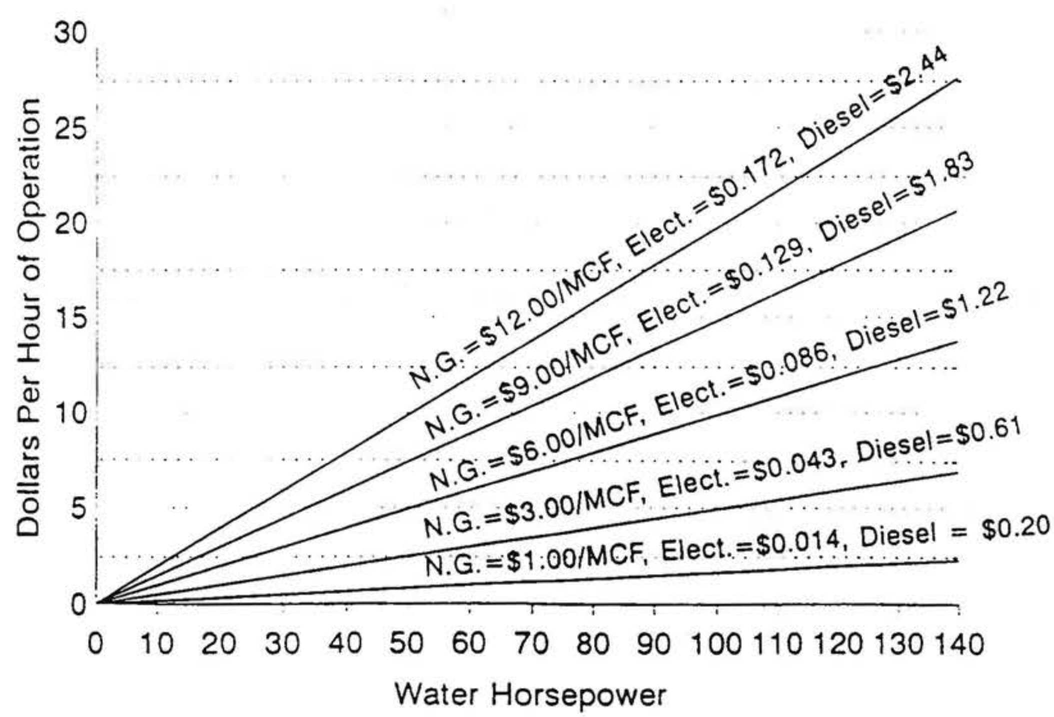


Figure 8: Hourly Irrigation Pumping Cost for Various Fuel Prices and Water Horsepower Requirements.



ECONOMICS OF CONVERSION FROM FLOOD TO PIVOT

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A number of factors generate producer interest in changing or modifying their irrigation systems. In addition to continual pressure to reduce costs, producers are increasingly facing concerns to reduce water use and the associated leaching of nitrogen. Also, a desire to increase operator output and convenience are often major considerations when looking at alternatives. The availability of funds to invest in system changes and the failure of system components can also prompt a look at the alternatives.

The purpose of the discussion here is to focus upon the budgeting of continued operation of a flood irrigation system versus switching to a pivot. The effect upon labor demands will be considered although evaluating the impact of switching to pivots upon potential size of farm and family income is beyond the scope of this paper.

Current System Costs

Continuing to operate the current system will involve operating costs (fuel, lube, repairs, and labor) with replacements made as and when needed with consequent additional ownership costs (depreciation and interest on the investment). There may also be some financing arrangements for the current system that involve current debt payments. The interest portion of these payments should be determined in case the interest rate on the new system is different. Any taxes or insurance premiums associated with the current system should also be determined.

The example budgeted costs of owning and operating a flood system with a well as its source of water are presented in Tables 1 and 2. For an established system, the budgeted annual ownership costs represent the annual revenue that is needed to replace components as needed assuming the budgeted costs are updated each year to reflect current prices. However, for any given year it would be profitable to continue to operate the system as long as the operating costs are covered. It would be most profitable to abandon the system if over time it would not be expected to generate enough revenue to cover the operating costs plus the annual return that could be expected from investing the funds realized from the sale of the equipment (or the returns from using the equipment elsewhere) net of any costs to deactivate the system (cap the well, for example). The net realized annually including operating costs saved from abandoning the system will be called its salvage cost. Alternatively, it would be most profitable to replace the system if the annual cost of the replacement system is below the salvage cost of the existing system.

To illustrate an extreme example, consider a situation where if the existing system were abandoned or replaced, the well would be capped and the value of the components salvaged equals the cost of shutting down the well. The salvage cost of the existing system would then be the cost of operating the system (repairs, duel, and labor). The alternative system would then have to have an annual ownership and operating cost that is less than the operating cost of the existing system to be least-cost. It is entirely possible that the existing system remains least-cost until some of it components fail and need to be replaced to continue operation. If the system is maintained and components replaced as in Table 1, the estimated average annual ownership costs are $44.88 as shown in Table 1. Although it may be least-cost to delay switching systems until replacement of a major component is required, it would be least-cost to eventually replace the existing system if the ownership and operating costs of the alternative system are less than the ownership and operating costs of the existing system. Replacing a flood system with a pivot, however, has the added complication that the pivot typically leaves some acreage unirrigated. We will first consider some possible field configurations and their effect on pivot investment and then return to considering switching from a flood to a pivot system.

Table 1. Example flood system investment and annual ownership costs.

	New Cost	Years Useful Life	Annual Cost/Acre[1]
Well			$26.81
Well (250')	$12,543	25	
Column Pipe (200')	8,160	18	
Fuel tank, filter, fuel line	2,160	20	
Leveling/shaping	20,000	50	
Pump base	1,663	25	
Pump			4.32
Bowls	2,898	18	
Gearhead and spicer shaft	2,085	15	
Power unit (diesel)	7,130	12	7.87
Delivery System			5.87
Pipe (2,970 ft.) and fittings	5,643	15	
Pipe trailer	800	20	
TOTAL	$63,082		$44.88

[1] Annual depreciation plus *real* interest (net of inflation) at a 5% annual rate, 100 acres.

Table 2. Example flood system operating costs.

Repairs per acre foot		$ 4.31
Fuel and oil per acre foot		12.86
		$17.17
	Acre feet	2
Fuel and repairs, 2 acre feet		$34.34
5 irrigations @ 0.3 hours labor @ $7/hour		10.50
Annual Operating Costs per Acre		$44.84

Center Pivot System Designs and Costs

Center pivot system capital requirements for alternative field scenarios are given in Table 3. The center pivot system costs were estimated using private industry cost figures and input from agricultural engineers. These were reported in the proceedings of the 1997 short course. The field radius represents the length of underground pipe needed. Worksheets presented in the KSU Extension publication, *Irrigation Capital Requirements and Energy Costs,* MF-836, are used as an investment analysis framework. Further explanation is given in footnotes to Table 3.

The Total Cost Per Acre column in Table 3 illustrates the higher capital cost per acre as center pivots are placed on successively smaller fields. For base Scenario A, total irrigation system investment cost is $326 per acre. Total investment increases from $326 per acre for a full 125 acre pivot circle to $978 per acre in scenario E (25 irrigated acres). The wiper system (Scenario F) cost is $532 per acre for 64 irrigated acres, or $34,527 approximately equal to the $34,050 for the centrally located pivot in Scenario C.

Table 3. Center Pivot System Capital Requirements for Alternative Field Sizes.

Center Pivot Field				Center Pivot System Cost[1] per Irrigated Acre				
Field Scenario	No. Pivot Acres	Dryland Corner Acres	Total Acres	Pivot System Cost	Field Radius	Pipe, Wiring, Electric[2]	Total Cost	Total Cost/ Acre[3]
Full Circle[4]								
A	125 ac	35 ac	160 ac	$31,500	1320 ft	$9,282	$40,782	$326/ac
B	100 ac	27 ac	127 ac	$29,400	1177 ft	$8,548	$37,948	$379/ac
C	75 ac	20 ac	95 ac	$26,775	1020 ft	$7,752	$34,527	$460/ac
D	50 ac	14 ac	64 ac	$23,100	832 ft	$6,809	$29,909	$598/ac
E	25 ac	7 ac	32 ac	$18,900	589 ft	$5,559	$24,459	$978/ac
F "Wiper"[5]	64 ac	16 ac	80 ac	$31,500	1320 ft	$2,550	$34,050	$532/ac

1 Cost in this table refers to initial investment cost.
2 8" underground pipe @ $3/ft, connectors @ $350, electric wiring @ $2.10/ft, 12 kVA generator @ $2,200.
3 No interest cost included. Calculated on a per irrigated acre basis.
4 Pivot makes a full circle in a square field in Scenarios A-E.
5 Pivot is centered on one side of a rectangular field and makes a half circle.

Switching to a Pivot

How does the cost of irrigating at 125 foot lift with a diesel gravity system compare with using a diesel center pivot system?

This comparison requires some assumptions on the area to be irrigated and the efficiency of application for the two systems. In the comparison made here, we consider two gravity systems serving 80 acres each versus one center pivot serving 130 acres with 30 acres remaining dryland. Crop water use is 12 AI. The yield from irrigated acres is assumed the same for both systems.

These data suggest the gain from irrigating the additional 30 acres does not cover the additional costs ($2,820 gain vs. $3,713 added costs). This result will depend upon a number of factors including the number of acres each system serves.

Table 4. Flood vs Pivot System.

	Flood	Pivot	
Irrigated Acres	160	130	
Head	148 ft	206 ft.	
Application Efficiency	50%	95%	
Acre-Inches pumped/acre	24	12.6	
GPM	1,000	800	
Pumping hours	1,728	921	
Repairs/hour	$0.80	$1.16	
Fuel and lube/hour	$2.39	$2.84	
Operator labor, hours/acre	1.5	0.4	
Annual Irrigation Costs			
Interest	$3,226	$2,596	
Depreciation	5,514	5,575	
Repairs	1,382	1,068	
Fuel and lube	4,130	2,616	Gravity
Labor @ $7/hour	1,680	364	Added Costs
Total	$15,932	$12,219	$3,713
Pivot Corners	Gravity	Dryland	
Corn yield (bu)	145	65	
Price/bu	$2.25	$2.25	
Revenue/acre	$326	$146	
Operating cost/acre	166	80	
Net/acre	160	66	Gravity Gain
30 Acres	$4,800	$1,980	$2,820

ACCESS AND USE OF ET DATA ON THE INTERNET

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ABSTRACT. The High Plains Climate Center (HPCC) was established in 1987 and is one of six centers providing coverage of the continental U.S. HPCC is located at the University of Nebraska in Lincoln. HPCC's mission is to carry out applied climate studies to aid in the development of improved climate products for use in an array of climate services, including data collection, analysis, and dissemination in the HPCC region. This paper describes the Automated Weather Data Network (AWDN) and the interfaces that provide near real time climate services with emphasis on ET or crop water use. Automated weather stations are monitored daily at 139 locations in ten states. Data are subjected to quality assurance testing and made available to the public. AWDN data are merged with a stream of data that includes the cooperative network data and historical data dating to the 1800's. Queries by the public to the subscription based On-line interactive system have reached 6000-7000 per month while queries to the HPCC home page average 15-20K per month.

1.0 INTRODUCTION

Regional Climate Centers (RCCs) have been established in response to the need to improve climate services at the local, state, and regional levels (Changnon et al., 1990). One of the fundamental challenges for RCCs is to advance the provision of climate information for the nation's economic, governmental, and social sectors.

Several major requirements must be addressed in order to improve climate services. One requirement is an adequate data collection system in terms of number of variables measured, sampling frequency, and timeliness of data transferal and receipt. A second requirement is the need for sufficient quality control and analyses procedures. This requirement demands that accurate data be available for use in summaries and products and that the content of these be keyed to the needs of decision makers and resource managers in the targeted sector of the economy. In many cases, applied research is needed to develop models and other technological tools for the purpose of relating the current climate situation to the area of interest (agriculture, water resources, energy, transportation, recreation, etc.). Another requirement is adequate technology to deliver the summaries and products in a timely manner.

The use of electronic equipment to automate the collection of measurements from weather-related sensors at remote sites has brought about a change in the ability to collect weather data (Hubbard et al., 1983). This advance in the field of data collection has found its way into the National Weather Service program of modernization, as more than 1000 ASOS (Automated Surface Observing System) weather stations were installed over the past decade (ASOS, 1988). Automated state and private networks also were initiated and a survey determined that these networks are comprised of more than 600 weather stations.

Communication and computer technology have greatly increased the ability of climatologists to monitor and disseminate the important characteristics of climate. RCCs are institutions that engage in such applied research as is necessary to improve climate products including crop water use estimates.

2.0 DATA COLLECTION

Automated weather stations are maintained at 139 locations in the ten-state region (CO, IA, KS, MT, MN, MO, ND, NE, SD, and WY). These stations collect hourly data for variables known to be of importance to agricultural crop and livestock production, including air temperature and humidity, soil temperature, precipitation, wind speed and direction, and solar radiation. A computer calls each station beginning at 1 A.M. The data for the previous 24 hours is downloaded, quality controlled, and archived for use by the HPCC system. A flow diagram is shown in Fig. 1. Software and system components have been documented for this system (Hubbard et al., 1990).

Weather stations at remote sites monitor sensors every 10 secs and calculate the hourly averages and where appropriate totals. The minimum set of sensors is shown in Table 1.

The installation heights shown are standard for AWDN stations. Other recommendations for standards have been put forth by the World Meteorological Organization, the United Kingdom Meteorological Office and the National Weather Service. For these standards and those of other Automated Weather Networks in the U.S. see Meyer and Hubbard (1992).

Growth of the AWDN was fairly rapid (see Table 2). Much of the initial growth was due to the interest of researchers who were operating digital weather stations without the benefits of telecommunication or a data management system. In 1983, the AWDN began to grow into surrounding states. As time passed private sector interests offered to add stations. Resource management agencies also have taken an active role in addition and support of stations in the network. One unique class of weather station sponsor is the community consortium. In this case a number of interested parties from a community (eg. agri-chemical dealers, farm elevators, radio station, public power agency etc.) agree to share in the expense of purchasing and maintaining a station.

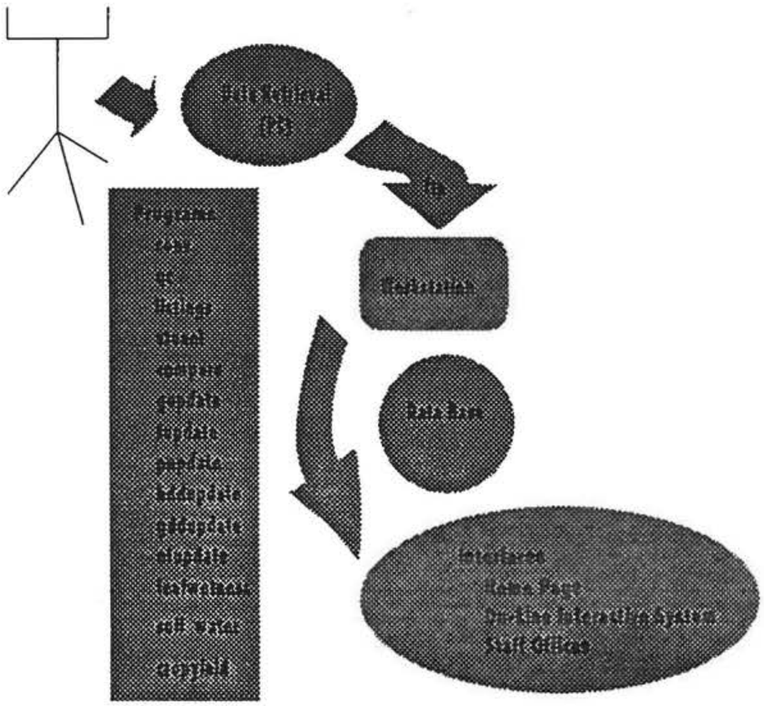


Fig. 1. The flow of data through the automated weather network

Currently the 139 stations in the Network are distributed in the region represented by the High Plains Climate Center as follows: Colorado 4, Iowa 10, Kansas 16, Missouri 2, Minnesota 5, Montana 2, Nebraska 47, North Dakota 42, South Dakota 10, and Wyoming 1. The station locations are plotted in Fig. 2. In general, each state is responsible for maintaining it's weather stations and the states with larger numbers of stations run a near-real time network to serve clientele within it's boundaries. The High Plains Climate Center calls these stations once each day in the early morning hours to download data.

An abbreviated maintenance checklist is given in Table 3. Replacement of sensor components includes bearings in the cup anemometer on a 2 year cycle. Relative humidity sensors are calibrated on an annual cycle. The potentiometer on the wind vane is replaced as needed. The tipping bucket is checked for level and

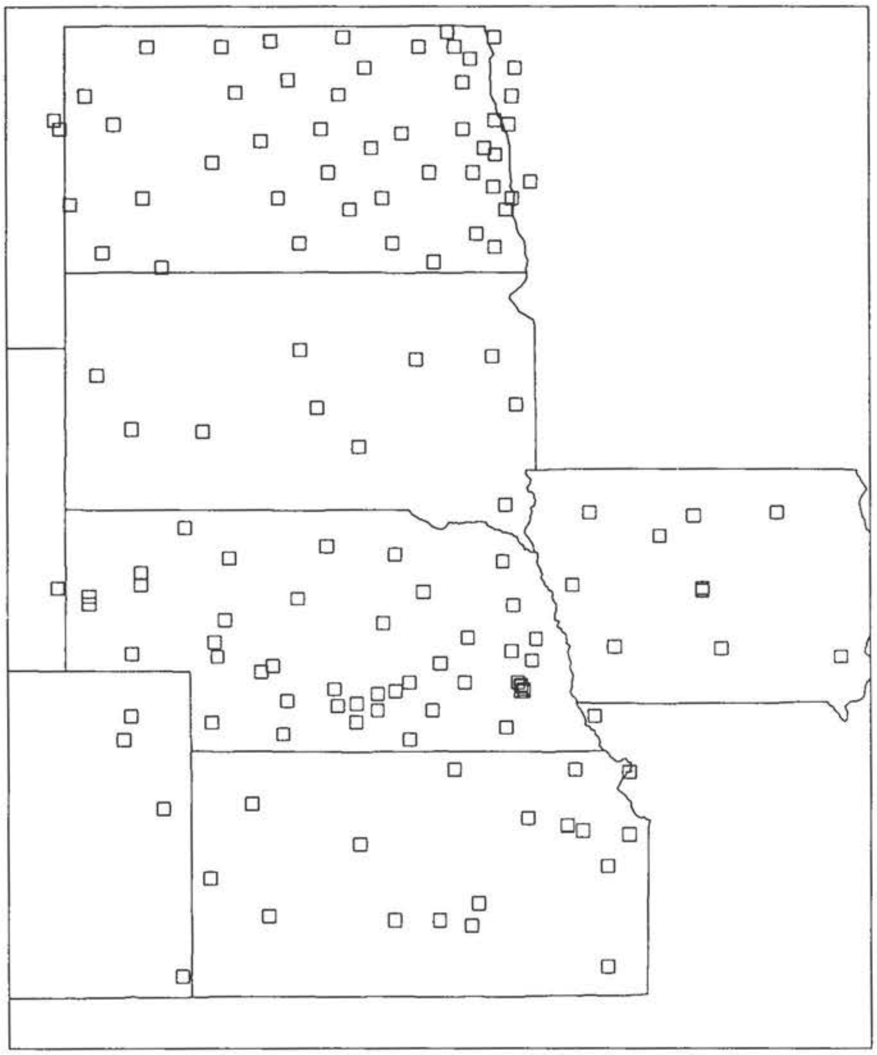


Fig. 2 Location of stations in the Automated Weather Data Network.

calibrated each year by using the volume to mass relationship for a known amount of water. Leveling screws are adjusted if needed in order to obtain the correct number of tips. The wind vane can be tested by simply using a sightable compass and magnetic correction to determine true north. The vane is calibrated so that for example a complete turn produces a range of values from 0° to 358° for a potentiometer with a 2° dead band. Certain sensors are removed from service for calibration. The silicon cell pyranometers are calibrated as a group against an Eppley Precision Spectral Pyranometer (Aceves-Navarro et al., 1989). In a similar manner anemometers can be calibrated against a "secondary standard." Thermistors and humidity sensors can be calibrated directly under controlled conditions. Devices like dry block calibrators and dew point generators are useful for this purpose.

Average annual costs associated with the network include: local telephone service ($480), telephone calls ($180), travel ($200), repair costs ($100), replacement costs ($100), and labor ($1,250). The total costs here is $2,310 per year but this cost does vary with the number of stations that are operating and other local rates.

3.0 DATA MANAGMENT AND APPLICATIONS PROGRAMS

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

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

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

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

4.0 RESEARCH NETWORK

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

Evaporation (ET) at the earth's surface is a major component of the hydrological cycle and is critical to irrigation scheduling from a water balance

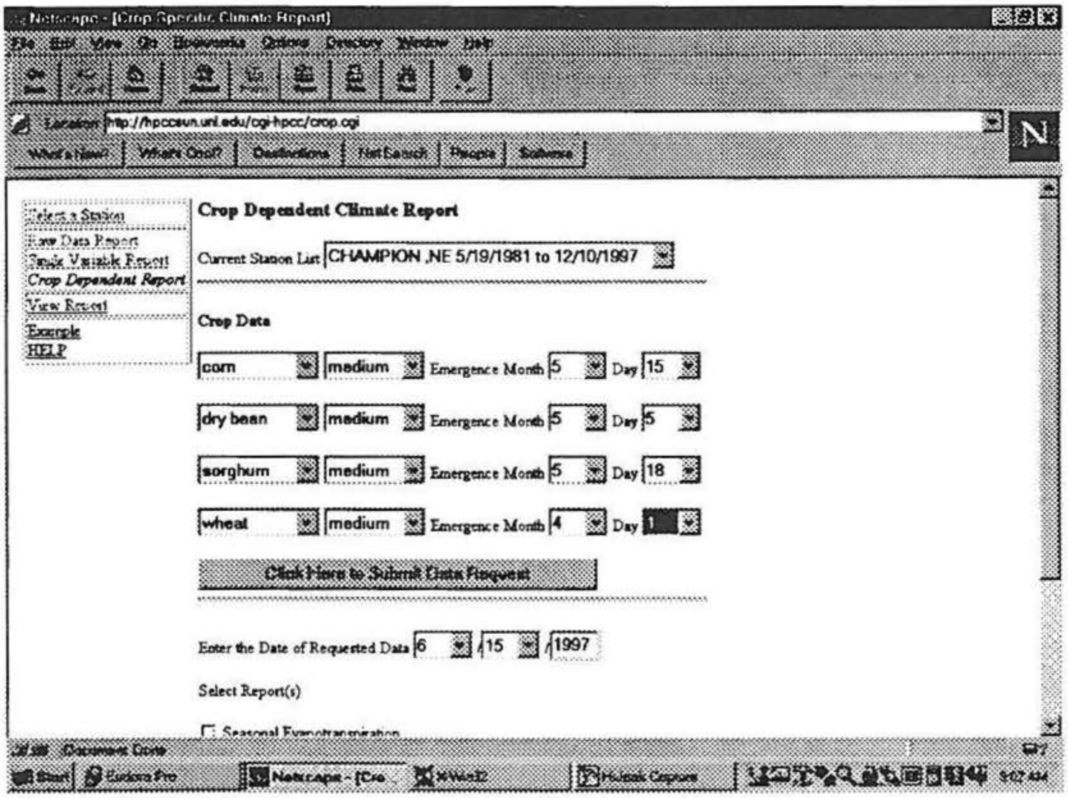
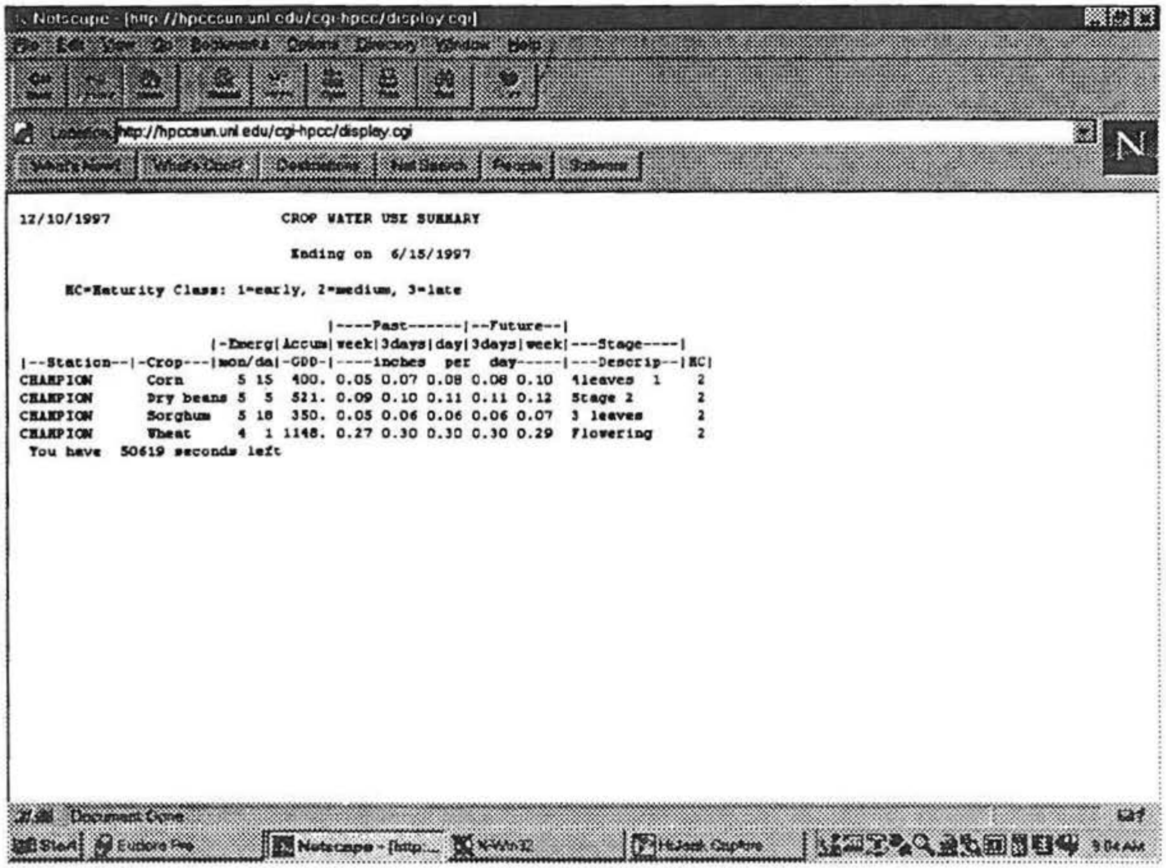


Fig. 3. Input specification screen for the ET product.

approach. Research in the area of evapotranspiration has included efforts to identify the effect of random and systematic errors in measurements used to calculate potential ET (Meyer et al., 1989) as well as efforts to improve the projections of potential ET (Meyer, et al. 1988). The AWDN has also been essential to determining appropriate limits for potential ET in the very arid parts of the High Plains region (Hubbard, 1992).

Monitoring of drought conditions is another research focal point. Robinson and Hubbard (1990) evaluated the potential use of network data in the assessment of soil water for various crops grown in the High Plains. A Crop Specific Drought Index (CSDI) for corn has been developed and tested (Meyer, et al. 1992a). Results from the studies indicate that the CSDI for corn will be valuable when applied to drought assessment (Meyer, et al., 1992b). A CSDI for sorghum (Paes de Camargo, 1992) is also under development.

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



12/10/1997 CROP WATER USE SUMMARY

Ending on 6/15/1997

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

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

You have 50619 seconds left

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

computing potential ET at a site or to interpolate the potential ET calculated at the surrounding stations (Ashraf, et al., 1992).

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

5.0 SERVICE NETWORK

Self-Service Access. The HPCC staff developed an On-Line Internet system for users which features interactive use of the entire historical archive of the HPCC. A revised system was released on May 1, 1996 and users of the former RBBS were invited to subscribe to the new system. Access to the new system jumped from approximately 2,000 to 6,000 per month in the initial six month period of operation. This is an sizeable increase as can be seen in Table 4 and Figure 5.

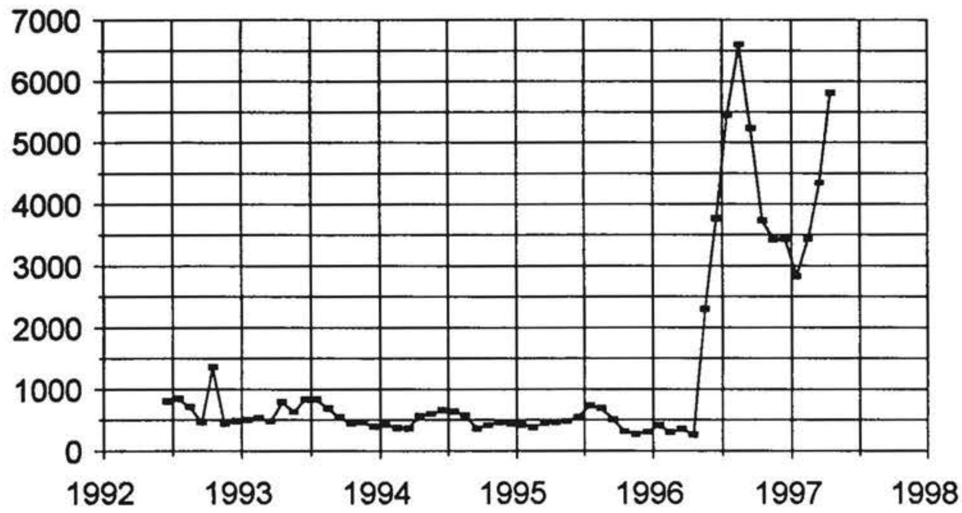


Fig. 5. The requests for climate data handled by the HPCC On-line System.

Digital data disseminated by the HPCC from the new system can be redistributed several times to larger audiences. A clear example is Data Translation Network (DTN). DTN, a private company, accesses HPCC's evapotranspiration, soil temperature, heating degree data and other reports which they broadcast to a network of subscribers. Paid subscribers to DTN are able to view this current information on their TV screen. They choose the pages they wish to view by simply indicating an index number on a push button pad supplied by DTN. There are more than 100,000 clients who subscribe to DTN.

On-Line Access System

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

- accessible by dial-up through direct modem connection or by using Telnet on the Internet
- the new system offers the computing power of a work station.
- clientele have on-line access to the historical data archives that date to the late 1800's.
- users can make general summaries according to their own specifications

- up-to-date data is available for decision makers who require it

- an autopilot feature allows users to schedule future summaries, saving the time otherwise required to logon and re-create the summary

- automated information delivery by email or ftp

The additional features and power of the new system have led to increaased use by the HPCC clientele. However, improvements are underway including:

- greater simplicity of interface

- decreased learning curve

- navigation by 'mouse' point-and-click

- new products for the system

The HPCC has formed a committee to look into the redesign of the On-Line system and the possibility of combining it with the HPCC home page.

Home Page

The HPCC home page committee designed a new home page (http://hpccsun.unl.edu). The number of accesses to the home page are shown in Fig. 6 and Table 6.

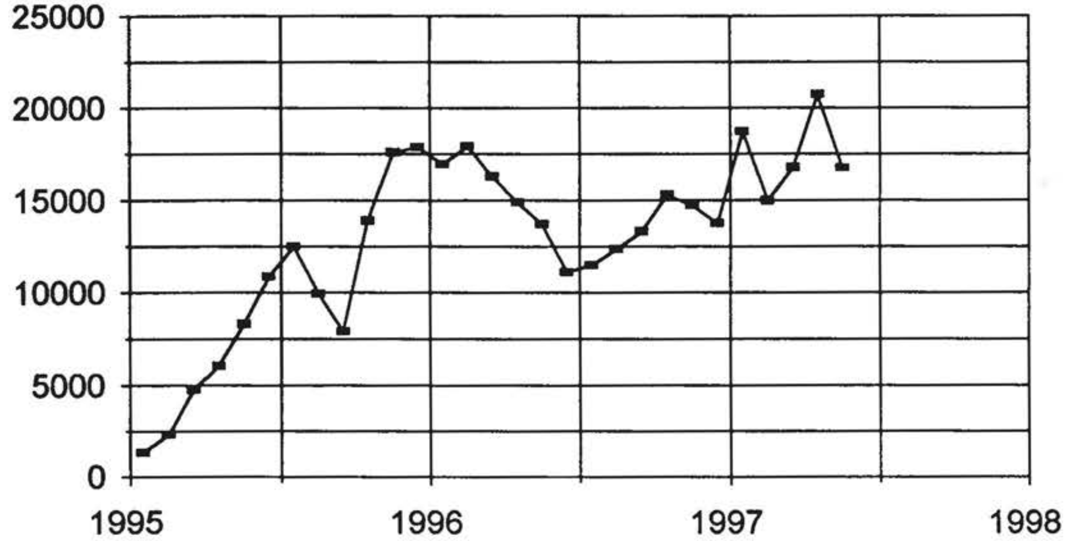


Fig. 6. The number of hits on the HPCC Home Page, http://hpccsun.unl.edu/

Table 1. Sensor installation, accuracy and sampling information.

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

Table 2. Number of AWDN stations.

Number of Stations in AWDN by Year					
1981	5	1989	74	1997	139
1982	14	1990	83		
1983	21	1991	93		
1984	29	1992	95		
1985	47	1993	112		
1986	51	1994	119		
1987	49	1995	132		
1988	60	1996	137		

Table 3. Maintenance checklist.

Check sensor readings (daily)
Clipping of vegetation (as needed)
Onsite testing (4-6 months)
Cleaning of sensors (as needed)
Calibration of tipping bucket (annual)
Calibration of solar sensors (annual)
Test and calibration of humidity sensor (annual)
Replace bearings in anemometer (two years)
Replace potentiometer in wind vane (two-three years)

Table 4. Monthly Accesses to the HPCC On-line Service.

		On-Line Requests				
	1992	1993	1994	1995	1996	1997
1		508	428	429	417	2830
2		536	378	385	303	3443
3		483	368	455	351	4343
4		799	578	460	263	5814
5		638	606	483	2304	7065
6	810	837	661	552	3770	
7	846	841	640	736	5452	
8	710	692	584	693	6603	
9	465	545	369	511	5239	
10	1364	441	420	315	3743	
11	448	468	467	271	3429	
12	485	396	441	309	3435	
Total		7184	5940	5599	35309	

Table 5. Origin of self service requests by sector, October 1996-April 1997.

Sector	(%)	Sector	(%)
Agricul. & Forestry	12	Legal	0
Construction	<1	Manufacturing	0
Consulting	4	Media	<1
Education	75	Recreation	0
Energy	<1	Retailing & Service	0
Engineering	<1	Transportation	2
Government	6		
Insurance	0	TOTAL	100

Table 6. Monthly accesses to the HPCC Home Page.

HomePage Hits			
Month	1995	1996	1997
1	1347	16973	18734
2	2330	17949	14993
3	4747	16295	16771
4	6055	14901	20733
5	8320	13718	16757
6	10890	11142	
7	12524	11518	
8	9963	12372	
9	7925	13325	
10	13909	15298	
11	17600	14729	
12	17904	13775	
total	113514	171995	

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IRRIGATION SCHEDULING......AN ON-FARM UPDATE

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During earlier discussions of irrigation scheduling, we have talked about well capacity (gallons per minute) and relating this to inches per day that can be applied to a center pivot circle. Next, we discussed crop water use, also in inches per day, and how this water use varies with the climate and the stage of growth of the crop. Irrigation scheduling, then, is timing the frequency and amount of irrigation such that crop water use requirements are met, but not exceeded (runoff or deep percolation) taking into account daily changes in crop water use.

The method of irrigation scheduling used on our farm for about the last ten years was developed by Drs. Dale Heermann, Harold Duke, and Gerald Buchleiter of the USDA-ARS, Fort Collins, Colorado. This method calculates soil moisture depletion at the end of each day during the growing season by accounting for crop water use, irrigation amounts and rainfall, all on a computer program developed for a personal computer.

A weather station, owned and located on our farm, is used to take daily measurements of maximum and minimum temperature, wind, relative humidity, and solar radiation. These data are entered into the personal computer and a reference evapotranspiration is calculated, then converted into actual crop water use by applying a crop coefficient that takes into account that crop and stage of growth. Rainfall data is recorded for each field using a standard rain gage mounted near each center pivot field and entered on days when rainfall occurs. Irrigations are entered by putting into the computer, for each center pivot field, the time the irrigation passed over the starting point, and the amount of water applied in inches (knowing the pumping rate and speed of the pivot and applying to this an estimate of application efficiency). When the pivot passes over the ending point (360 degrees later in time), this time and amount applied are also entered.

Twice each week, we run a printout for each of our circles showing the actual soil moisture depletion for each circle, and how that depletion relates to the management limit of 50 % depletion in the root zone. We make the decision of whether to start, continue to run, or to stop each center pivot based on this information. The computer program also projects the crop water use for the next 10 days to give the manager an idea of what to expect over the entire farm. Three to four days later, after updating climate, rainfall, and irrigation data, the computer again prints an update, and management decisions are then updated for each circle.

This procedure has worked well, giving our farm employees a "feel" for the daily climate during the growing season and how daily changes in climate affect water use. Careful attention to the soil moisture depletion has yielded considerable water savings on each center pivot circle. However, all of the data collection required to do this method of irrigation scheduling requires at least 12 hours per week. Much of the interaction with the program requires technical interactions and judgment learned after years of experience. Therefore, in order to make this system more user friendly and to simplify the data collection, we began working with Underhill International Corporation in development of a radio control and data collection system that would utilize the irrigation scheduling methods developed by Heermann, et. al. mentioned earlier. This work was begun in 1994, and will be the subject of the remainder of this update. 1997 was the third year of use for this system, called by the trade name, "Pivot-Alert". Let's start by describing the radio control system. The system includes a base station module and antenna located at our farm office. This base station is connected to a personal computer. Although the control and monitoring features can be done by the base station as a stand-alone unit, the personal computer opens up capabilities for software involving display, data organization, the telephone, and interaction with the Pivot-Alert system by the operator. Next, there is a licensed radio repeater used to receive and transmit signals over a 40-50 mile radius. Finally, at each center pivot there is a radio receiver and antenna. The radio equipment is wired into the power supply and safety system within the center pivot panel box.

After using this radio control system, our farm has benefitted in several ways. We get to shut down pivots faster, since we see that color change on the display in the office or are notified by telephone when a pivot shuts down. During mid-summer in critical growth stages of the crop, this is very important. Before this control system, we would get into two pickups each morning and drive the entire route looking to see which pivots had turned off. Now we look at the display early in the morning, and by the time the employees arrive, we go to just the pivots needing attention, then focus later on the routine checking and maintenance of the rest of the pivots. A subtle benefit is that our employees appreciate fixing the flat tires, gear boxes, and major problems early in the day before the heat and humidity get severe. We have completely eliminated the second trip around the curcuit in late afternoon to check pivots, saving us labor and wear on vehicles. If we receive a significant rain, we shut the systems off at the computer instead of driving, often in the dark, on muddy pivot roads and township roads to reach pumping plants at each pivot. Pivots can be programmed from the computer in the office to shut off at a certain position or time of day. Finally, a regular or cellular phone can be used to interrogate or control center pivots during the time the operator is away from the computer system located, in our case , in the farm office.

In 1997, the irrigation scheduling module adapted from Heerman, et al, was added to the software, and we used this module in conjunction with our normal scheduling routine. The Pivot-Alert irrigation scheduling module inputs the data on the soil, well capacity, crop and related information very similar to our present irrigation scheduling program. Where they have made improvements, however, is in the handling of crop coefficients for corn, soybeans and alfalfa, and in the way the the user interacts with the scheduling information. Also, the climate data is more automated in that the computer calls a nearby weather station at 1 a.m. each day to get the climatic data for the previous day and enters this data automatically into the scheduling module.

The central problem in using crop coefficients is to match the crop coefficient curve with the way the crop is actually growing in the field. In our previous work with the Heermann, et al, computer program, judgment had to be used in establishing dates for root development date, effective cover date, and harvest. When abnormal growing seasons occurred, for example, a cold late spring with slow emergence, the dates had to be adjusted, which takes experience, in order to get the crop coefficient curves to match the actual crop growth. With the Pivot-Alert scheduling module, the manager must simply look at the crop, determine the stage of growth the crop is in, and input this stage of growth into the scheduling module. The only disadvantage to the new method is that, as the crop grows, the successive crop stages have to be input in a timely manner to keep the crop coefficients current with the growth of the crop. Nevertheless, estimating the crop stages is easier for new operators to master, and therefore a definite improvement in the technique of determining crop coefficients in the field.

Finally, regarding irrigation scheduling data output and interpretation. With the Heermann, et al, scheduling program, a printout is generated which gives the current soil moisture depletion for each field in numeric form. The program then forecasts water use for the next 10 days for each field and predicts when the 50% allowable depletion will be reached. The output is a "snapshot in time" of each field that must be updated in 3-4 days after the climatic data, rainfall, and irrigation data are input. The manager interprets these data to decide whether to or not to start, continue running, or stop each system. The Pivot-Alert scheduling module, first of all, collects the data on irrigation automatically, since irrigation amounts are logged in every time the center pivot passes a pre-selected control point based on the well capacity of the well supplying water to the center pivot. Effective rainfall still must be entered manually from rain gages placed adjacent to each circle. The module gets the climatic data automatically as mentioned above, and using the crop coefficient based on stage of growth, the crop water use is calculated internally.

Irrigation scheduling output for the Pivot-Alert module is in pictures rather than numbers. The manager looks at the color of that particular circle on the computer display monitor to see how close to 50 % depletion the circle is. For example, blue might be used to denote 0-10 % depletion, green for 11-40 % depletion, yellow (caution) for 41-50 % depletion, and red (possible crop injury) for depletions below 50 %. There is a "thermometer-type" indicator, as well, that shows the soil moisture status in the root zone. Each day, as water is used, the "thermometer" drops, indicating the circle is getting closer to 50 % depletion. An irrigation raises the "thermometer" line accordingly. All the while the whole circle is changing color in accordance with the preset color limits as soil moisture goes up or down. A second colored circle shows the status of the circle ahead in time just before the center pivot gets to the control point. This can be used to see if the current rotational speed of the center pivot is too slow or too fast. All of the data for the crop stage, well capacity, and evapotranspiration are also displayed conveniently on the same screen. Thus the irrigation manager studies the screen display for every center pivot each day or as required and visually determines if the pivot should be started, continue to run, or be stopped. We think this visual display concept is a big improvement that will allow irrigation scheduling to be mastered without as much experience and training.

Irrigation scheduling continues to be a high priority for our farming operation in the light of good stewardship and to demonstrate to all concerned that a diligent effort is being made to conserve our most valuable of natural resources, water. Technology offers much in improving the techniques in this effort, in particular radio control concepts.

VALIDATION OF CROPFLEX

A CROP MANAGEMENT PROGRAM

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Program Overview:

Cropflex is a flexible crop management computer program developed by the Department of Chemical and Bioresource Engineering and Cooperative Extension at Colorado State University. This easy to use tool provides irrigation and fertility management advice to assist producers maintain or increase yields while minimizing the potential of leaching nitrates into the groundwater. Studies have shown that costly applications of fertilizer can be substantially reduced without reducing yield. Cropflex is a decision support system based on heuristic as well as procedural knowledge.

Cropflex handles a variety of crops as long as the crop basic information exists in the program data base. Basic crop information has been developed for corn, alfalfa, sorghum, onions, potatoes and barley. Entering adding additional crops to the data base is simple and straight forward. As a matter of fact, all the data bases 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. Cropflex can be run in Windows 95 or Windows 3.11 environments and is user and producer friendly.

Cropflex for Windows is composed of four components: irrigation scheduler, fertility scheduler, yield prediction module and a leaching assessment module. The purpose of the irrigation scheduler is to recommend the amount and timing of irrigation applications. The irrigation scheduler uses a soil water mass balance approach to calculate the soil moisture within the crop root zone for every day of the growing season. The amount of water used by the crop is calculated from reference evapotranspiration methods and corrected by the crop coefficient stored in the crop data base. It then uses pre-set, critical soil moisture depletion levels to determine if the current soil moisture is dry enough to warrant irrigation.

The fertility scheduler provides nitrogen, phosphorus, and potassium nutrient recommendations. It tells the user when to fertilize and how much fertilizer to apply in order to supply the crop's nutrient needs. The fertility scheduler uses a series of different methods to arrive at its nitrogen recommendation, including: the Colorado State University soil test method, the Nebraska soil test method for corn, the inorganic nitrogen mass balance, or crop uptake efficiency methods. Phosphorus and potassium nutrient recommendations are based on the Colorado State University soil test method. After the recommendation is made the program will help the user in scheduling fertilizer applications for the season, including calculating the amount of source material to be used at each application. Since the fertilizer recommendation is based on the end of season yield, the preseason fertilizer recommendation is only a guess. A model to predict the end of season yield based on the number of growing degree days at the first four to eight weeks of the season was developed and incorporated into Cropflex. New soil test results taken after planting can be entered and will provide mid season fertilizer recommendations based on the predicted end of season yield. It will also provide mid season fertilizer recommendations without a new soil test. So far end of season yield prediction is available only for corn crop.

The leaching module assesses the amount of nitrate leached under the proposed irrigation and fertility management scheme. Leaching assessment can be done in the middle of the season, usually after the first mid season fertilizer recommendations and again at the end of the season. Deep percolation, nitrate available for leaching, and nitrate leached are estimated by the model. The user can then assess her/his water and management practices and take corrective measures if needed. The leaching module also estimates the yield reduction sustained if the nitrogen fertilizer is reduced to eliminate the leaching problem.

Cropflex has been developed to be used by any person who is involved in crop management. Weather information can be imported by the program using several weather file formats, thus eliminating the need to type weather data manually. The Windows environment allows the user to keep several screens open at the same time so the user can see a weather screen as well as irrigation scheduling and leaching screens for several fields at the same time.

Objectives:

Cropflex was validated in a field experiment by comparing various decisions made by Cropflex with those made by a human expert. Irrigation water recommendations from Cropflex were compared with those of the human expert. This comparison indicates whether Cropflex is meeting crop requirements while not over applying water; thereby reducing the chance of nitrate leaching.

Fertilizer recommendations from Cropflex and the human expert were compared to determine whether Cropflex recommendations meet crop nutrient requirements while reducing excess nitrogen available for leaching. Preseason and post-season soil nitrate profiles were also compared to detect nitrate movement through the soil and any possible leaching that may have occurred during the season. The most important comparison was that of the final yields of the two management practices.

Procedure:

Twelve test plots at the United States Department of Agriculture's Research Station in

Akron, Colorado were planted on May 1st to the corn variety Pioneer 3893. Due to cold dry conditions germination didn't occur until after an one inch irrigation on May 15th. The planting density was 30,000 plants per acre. The distribution of the test plots to Cropflex or human expert management was randomized. Six of these plots were managed by a human expert, and six were managed by Cropflex. Each of the plots consisted of ten rows with a thirty inch row spacing and a length of 175 ft.

The soil was a silty loam with a field capacity of 4.57 in/ft and a permanent wilting point of 1.83 in/ft. Irrigations were applied on these plots using a buried drip system with an application rate of 0.26 inches per hour.

Results and Data Analysis:

A preseason fertilizer consultation was run to begin the field study for the Cropflex managed plots. Using a yield goal of 150 bu/acre and a composite soil sample taken before planting, Cropflex recommended 101 lbs/acre of nitrogen be applied as fertilizer. The midseason nitrogen correction estimated end-of-season yield at 156 bu/acre, recommending an additional 92 lbs/acre of nitrogen be applied to complete the growing season. This 92 lbs/acre plus the 20 lbs/acre applied during the preseason totaled 112 lbs/acre nitrogen for the entire season.

The human expert determined that for 150 bu/acre yield goal 180 lbs/acre nitrogen was needed to meet the crop requirement. From this 180 lbs/acre nitrogen, 47 lbs/acre were subtracted to credit residual soil nitrogen to produce a fertilizer recommendation of 132 lbs/acre nitrogen. The human expert then applied 20 lbs/acre of nitrogen and 15 lbs/acre phosphate before planting. During the season the human expert applied 132 lbs/acre nitrogen in five fertigations using ammonium nitrate for a total of 152 lbs/acre for the entire season. This amounts to 40 lbs/acre more nitrogen applied by the human expert than by Cropflex management (Table 1).

Table 1. Fertilizer Application Management Comparison.

Management	Yield Goal (bu/acre)	Recommendation (lbs/acre)	Nitrogen Applied (lbs/acre)
Human Expert Preseason	150	20	20
Human Expert Fertigations	150	132	132 (152 total)
Cropflex Preseason	150	101	20
Cropflex Midseason	156	92	92 (112 total)

The human expert recommended more frequent and larger irrigations on average (ten applications, 1.77 inches per application) as compared with Cropflex management which recommended seven applications averaging 1.64 inches per application, Figure 1.

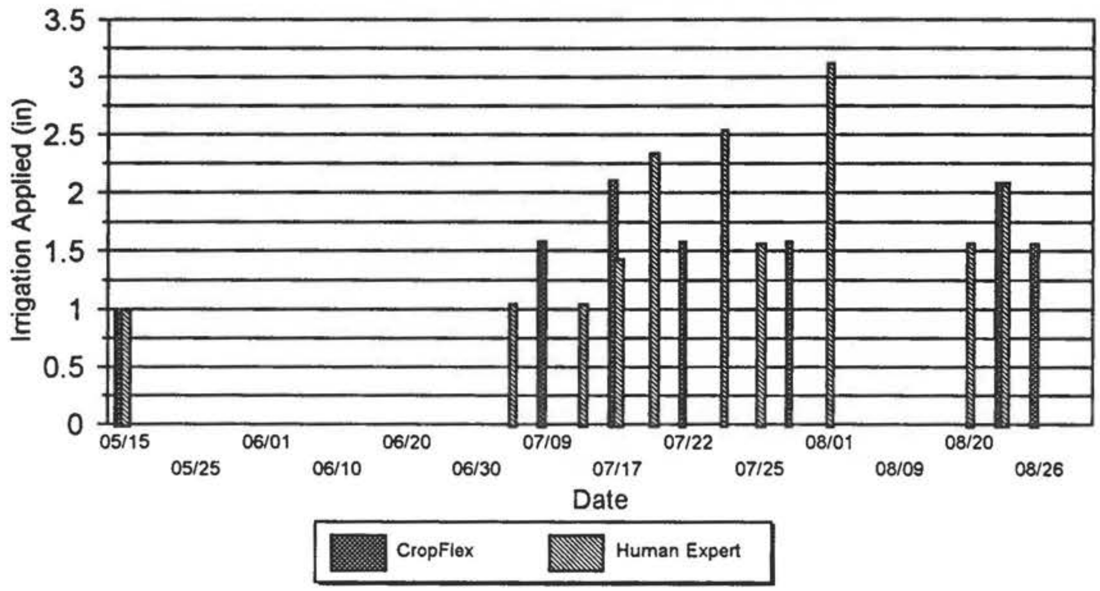

Figure 1. Irrigation Schedule.

The human expert applied a total of 17.7 inches of irrigation which is 6 inches more water than applied by Cropflex management (11.5 in), Table 2. This resulted in increased deep percolation by the human expert's management (4.2 inches) by more than 2 inches over Cropflex management (1.9 inches) as calculated by the Cropflex end-of-season leaching consultation.

Table 2. Total Irrigation Water Applied and Seasonal Evapotranspiration Comparison.

Management	Evapotranspiration (in)	Rain (in)	Irrigation (in)	Deep Percolation (in)
Cropflex	22.4	9.75	11.5	1.9
Human Expert	22.4	9.75	17.7	4.2

Prior to planting and after harvest, soil samples were taken to a ten foot depth and analyzed in one foot increments to monitor nitrate movement through the soil profile, Figures 2 & 3.

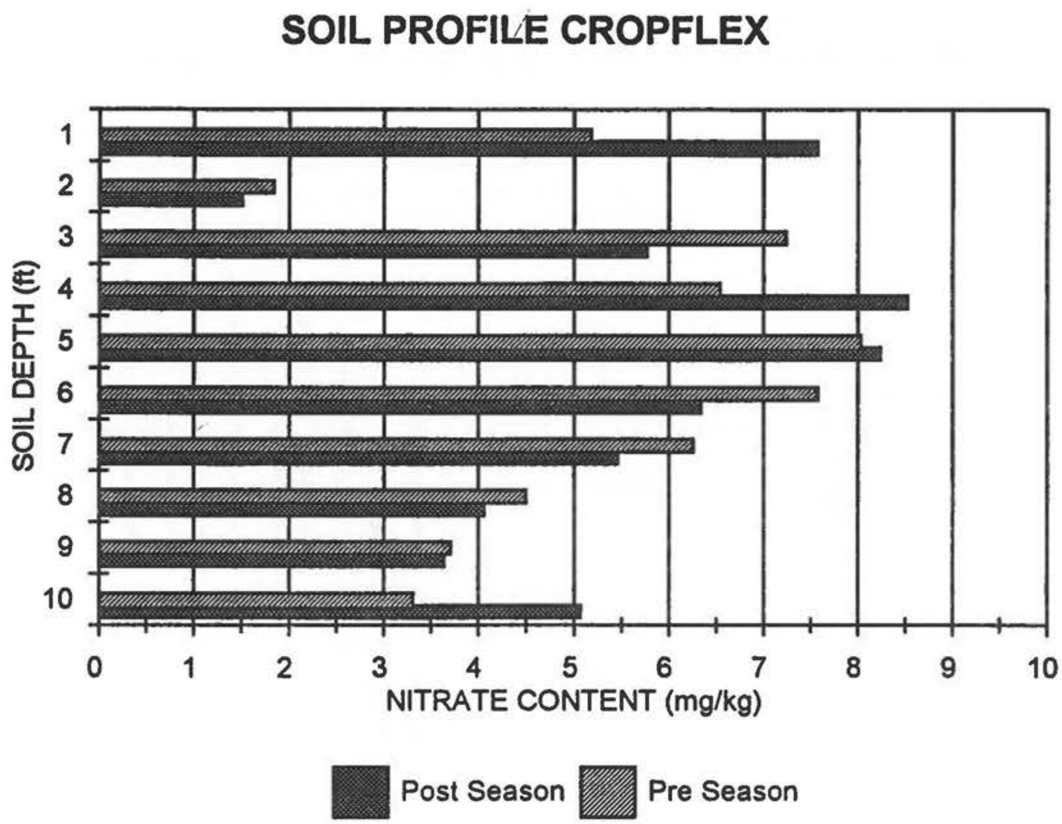

Figure 2. Cropflex Soil Nitrate Profile.

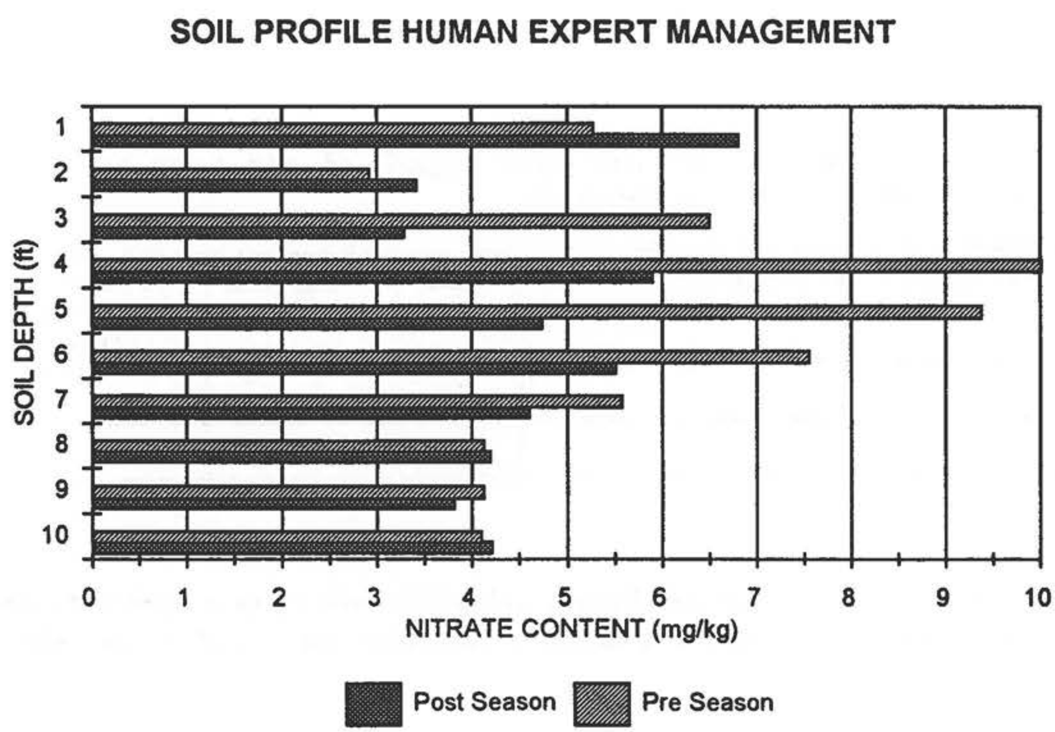

Figure 3. Human Expert Management Soil Nitrate Profile.

A general trend was observed where Cropflex managed plots leached smaller amounts of nitrates out of the soil profile (ten feet) and retained larger amounts of nitrates in the crop root zone (48 inches) when compared with plots managed by the human expert, Table 3. Despite this trend the differences are not statistically significant due to the variability of the plots and the large standard deviation of the measured levels of nitrates in the soil.

Table 3: Soil Nitrate Movement.

Management	**Residual Root Zone Nitrate (48 inches) (lbs/acre) (90% CI)**	**Nitrate Leached Past Soil Profile (10 ft.) (lbs/acre) (90% CI)**
Cropflex	83.8 (+ or - 17.9)	2.1 (+ or - 21.7)
Human Expert	69.4 (+ or - 31.6)	28.0 (+ or - 21.8)

Field observations during the season yielded no visible difference between the Cropflex and human expert managed plots and no signs of stress due to insufficient water or nutrients were observed.

Table 4. Final Yield Comparison.

Management	Average Yield (bu/acre)	Maximum Yield (bu/acre)	Minimum Yield (bu/acre)
Cropflex	**123.1**	**140.8**	**96.2**
Human Expert	**122.5**	**134.4**	**103.7**

The average final yields of both Cropflex and human expert management showed no significant difference at 123.1 bu/acre and 122.5 bu/acre, respectively, Table 4.

Discussion:

The two primary criteria set forth for Cropflex management were that it minimizes nitrate leaching potential while maintaining or increasing crop yield. The objective of this field test was to determine if Cropflex management meets these criteria.

The field test produced indications that Cropflex reduced nitrate leaching potential when compared with the human expert management. Cropflex management reduced the nitrate leaching potential by recommending smaller amounts of nitrogen fertilizer to be applied as compared to expert management. These smaller nitrogen applications reduce the amount of nitrogen available for leaching.

Cropflex also recommended less irrigation water be applied as compared to the amounts of irrigation applied by the human expert. The smaller amount of irrigation water applied reduced the potential for deep percolation past the maximum root zone.

The comparison of soil nitrate profiles taken prior to planting and after harvest showed a trend of increased leaching under human expert management when compared with Cropflex managed plots. However, these results were not statistically significant due to the high degree of variability and large standard deviations observed in the soil nitrate measurements.

The Cropflex managed plots average yield was equal to that of human expert managed plots. This therefore meets the second criterion set forth for Cropflex, that is, maintaining or increasing yield.

SUMMARY[*]
COOPERATIVE AGREEMENT

Basinwide Recovery Program for Endangered Species in the Central Platte River Basin

Nebraska, Colorado, Wyoming and the United States Department of the Interior have developed a proposed basinwide recovery program for endangered species in the Central Platte River Basin. The program's primary purpose would be to provide and protect water and land for the habitat of whooping cranes, piping plovers, and least terns. The program would also serve as a reasonable and prudent alternative for water related activities requiring Section 7 consultations under the Endangered Species Act. Such consultations are required by that Act to ensure that federal actions, such as the relicensing of water projects, are not likely to have an adverse impact on endangered species or their habitat.

A cooperative agreement outlining the proposed basinwide program was signed on July 1, 1997 by Nebraska Governor Ben Nelson, Colorado Governor Roy Romer, Wyoming Governor Jim Geringer, and Secretary of Interior Bruce Babbitt. The cooperative agreement specifies the activities to be undertaken in the next three to four years while the proposed program is being reviewed under the National Environmental Policy Act (NEPA). Funding will begin this fiscal year and a governing body has been established so that the states, the federal government and the other parties involved can work together on the activities planned during that time. The cooperative agreement also describes what the parties intend to accomplish during the proposed program's first increment, which is expected to begin after the NEPA review and last for ten to thirteen years thereafter.

TERMS OF THE AGREEMENT

Governing Body. A ten-member governing body will be responsible for the activities undertaken both in the initial three to four years and in the long-term program if it is initiated. That governing body will include representatives from the U.S. Fish and Wildlife Service (USFWS), the U.S. Bureau of Reclamation, each of the three states, water users from three geographic areas in the Platte River Basin, and environmental organizations. As of this writing, the appointees for the term of the cooperative agreement and their alternates are:

[*] This summary was prepared by Jim Cook, Natural Resources Commission staff member.

	Member	Alternate
State of Nebraska	Dayle E. Williamson Director of Natural Resources	David Vogler, Governor's Policy Research Office
State of Colorado	Jim Lochhead, Dir., Colorado DNR	Doug Robotham, Asst. Dir., Colorado DNR
State of Wyoming	Mike Besson, Dir., Wyoming Water Development Commission	Jeff Fassett, Wyoming State Engineer
U.S. Fish and Wildlife Service	Ralph Morgenweck Regional Director, USFWS	Joe Webster, Assistant Regional Director, USFWS
U.S. Bureau of Reclamation	Patty Beneke Asst. Secretary of Interior	Neil Stessman Regional Director, BuRec
North Platte Water Users[1]	Norm DeMott Goshen Irrigation District (Wyoming)	Dennis Strauch Pathfinder Irrigation District (Nebraska)
South Platte Water Users[2]	Alan Berryman, Northern Colorado Water Cons. Dist.	Dave Little Denver Water Board or Eric Wilkinson, Northern CO Water Cons. District
Downstream Water Users[3]	Brian Barels, Nebraska Public Power District	Don Kraus, Central Nebraska Public Power & Irrigation District
Environmental Organizations	Dave Sands [4] Nebraska Audubon Society	Paul Currier [4] Whooping Crane Trust
	Dan Luecke, Natural Resources Defense Council [4]	

The governing body will be assisted by adjunct committees on land and water. Technical groups may also be created to support and advise the governing body.

Program Goals - Water. The USFWS has identified target flows for endangered species in the Central Platte, i.e. flow levels the USFWS believes are needed to provide adequate habitat for those species. Actual flows currently fall short of those target flows by about 400,000 acre-feet per year, on average. However, the USFWS is willing to review and possibly revise its target flows as better science becomes available through the proposed program and otherwise.

[1] North Platte water users in Wyoming and Nebraska water users upstream of Lake McConaughy with storage contracts in Wyoming reservoirs.

[2] South Platte water users upstream of the Western Canal in Nebraska (near the Colorado/Nebraska state line).

[3] North Platte, South Platte and Platte water users in Nebraska other than those included in the North Platte or South Platte groups.

[4] As of this writing, the environmental organizations had named these three individuals, but had not yet decided which two would serve as the members and who would serve as the alternate(s).

The long-term goal of the program would be to eliminate shortages in the target flows as those flows are later refined.

In the meantime, incremental improvements in flows would be sought. The goal during the first increment of the proposed program would be to reduce shortages to the current target flows at Grand Island by at least 130,000 acre-feet on average. The first three projects planned would be to: (1) operate Kingsley Dam and related facilities in Nebraska to store a portion of the inflows to Lake McConaughy as well as environmental water made available from upstream projects in an environmental account that would be managed by the USFWS; (2) modify Pathfinder Reservoir in Wyoming to store water in another environmental account to be similarly managed; and (3) construct and operate the Tamarack Project in Colorado. The Tamarack project would take water out of the river during times of excess flows (most often during winter months) and temporarily store it underground in locations where it would naturally return to the river at times when flow shortages are more likely (in the summer months).

The states and the Department of Interior agree that these three water projects combined would reduce the shortages to current target flows by an average of 70,000 acre-feet per year. The additional 60,000 acre-feet necessary annually to realize the 130,000 acre-feet goal for the first program increment would have to be obtained through water conservation and water supply projects. A study will be conducted during the term of the cooperative agreement to determine if that goal is feasible, and if so, what types of conservation/supply projects would be the most promising.

Program Goals - Land. Land habitat is also necessary to meet the needs of the species. The proposed program would over time result in the development and protection of 29,000 acres of habitat. This land would be in ten habitat complexes between Lexington and Chapman. The goal for the first increment of the proposed program would be to develop and/or protect at least 10,000 acres. If dedicated to the program as currently expected, the Nebraska Public Power District's (NPPDs) Cottonwood Ranch between Overton and Elm Creek (2,650 acres) would contribute substantially to that goal.

Also, the Platte River Whooping Crane Maintenance Trust, the Nebraska Game and Parks Commission, the Nature Conservancy, and the Audubon Society already own about 9,000 acres of potentially eligible land in the area involved in the proposed program. Eventually, those habitat holdings are expected to contribute to meeting the 29,000 acre goal, but they will not count towards the initial 10,000 acre goal.

Costs of the Program. The total cost for the proposed program during the combined times of the cooperative agreement (three to four years) and the first program increment (an additional ten to thirteen years) has been negotiated at $75,000,000. Half of that cost would be paid by the federal government; the other half would be shared by the states. During those first two periods, Nebraska and Colorado would each contribute 40% of the states' share ($15 million) and Wyoming would contribute 20% ($7.5 million). The 40/40/20 split is also the result of negotiations. It reflects the high use of water in Colorado and the fact that Nebraska is where the endangered species critical habitat is located. A summary of the contributions proposed is found on the attached Table 1.

Nebraska's cash contribution of $700,000 during the initial two periods is relatively small compared to that of the other states. That is because Nebraska would be credited with $14.3 million in cash equivalents for the value of water made available through the operation of the Environmental Account in Kingsley Dam ($9.0M) and for the contribution of NPPD's Cottonwood Ranch ($5.3M). Of the $700,000 to be provided in cash (all during the time of the cooperative agreement) $300,000 will fund part of the water conservation study and the other $400,000 will be for other initial activities undertaken by the governance committee.

Additional Program Responsibilities. Effective on the date the cooperative agreement was signed (July 1, 1997), each state assumed responsibility to mitigate, offset, or prevent any new depletions to the river's target flows as part of the proposed program. For a program to be initiated, each state must develop a mitigation plan that offsets or mitigates, within its own boundaries, any depletions resulting from new water related activities in that state. Those include new uses of hydrologically connected ground water as well as new uses of surface water.

Colorado has developed and proposed a method for monitoring and mitigating for its future depletions to target flows. That proposal will be evaluated by other cooperative agreement participants within the next three years. Wyoming and Nebraska have not yet decided how they would propose to mitigate, offset, or prevent depletions resulting from new water related activities in their states, but will need to do so in the next three years. Those proposals will also be submitted to the other participants for review. To prepare for this responsibility, each state will begin monitoring new water related activities in order to distinguish between those in existence before the cooperative agreement was signed and those initiated or expanded thereafter. The knowledge gained from this monitoring process will enable each state to quantify depletions, if any, that must be mitigated or offset. Institutional changes may be needed in Nebraska to accommodate these provisions and also to guarantee that water made available upstream will actually reach the critical habitat area.

FUTURE OF THE AGREEMENT AND THE PROPOSED PROGRAM

Signing the cooperative agreement represented only a first step in a long-term program. As mentioned earlier, the federal government will conduct an environmental impact analysis and will determine whether the proposed program can serve as a reasonable and prudent alternative for Section 7 consultations. During the NEPA review, public and private interests may propose their own alternatives to the proposed program. A full range of alternatives will be analyzed in the environmental impact statement. That process may result in substantial changes to the proposed program by the end of the first three years. The program may also be modified to take into consideration the results of the water conservation study and other lessons learned in the meantime.

The states are not legally bound to participate in the program even if it remains unchanged after the NEPA review. In fact, the states can pull out of the current cooperative agreement at any time. However, the consequences for doing so could be very significant to individual Nebraska projects and activities that require federal action in the future. The states recognize that dealing with these issues without a basinwide program could be much more painful than working together in the future.

If the basinwide program is implemented, the first program increment will be evaluated as it draws to a close and plans for a second increment will be prepared, if necessary. The same process could continue indefinitely in order to maintain the integrity of the ecosystem and the commitment of the parties to habitat recovery and ecosystem maintenance and development.

RELATIONSHIP TO RELICENSING

Relicensing by the Federal Energy Regulatory Commission (FERC) for Central Nebraska Public Power and Irrigation District's Kingsley Dam and related facilities, and for Nebraska Public Power District's North Platte Keystone Diversion Dam and related facilities is proceeding. The USFWS and those districts are encouraging FERC to base its license terms on the proposed program. For example, FERC is being urged to endorse the proposed environmental account for storing water in Lake McConaughy and the proposed contribution of Cottonwood Ranch by NPPD. The new licensees will have reopeners which will allow FERC to reconsider license terms if the basinwide program fails.

(COOK\SUM COOP AGR1698)

Table 1

Program Contributions, Cooperative Agreement Through First Program Increment
(values in millions of 1997 dollars)

CASH AND CASH EQUIVALENTS[1]

	CO	WY	NE	States[1] Total	Federal	TOTAL
Term of Cooperative Agreement[2] (3 years anticipated)						
Conservation Study	0.3	0.3	0.3	0.9	0.0	0.9
Habitat (Cash Equiv.)	0.0	0.0	5.3	5.3	0.0	5.3
Other Cash	0.6	0.3	0.4	1.3	7.5	8.8
Total	0.9	0.6	6.0	7.5	7.5	15.0
First Program Increment/Years 1-3						
Cash and Cash Equiv.	2.475	0.85	0.0	3.325	7.5	10.825
First Program Increment/Years 4 to End						
Cash and Cash Equiv.	7.425	2.55	0.0	9.975	22.5	32.475
TOTALS OF CASH AND CASH EQUIVALENTS DURING THE COOPERATIVE AGREEMENT AND THE FIRST PROGRAM INCREMENT						
	10.8	4.0	6.0	20.8	37.5	58.3
CONTRIBUTED VALUE OF WATER PROJECTS DURING THE COOPERATIVE AGREEMENT AND THE FIRST PROGRAM INCREMENT						
	4.2 (Tam.)	3.5 (Path.)	9.0 (King.)	16.7	0.0	16.7
PROGRAM TOTALS THROUGH THE FIRST INCREMENT						
	15.0	7.5	15.0	37.5	37.5	75.0

[1] Individual signatories may propose to the Governance Committee that certain interim measures undertaken prior to the execution of the Cooperative Agreement may be credited to their cash or cash equivalent contributions.

[2] Contributions made during the term of the Cooperative Agreement will be credited to the appropriate parties at the inception of the first Program increment.

POTENTIAL FOR VARIABLE WATER AND CHEMICAL APPLICATION

Harold R. Duke, Agricultural Engineer
USDA-Agricultural Research Service
AERC-Colorado State University
Fort Collins, CO 80523

COMPUTER CONTROLS FOR CENTER PIVOT/LINEAR

As consumer electronics have become computerized, agricultural equipment is also seeing computerization. Virtually all manufacturers of center pivot and linear move irrigation machines have offered computer controlled irrigation system panels for several years. These panels allow programming of sprinkler operations based on time, position in the field, or other conditions such as air temperature or wind speed. In addition, the presence of an on-board computer opens the way for as wide range of information processing to make intelligent irrigation decisions and control. For example, our first computer controlled prototypes automatically collected weather data, estimated crop water use, and made irrigation recommendations. They also interacted with the electrical power supplier to assist in managing electrical demand while protecting the crop from water stress.

New generations of these computer controls add increasing capabilities to monitor irrigation operation and control irrigations from the farm office, the pickup cab, or from virtually anywhere in the world. Each of these systems offers remote telemetry options, which may vary from a dealer-owned radio network to cellular telephone links or even satellite communication.

Over the past several years, our research group has operated under a Cooperative Research and Development Agreement with Valmont Industries to develop additional capabilities for irrigation and chemical management using the self-propelled sprinkler as a transport platform.

VARIABLE WATER APPLICATION

New sprinkler controls allow the irrigator to vary the application depth depending on rotational angle of a center pivot in the field. As we embrace the concepts of precision farming in the future, it may well become desirable to vary the amount of water applied along the pipeline to various shaped spots in the field. Non-productive areas, such as rock outcrops or seeps, need not be irrigated. Areas receiving precipitation from small convective storms need less water than those outside the storm path. Soils with low water holding capacity may need more irrigation than spots with heavy soils to carry the crop through until a rain. Computerization of sprinkler panels allows us great capabilities to irrigate in a manner never before practical.

Method of Changing Application

Most efforts at changing application amounts along the pipeline have been elaborate schemes to create water treatments to research plots. Two or more sets of sprinkler heads with different nozzle sizes can be installed on the machine, with appropriate controls to turn on one set, the other, both, or none according to water needs. Such a system has been patented in Idaho, and the patent has been licensed commercially.

A second method of variable application, which we have incorporated into a research unit at Fort Collins, uses a method which might be called pulse-width modulation. Sprinkler heads are controlled by solenoid valves, which are turned on and off over about a one minute cycle. The fraction of each minute that the head is on determines the fraction of full water output that is applied from that head.

Someday, it may be practical to modulate each sprinkler head by changing the nozzle size electronically to change the water application rate. Although such methodology exists today, it is cost prohibitive at this time.

Intensity of Control

Regardless of the method of controlling water application along the pipeline, the intensity of sprinkler control has significant impact on the cost of necessary wiring, plumbing, and computer power. On the one extreme, controls can be configured to operate each sprinkler head independently of the others. Although this provides the greatest flexibility for variable application, it is also undoubtedly the most expensive method. At the other extreme is an "all or none" control, which is achieved by the sprinkler in its standard configuration. The application depth is the same along the entire pipeline, and any variability is imposed in the direction of travel. An intermediate step, which we have incorporated into our control system at the ARDEC is to subdivide the sprinkler into a number of manifolds, each of which can be controlled independently. Current thinking is that segments of one-half to full tower span lengths will likely be practical for individual control.

A second issue is the number of increments of water application necessary to obtain benefit to variable application. In the beginning perhaps two levels, "on" and "off," will satisfy the most pressing needs to vary application (for example, avoid irrigating rock outcrops or seepage areas). With additional control complexity (but not necessarily more equipment), we could apply "high", "medium", and "low" amounts of water. Personally, I doubt that we will reach the point in the foreseeable future that we can quantify the difference in water needs for various places in the field to justify more than three or four different amounts of water application in a single field during a given irrigation.

Operator Interaction.

The ease with which the irrigator can implement variable management decisions will likely be a determining factor in the acceptance of such technology. At the present time, we have developed software for the base station of the Valley CAMS system to allow the irrigator to set up patterns of proportional water application. Prior to the irrigation, a map must be created to show areas of the field to receive more or less water, and decisions must be made about how many different application depths to apply and the size of areas to receive a given amount. Figure 1 shows such a map, for the linear sprinkler at ARDEC, under development.

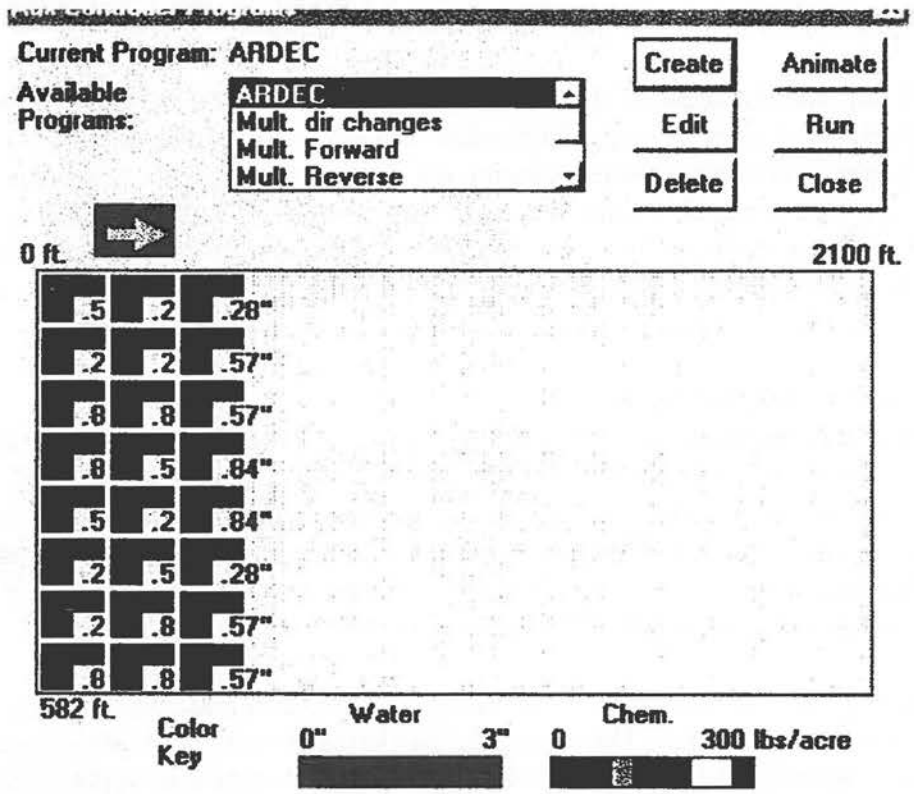

Figure 1. Variable water application map partially created for a rectangular field.

Along with development of hardware to apply varied amounts of water, we and others are developing techniques to develop a more complete (and inexpensive) picture of how much water needs to be applied and where. Remote sensing techniques, whether by handheld instrument, aircraft, or eventually satellite, have promise to identify the amount of plant material present in a small area and its water needs.

The next step beyond remote sensing and development of maps of crop water need is the software to automatically translate that map into signals appropriate to tell the sprinkler control panel which heads to operate at what point in the field in order to apply the required amount of water.

VARIABLE CHEMICAL APPLICATION

Chemigation

Chemigation, or injection of agricultural chemicals into the irrigation stream, has been a common practice for two decades or more. Regulations on chemigation systems have been developed in most states to safeguard against contamination of the water supply in case of system failure, so that this technique is now considered a good management practice. Variable application via chemigation is presently limited primarily to systems which inject chemical at intermediate points in the pipeline to apply chemical at the periphery.

In conventional chemigation, there may be considerable time delay between when the chemical is injected and when it leaves the pipeline through a downstream sprinkler. Thus, variable application of chemicals means changing the concentration of chemical in the water and becomes very complicated. In addition, the potential exists for contamination of water supplies if certain components of the system fail. Most states have developed regulations to require certain protective equipment whenever chemigation is practiced. Further, use of pesticides for chemigation requires specific registration for that application method.

Irrigation System Transported Sprayers

Because of the limitations of chemigation systems, particularly to variable application, we have concentrated our efforts on utilization of separate systems, mounted on the sprinkler to transport them around the field. This is not a new concept, having been developed in Georgia some twenty years ago. That system, named PASS (pivot attached spray system), was a relatively high volume system (200+ gallons per acre), utilizing large orifice spray nozzles, and configured to spray only when the nearest wheel tower was moving.

A unique system developed for orchard irrigation (Intertec, Inc) has been adapted as a sprinkler attached spray system. This system utilizes injection molded plastic components to control cost. The individual heads are connected in banks to control the application along segments of the sprinkler pipeline. The amount applied is controlled by pulsing the discharge from the heads, with higher frequency pulses resulting in greater application amounts. The system is readily adjusted for height to control wind effects, and is capable of applying from about 3 gallons per acre to about 200 gallons per acre with high uniformity. Valmont announced commercial availability in Fall 1997. The commercial system does not yet have the capability of variable application along the pipeline. As for variability of water application discussed above, the system is presently pre-programmed by the irrigator to determine how much chemical is applied and where. Figure 2 shows a typical screen in the base station software in which the irrigator creates the application map for a field.

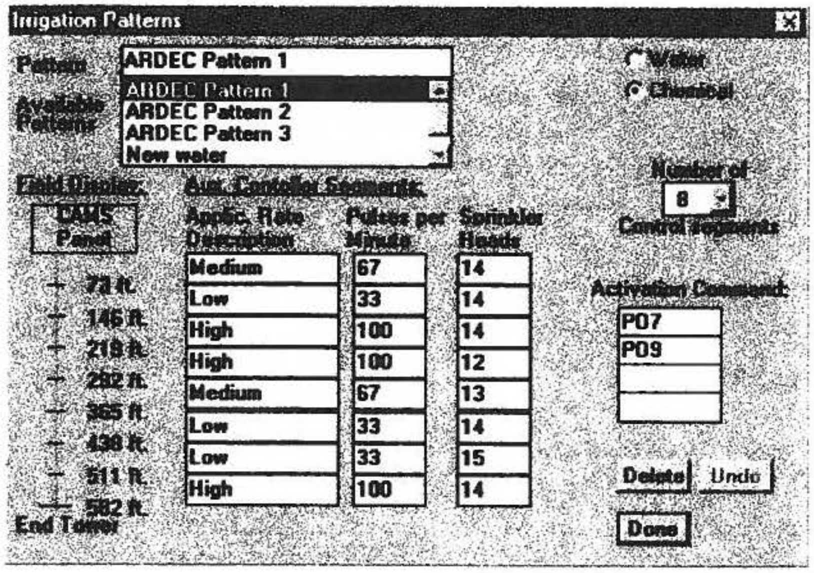

Figure 2. Setup for variable chemical application.

MOVING PRECISION AGRICULTURE TO A NEW DIMENSION
The ARS/CSU Precision Farming Project at Wiggins, Colorado

Kim L. Fleming, Dwayne G. Westfall,
Colorado State University, Fort Collins, Colorado
and Dale F. Heermann
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ABSTRACT

As more producers become aware of precision farming technology they are asking how it can improve productivity and profitability. There is a vast array of claims, beliefs, and testimony, yet little quantitative data to answer this question. Multi-disciplinary field scale research is needed in precision farming to answer the questions of productivity and profitability. The Agricultural Research Service and Colorado State University have begun a multi-disciplinary research program that focuses on developing a clearer scientific understanding of the causes of yield variability. We intend to develop decision support systems for site specific management. A team of 15 scientists covering the areas of soil fertility, crop production, weed science, entomology, plant pathology, system engineering, remote sensing, GIS, irrigation engineering, agricultural economics and statistics has started a project to develop a better understanding of precision agriculture in Colorado. They are collecting and analyzing data from 2 center pivot irrigated fields. Cooperating farmers manage all the crop production operations and provide yield maps of the corn grown on the fields (175 and 130 ac.). The important variables for crop production have been sampled at several different intervals. Both fields have been sampled at a grid spacing of 250 feet. More intensive sampling has been done by various disciplines in smaller areas at a variety of scales down to 50 feet. Concurrent work, in cooperation with industry, is developing center pivot and linear move irrigation systems to apply variable site specific rates of chemicals and water. We will discuss the project and the various data layers being collected.

INTRODUCTION

Precision farming is a management system based on variability that occur in farmers fields. Although farmers have been aware that fields have variability, conventional management has generally been uniform within fields. Precision farming seeks to match production inputs with potential production and profit. This, in theory has the potential of providing economic and environmental benefits due to reduced waste of inputs. For example, fertilizer and herbicides would be applied only where needed, avoiding applying too much or too little on specific sites.

This new opportunity for replacing uniform application is derived from recent technological advances. These include: (i) improved microcomputer capabilities, (ii) global positioning systems (GPS) for field navigation (Larsen et al., 1994: Petersen, 1991), and (iii) variable rate fertilizer and pesticide application equipment (Larsen and Robert, 1991).

Crop producers in Colorado are beginning to adopt precision farming technology, with DGPS yield monitors and variable rate fertilization two of the most common applications. As more producers become aware of this technology they are asking how precision farming can improve my productivity and profitability. There is a vast array of claims, beliefs, and testimony, yet little quantitative data exists to answer the basic questions (Nowak, 1997).

Multi-disciplinary field scale research is needed in precision farming. Colorado State University and the Agricultural Research Service Water Management Unit (ARSWMU) in Fort Collins have assembled a multi-disciplinary team to assess the technical and economic feasibility of precision farming. This project involves fifteen scientist, two farmers, three extension specialist, and four graduate students working on two center pivot irrigated fields near Wiggins, Colorado.

Our initial goal, before precision farming treatments are applied is to complete two years of intensive and coordinated data collection and analysis. With these data we can begin to identify and quantify the factors contributing to yield variability under sprinkler irrigated conditions. In addition, through intensive data collection we will develop and evaluate various aspects of precision farming sampling methods and strategies, along with analysis techniques. Ultimately we hope to develop models to predict the effect of spatial variability on the profitability of precision farming. The levels of spatial variability within a field is in itself variable, thus increased production and savings in input cost from site specific management should also vary. We then hope to incorporate those models into a decision support system we feel is essential in moving precision farming from the early adopter phase into the mainstream farming community.

DISCUSSION

Farm Management and Operation

Both center pivot irrigated fields were in sugar beets in 1996 and will be in continuous corn throughout the study. Pivot 6 (175 acres) is operated by Larry Rothe while pivot 39 (130 acres) is operated by Bob Geisick. They are responsible for all management decisions and farming operations on the fields.

Topography

The Natural Resource Conservation Service assisted in topomapping both sites in March. Two methods were used, a laser level to determine elevation along with GPS to generate position and Total Station which determines xyz data.

Soil Fertility

Dwayne Westfall, CSU completed our initial spring soil sampling in April 1997. A 250 foot coarse grid was sampled over the entire field at both locations. In addition a 500 x 1000 foot area of maximum variability within each field was identified. Within these areas soils were sampled on a 50 foot fine grid. Sample locations within the grids were randomly selected . The surface 0-8 inches was analyzed for NO_3N , NH_4N, P, K, Zn, pH, organic matter, and texture. Subsoil samples from 1 to 2, 2 to 3, and 3 to 4 foot increments were analyzed for NO_3N and NH_4N.

Conductivity Mapping

Newell Kitchen (USDA,ARS, Columbia, Missouri) mapped conductivity at both sites using a electromagnetic induction (EM) ground conductivity sensor. Originally developed for geophysical surveying applications, EM sensing uses electromagnetic energy to measure the apparent conductivity of earthen materials. This method has been used to measure the apparent conductivity of saline and sodic soils, map thickness of clays, measure soil water content, and for groundwater research. Factors that influence variation in EM response include the volumetric water content, the types and amounts of ions in the soil solution and clays present.

We found a wide range of conductivity readings with systematic rises and dips across the fields. We plan to ground truth the data working with NRCS personnel. This should prove to be a valuable layer in assessing and correlating variability at our sites.

Weed Sampling
Phil Westra, CSU and Lori Wiles, ARSWMU collected weed seed and seedling data. In May they collected soil cores for weed seed bank assessment at the center of the coarse grid locations established for soil sampling. In addition three 500 by 500 foot star shaped locations were sampled each containing 150 samples. In early June and September weed species counts were taken at the same locations weed seed bank samples were collected. Weed seed sampling was repeated in November after corn harvest. The weed seed soil cores were also analyzed for nematodes and corn rootworm eggs.

Insect Monitoring
Frank Peairs, CSU feels we have set a world record for the number of insect traps in one field. European Corn Borer, Western Bean Cutworm, and Western Corn Rootworm populations were monitored throughout the growing season. Pivot 39 had 189 locations with pheromone traps at all coarse grid locations plus an additional 101 randomly selected locations. One hundred seventy eight locations were monitored on pivot 6, again at all course grid locations plus an additional 53 random locations. Populations were determined on weekly basis from mid June through mid September.

GPS
A GPS base station has been established in the area which will continuously broadcast the differential correction using an Ashtech Super C/A 12 (C/A code + carrier phase) receiver. The radio used to broadcast the differential correction is a FreeWave spread spectrum transceiver. A computer will be located at the base station site to store raw data for post processing to improve position accuracy, if desired.

Four control points (benchmarks) have been established outside each of the two fields for georeferencing aerial photography. These points can also be used to evaluate the accuracy of GPS receivers.

Remote Sensing
Walter Bausch, ARSWMU is heading up the remote sensing work for the project. He has equipped a high boy sprayer with multi-spectral remote sensing tools. A boom-mounted instrument platform carries two Exotech four-band radiometers 30 feet above the soil surface. One measures the irradiance while the other one measures target radiance, the down-looking radiometer is pointed perpendicular to the crop surface (nadir view). Radiant energy is measured

in the green, red, and infrared wave bands. These wavebands are the same as on the Landsat Thematic Mapper as well as what will be in the upcoming commercial satellites operated by Resource 21, SpaceImaging, and EarthWatch. The instrument platform also carries an IR transducer to measure surface temperature which also has a nadir view. A GPS antenna is mounted directly above the down-looking radiometer to determine the approximate position.

A side-mounted arm near the tractor carries a IR transducer (6° below the horizontal), an aspirated relative humidity/air temperature sensor, and a 15° Exotech radiometer (15° below the horizontal). These are located at 0.3 m, 0.8 m, and 1 m, respectively, above the crop surface. The IR transducer and Exotech radiometer look perpendicular to the crop rows.

A data point is collected and stored every 2 s. Traveling 4 mph, the distance between centers is approximately 12 ft. Fifteen transects were run thru each field with the high boy to measure canopy reflectance, each covering 40 rows. Measurements were taken each week from V6 through R5 growth stages. In addition population, leaf area, and chlorophyll measurements were taken at 46 course grid locations corresponding with the transects within each field.

Color 35 mm aerial photographs of each field were taken each week from V6 through R4 growth stages. In mid July TASC an east coast based imaging company flew the fields with a Kodak digital infrared imaging system. This data was correlated with Walter's ground based data.

Sorptivity and Hydraulic Conductivity Measurements

To begin to assess the spatial variability in soil infiltration and drainage properties Gerald Buchleiter and Roger Smith, ARSWMU, took sorptitvity readings using three and 3/4 inch rings. The coarse grid at both pivots was measured in April, plus an additional 140 locations in the fine grid on pivot 6 and 80 locations in the fine grid on pivot 39.Soil samples were taken for moisture and bulk density measurements at 10 % of the locations.

In late April through early May one hundred 12 inch single ring infiltrometer readings were taken in the fine grid on pivot 6. The rings were initially saturated before the infiltrometer measurements were taken to determine saturated hydraulic conductivity. Soil samples were taken at each location down to three feet to determine bulk density and 1/3 bar field capacity.

Irrigation Monitoring

Dale Herrmann and Harold Duke, ARSWMU, are exploring the spatial variability in center pivot water application. They performed sprinkler uniformity tests at various locations in the field. The data will be used to correct irrigation models for wind and validate spatial water applications models. Pump tests were also performed at many locations in both fields, flow, power consumption, and pressure were measured at the pivot point. They found variability in water application within both pivots.

Each pivot was equipped with a Valley CAMS panel with phone links to the ARSWMU in Fort Collins. Scientists could monitor the pivots position from Fort Collins and plan field activities accordingly.

Weather Data

Weather stations are located at each pivot. In addition six tipping bucket rain gauges are installed around the pivots. The project is also coordinating with CSU-CHILL National Radar Facility to track raindrop and hail size and intensity.

Yield Mapping

Both fields were yield mapped during the 1997 harvests. Pivot 6 was harvested with a Case IH 1460 Axial Flow combine, while a 1680 Axial Flow was used at pivot 39. Both were equipped with Micro-Trak yield monitors with Ashtech GPS equipment and a base station for differential correction discussed earlier.

SUMMARY

A multi-disciplinary team from CSU and the ARSWMU are accessing the technical and economic feasibility of precision farming. Baseline data was collected and analyzed on two center pivot irrigated fields near Wiggins, Colorado in 1997. In 1998 all data collection will be repeated with the same parameters being measured at the same locations to monitor shifts in parameters with time. Precision farming treatments will be explored in years 3 thru 5 to maximize yields and economic return, while maintaining the resource base. From this project the team ultimately hopes to develop models to predict the effect of spatial variability on the profitability of precision farming and incorporate those models into a decision support system.

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POLYACRYLAMIDE - A METHOD TO CONTROL EROSION

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Soil erosion due to irrigation can range from zero, on many center pivot irrigated fields to over 30 tons per acre per year on intensely farmed furrow irrigated fields. These high soil erosion losses occur primarily from furrow irrigated fields with slopes greater than 3% or on soil prone to erosion. Yet the total amount of top soil lost each year is greater on furrow irrigated fields having slopes of 1-3% than on fields with slopes greater than 3%. This happens simply because there are far more acres planted on a 1-3% slope. To reduce the total amount of soil that is lost due to irrigation means we must reduce sediment loss on any field with a potential for erosion.

The loss of topsoil can mean a long term reduction in soil productivity, crop yield and the life expectancy of downstream storage reservoirs. In the short term, it means producers or county governments are faced with reuse pits or borrow ditches filled with top soil that must be removed. To avoid a loss, the producer must spread the soil back on the field to try and maintain soil productivity. To sustain Nebraska's soil resource means we must use different methods to reduce or eliminate soil erosion.

WHERE DOES SOIL LOSS OCCUR?

Center pivots account for only a small portion of the total soil that is eroded. The majority of soil that is lost under pivots is due to runoff when precipitation comes faster than what the soil can take in during a given period of time. During irrigation, runoff and associated soil loss should be minimal for center pivots. When designed properly, center pivot systems will apply water at or below the rate at which the soil can take in water. Using this design criteria, little water should move from the point of application and therefore soil cannot be eroded. If you're experiencing runoff and subsequent soil erosion, address this potential problem first.

Furrow irrigation is a major contributor to soil loss. With nearly half of the irrigated acres in Nebraska under furrow irrigation, reducing soil erosion here could have a significant impact on maintaining top soil for future generations. Furrow irrigation is a major contributor because unlike a center pivot that uses a pipe to transport the water prior to distribution, furrow irrigation uses the soil as the transmission line and distributes the water along the irrigation furrow. To have a reasonably uniform irrigation, it is necessary to have runoff. Unfortunately, with runoff water comes soil, and often lots of soil. When the water leaves the field and movement of the water slows sediment begins to settle out at the end of the field and in borrow ditches.

To gage how much sediment is being lost from furrow irrigated fields, one can look at some of the concrete irrigation ditches installed just 30 - 40 years ago. Some of these ditches are now far above the field level. Another way to gage soil loss is to consider the number of times the ends of fields have to have soil removed so water in the furrows can reach the end of the field. The furrow erosion process is slow. For example, a field that has lost 2 ft of top soil in the last 40 years, lost only about ½ inch each year. This amount of loss would go unnoticed without a permanent structure, like a concrete ditch, to compare to. Even though the process is slow, the top soil is gradually being removed and fields are becoming less productive.

METHODS TO CONTROL SOIL EROSION

Center Pivots should not have runoff and soil erosion due to irrigation unless there are design problems. If intake rate is of concern under a pivot, consider some type of soil tillage to increase the rate of water infiltration. If infiltration cannot be increased, use tillage to create surface storage. Water that is stored or puddled on the soil surface can infiltrate into the soil at a later time. Another practice is conservation tillage which leaves residue on the soil surface. During irrigation or rainfall the residue will take part of the energy out of water droplets that otherwise would break down soil structure and reduce infiltration. The soil infiltration rate also increases by having residue mixed in the surface soil. In this situation, the residue helps maintain open pores for water to infiltrate. Similar to tillage, residue can also increase surface storage capacity by stopping the flow of water.

Of equal importance is evaluation of the sprinkler package. For low pressure systems, it may be necessary to use a different sprinkler or increase pressure. These changes will allow water to be applied over a larger area thus reducing the application rate. For more information on controlling irrigation runoff from center pivots and the associated water loss from different sprinkler packages, see *Water Loss from Above-Canopy and In-Canopy Sprinklers,* NebGuide G97-1328 and *Application Uniformity of In-Canopy Sprinklers,* NebGuide G97-1337.

Vegetative filter strips on the edge of the pivot can also slow runoff and prevent soil erosion. Although filter strips can prevent soil from moving off of a field, it still allows soil to be moved to the edge of the field. See NebFact NF97-352 *Vegetative Filter Strips for Agriculture,* for more information on using filter strips.

Furrow Irrigation. A number of things have been tried or introduced to help reduce the amount of sediment being lost with furrow irrigation. Some research has involved putting straw or growing grass in the furrows to slow the water and keep sediment on the field. Conservation tillage, like with center pivots, slow the water down in the furrow and can reduce soil loss. Although for many irrigators, slowing water advance, especially during the first irrigation, is not advantageous. These procedures can help reduce sediment loss but they also impact the efficiency of irrigation.

WHAT IS POLYACRYLAMIDE?

Polyacrylamide or PAM is a long chain polymer that acts as a strengthening agent to bind soil particles together. With particles held together, water can no longer easily move the larger and heavier particles of soil. USDA researchers in Kimberley, Idaho began working with PAM in the early 1990's. They worked with PAM as a method to reduce erosion in furrow irrigation. Tests in Idaho have shown soil erosion in furrows to be reduced by over 95% when compared to irrigation without the polymer added. Polyacrylamide can be purchased both as a dry material or in a liquid formulation.

WHAT ARE THE BENEFITS OF PAM?

Benefits of using polyacrylamide may go beyond erosion control. If the soil in the furrow can be held in place, this means more water can be put down individual furrows without causing erosion. Getting water to the end of the field can be difficult. The ability to put more water in the furrow without having erosion can reduce furrow advance time and improve irrigation performance.

Holding the soil in place can also be a big advantage when furrows are small or the soil is loose from cultivation. In many cases furrows are eroded at the top of a field. As water moves down the field less water is in the furrow so the water advance slows. As the water slows, the ability of water to carry soil particles is reduced and soil begins to settle to the bottom of the furrow. In another case a field may have more slope at the top of the field than at the bottom. The faster moving water at the top of the field erodes the soil. When the water in the furrow slows in the flatter portion of the field sediment begins to settle out. In these cases, as sediment continues to be deposited, the furrows get shallower. This can sometimes occur within one irrigation and in other cases it may take several irrigations. Either way, the result is the furrow eventually fills with soil and water begins to flood adjacent rows. Furrow identity in the lower portion of the field can be completely lost which can impact irrigation performance and yield. The use of PAM can reduce this problem by not allowing the soil to erode. Furrows can be maintained both at the top and bottom portions of the field.

Using polyacrylamide has also been shown to increase the intake rate of some soils. This occurs as a result of the soil particles binding together. Small particles are not dispersed as with normal irrigation when they are carried in the water to block larger pores. During the first irrigation soil intake rate is normally high. If using PAM causes an increase in the intake rate of the soil, changes in water management must be made. For example, increasing furrow stream size is needed to account for the increase in the intake rate of the soil so water advance remains acceptable. See *Managing Furrow*

Irrigation Systems, NebGuide G91-1021 for more information on advance time and stream size selection for efficient furrow irrigation.

Soil erosion can occur in furrows even though only small stream sizes are used. As the season progresses, the furrows become narrow deep channels that carry the water. In some cases these narrow channels can be 12-18 inches deep or more. When this occurs, water is being applied at a 12-18 inch depth below the most active portion of the root zone. Without a constant source of water, it is difficult to move water up in the soil profile. The result can be plant water stress for any crop but especially for shallow rooted crops like dry beans and soybeans.

APPLICATION OF POLYACRYLAMIDE

If adding PAM to an open ditch, keep the point of discharge at least 2 ft away from the water. If turbulence in the water is causing splashing, move the applicator far enough away that water does not contact the container. Small droplets of water can cause the PAM to clog and stop flowing. Another concern with using PAM is the type of water being used for irrigation. If the water source is filled with sediment, it is possible to settle out the sediment before the water is diverted into furrows. Although this does not affect the effectiveness of the PAM, it could cause a sediment buildup in the head ditch or gated pipe.

Pam should be applied at a rate of 10 ppm. Again, different soil types react differently. It is possible to get good erosion control using a lower rate but higher rates may be needed for other soils.

Before the water with PAM is applied to the soil, make sure it has been mixed with the irrigation water well. In an open ditch, let the water pass over at least one drop or some obstruction in the ditch that will cause turbulence before water is diverted into the furrows. In some cases you may have to create the drop in order to mix the material in the water. In gated pipe, the swirling action in the pipe will generally cause enough mixing within the first 2-3 joints of pipe.

Having the PAM mixed with the water well is important to get maximum effectiveness. This means that before the gates are opened or the tubes are set, the PAM must be mixed in the water. This will cause the soil particles in the upper reaches of the furrows to be bound together and less susceptible to erosion where stream flow is the highest.

The furrow is considered treated once the water reaches the end of the field. Additional polymer is normally not required for that irrigation. In many cases producers are finding that applying PAM only during the first portion of the irrigation provides adequate protection and reduces erosion to acceptable levels.

If cultivation or ditching occurs after PAM has been applied in a furrow, its

effectiveness in controlling erosion is essential lost. After cultivation, it is recommended to reapply PAM. Although the PAM does not remain all season long, there is some erosion control benefit for the irrigation following application. This again will depend on soil type, field slope and irrigation furrow stream size.

RESEARCH RESULTS

Research has been conducted at the Panhandle Research and Extension Center in Scottsbluff in both 1996 and 1997. Furrow stream size was approximately 12 g.p.m. Field slope was only 0.2% and field length was 1000 ft. The soil was a Tripp very fine sandy loam. The crop grown was dry beans in 30 in. rows with every other row irrigated. In both years furrow advance time to 1000 ft and the sediment loss (tons/ac) were measured

In 1996, three treatments were tested PAM, no PAM and patch PAM. The patch PAM treatment was sprinkling PAM in the dry furrow before water was started. Advance time was similar for all treatments. The amount of soil loss was greatest for the no PAM treatment and the least for the PAM treatment. The patch PAM treatment, although providing some reduction in erosion, was not as effective as the PAM treatment.

Four treatments were compared in 1997, PAM, no PAM, surge with PAM and surge with no PAM. Advance time to 1000 ft was similar for all four treatments during the three irrigations. However, the advance times for the treatments using PAM were slightly below the advance times for the treatments with no PAM.

If a producer is using surge and tries PAM, particular attention should be paid to furrow advance time. Surge irrigation through its wetting and drying process tends to seal the surface of the soil and reduce intake rate. This in turn advances water down the field faster. On the other hand, on many soils PAM tends to increase intake as a result of maintaining open pores on the soil surface.

CONCLUSIONS

Polyacrylamide can control soil erosion that occurs while furrow irrigating. However, like many farming practices, its use and effectiveness can vary from field to field based on slope and soil type. The use of PAM is relatively new and will require individuals to try different things until recommendations can be developed for specific soil textures and field slopes.

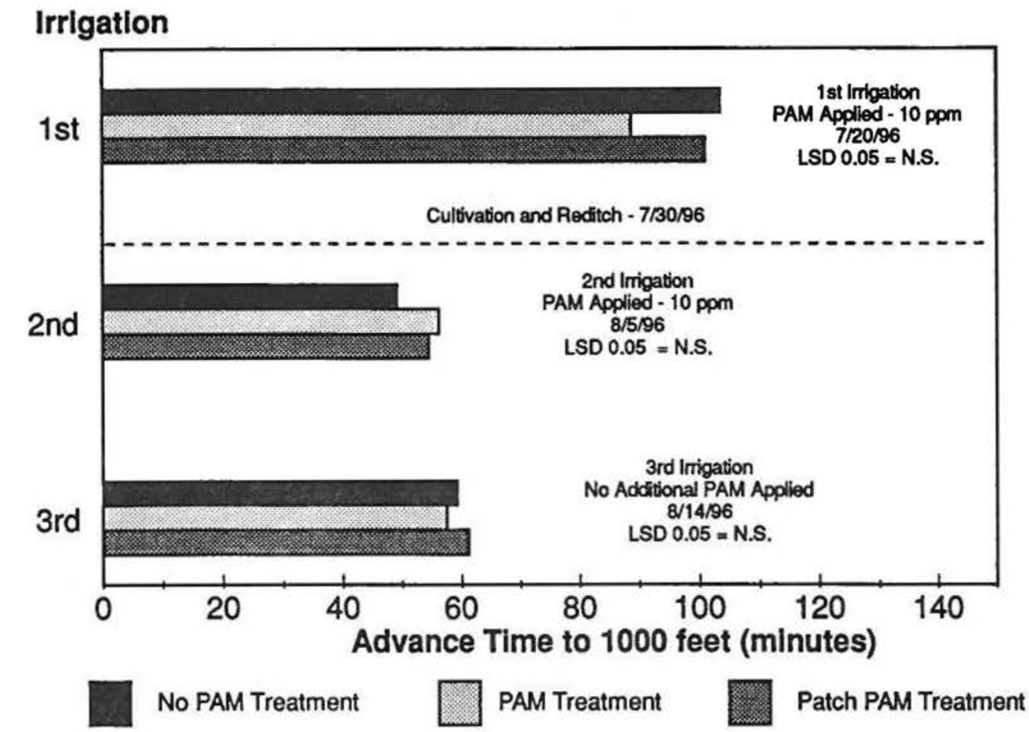

Figure 1. 1996 Furrow advance time to 1000 feet for each irrigation , treatments of no PAM, PAM, and patch PAM.

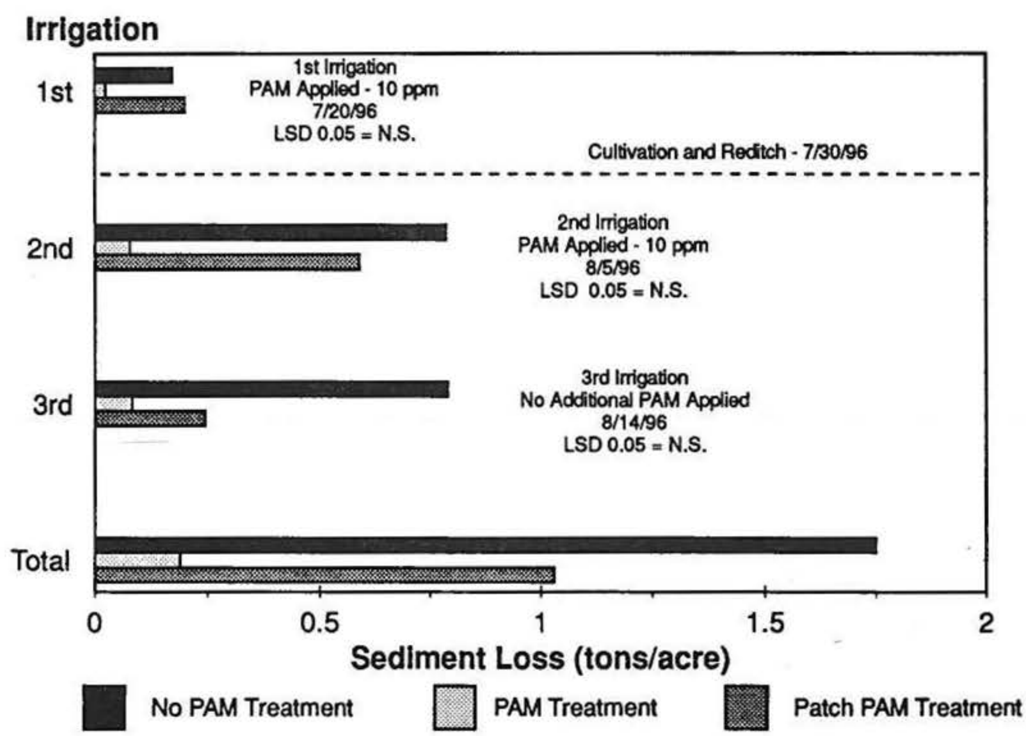

Figure 2. 1996 Sediment Loss (tons/acre) for each irrigation and total sediment loss (tons/acre) for treatments of no PAM, PAM, and patch PAM.

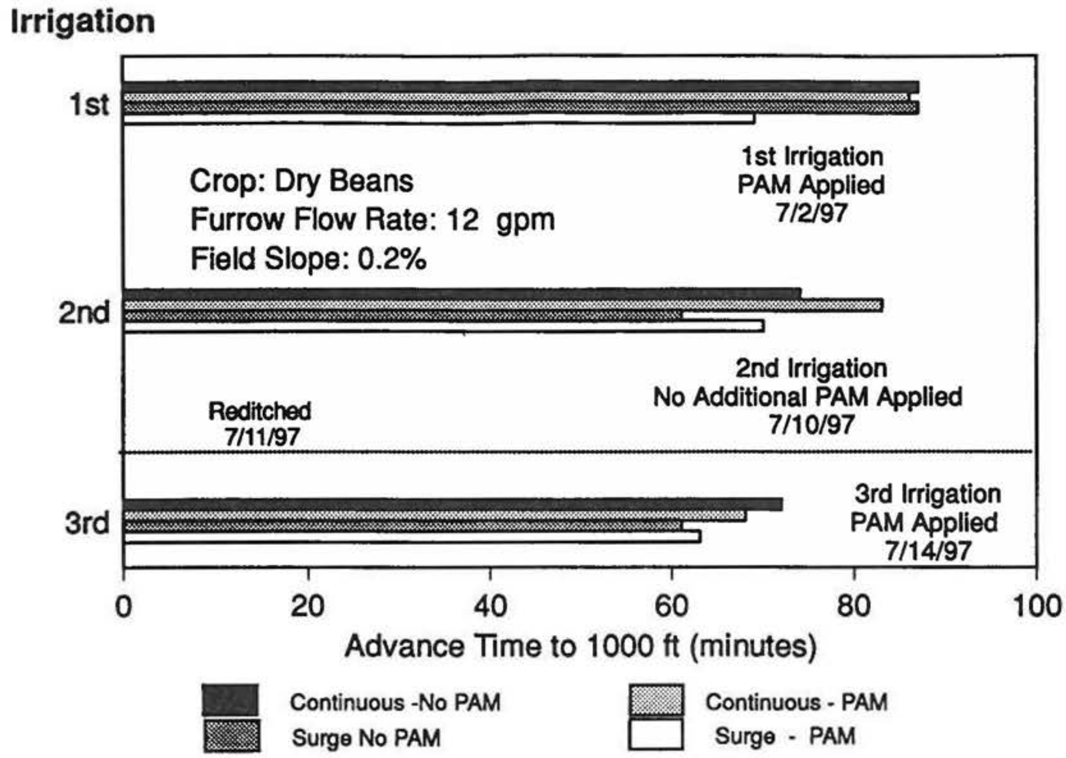

Figure 3. 1997 Furrow advance time to 1000 feet for each irrigation , treatments of no PAM continuous irrigation, PAM continuous irrigation, no PAM surge irrigation and PAM surge irrigation.

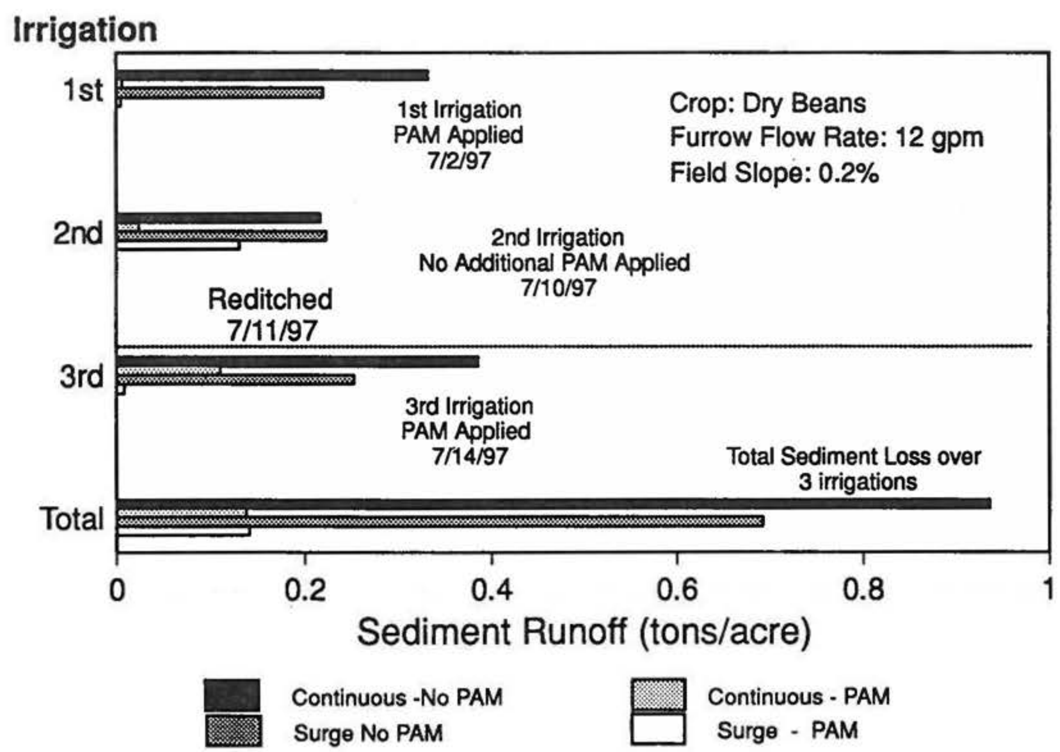

Figure 4. 1997 Sediment Loss (tons/acre) for each irrigation and total sediment loss (tons/acre) for treatments of no PAM continuous irrigation, PAM continuous irrigation, no PAM surge irrigation and PAM surge irrigation.