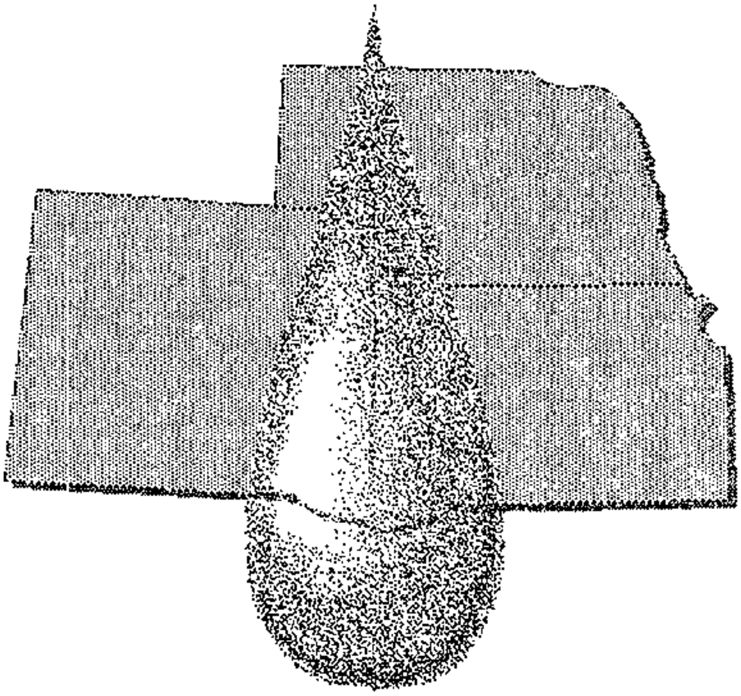
Central Plains Irrigation
Short Course & Exposition
Proceedings



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Endangered Species Act / Recovery Drives
Platte River Cooperative Agreement

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Executive Summary

On July 1, 1997, Nebraska, Colorado, Wyoming and the United States Department of the Interior entered into a partnership to develop a basin-wide recovery "program" for threatened and endangered species in the Central Platte River Basin. The program's primary purpose is to provide recovery oriented habitat and water for the whooping crane, piping plover and the interior least tern. The pallid sturgeon, which uses the Platte only near its mouth, is also a target species for the proposed program. For now it is uncertain what types of efforts if any will be directed specifically towards sturgeon recovery.

Each party entered into the agreement voluntarily and each could opt out at any time. The proposed program takes a phased, adaptive management approach and has three primary components; the Water Action Plan (WAP), the Depletion Plan, and a Habitat Plan. The WAP is designed to put "new water" into the river *(water that would not normally be there, **at that time**)*. Water goals for the program relate to "target flows", which have been identified by the USFWS. The Depletion Plan is designed to prevent increased shortages to target flows caused by new or expanded uses of water. New uses that contribute to target flow shortages would be subject to mitigation, either with water or with dollars that could be used to produce water. The Habitat Plan has a first increment goal to develop and/or protect at least 10,000 acres of terrestrial habitat between Lexington and Chapman. This habitat would be acquired from willing participants via leasing, conservation easements, and (as a last option) through purchase. Focus would be placed on riverine and wet meadow type habitat.

Nebraska has undertaken a comprehensive study called the Cooperative Hydrology Study (COHYST), to determine to what extent ground water is hydrologically connected to surface water and how new ground water uses adversely effect the Platte and it's tributaries. Nebraska and the other states will also contract for a study to determine how improving flows to better meet target flows with "new water" or otherwise might impact sediment load and transport, and what (if any) effect that might have on the depth and width of the streambed.

A Draft Environmental Impact Statement for the proposed program is to be released in early 2002. One of the alternatives to be considered in the draft EIS is the proposed "program". Another is called the "No Action" alternative, which is basically no "program". Under the "No Action" alternative the obligation for overcoming adverse effects rests with individual citizens and water project operators instead of with the "program".

Sometime in late 2002 or early 2003, Nebraska will be presented with a "program" document and with a decision about whether to sign on. The best we can do until then is to stay informed, as this program is being drafted and revised continually.

Introduction

Nebraska, Colorado, Wyoming and the United States Department of the Interior have entered into a partnership to develop a basin-wide recovery program for threatened and endangered species in the Central Platte River Basin. The program's primary purpose is to provide recovery oriented habitat and water for the whooping crane, piping plover and the interior least tern. The pallid sturgeon, which uses the Platte only near its mouth, is also a target species for the proposed program. For now it is uncertain what types of efforts if any will be directed specifically towards sturgeon recovery.

The "Cooperative Agreement" (CA), or the "agreement to try to reach and agreement" on a basin wide recovery program, was signed on July 1, 1997 by the Secretary of Interior Bruce Babbit and the Governors of Nebraska, Colorado, and Wyoming. Each party entered into the agreement voluntarily and each could opt out at any time

The proposed "program" takes a phased, adaptive management approach. Adaptive management means that initial actions may be modified as determined by the results of those actions. Assuming the cooperating partners agree to the terms of the program, the first phase is expected to be 10 to 13 years in length. A ten-member governing body call the Governance Committee (GC) has been responsible for the activities undertaken to date. The GC includes representatives from the U.S. Fish and Wildlife Service (USFWS), the U.S. Bureau if Reclamation, each of the three states, water users from three geographic areas in the Platte River Basin, and environmental organizations. Dale Strickland of West Inc., an environmental consulting firm out of Cheyenne, WY is the acting Executive Director. The Executive Director is responsible for assisting the parties in developing the different elements of the proposed program. The proposed recovery program has three primary components; Water Action Plan, Depletion Plan, and a Habitat Plan. Following is a brief description and the current status of each.

Water Action Plan (WAP)
The USFWS has identified target flows for the endangered species in the Central Platte; i.e. flow levels the USFWS believes are needed to provide adequate habitat for those species. These flows would be measured at Grand Island. The USFWS believes that actual annual flows currently fall short of those target flows by an average of approximately 417,000 acre feet (af) per year. To put this into perspective, one cubic feet per second (cfs) of river flow is equal to approximately 2 af per day, so a flow of 570 cfs would result in a daily total of 1,140 af, which would result in an annual total of 416,100 af. There is some disagreement on whether the identified target flows are biologically or hydrologically necessary or even beneficial to the habitat and/or recovery of the species. The USFWS is willing to review and possibly revise the target flows, as better science becomes available.

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 an average of 130,000 to 150,000 af per year. Three projects already being implemented by the three States will produce an estimated 80,000 af per year. The first project is an "environmental account" (EA) in Lake McConaughy, where 10% of the storable inflows between October and April are available to be stored, managed and released in a manner to reduce shortages to target flows. There is a cap of 100,000 af that can be stored annually and a carryover limit of 100,000 af, leaving a 200,000 af total storage cap. The year 2000 was the first year of operation for the EA and favorable weather resulted in a 137,000 af balance to start the water year. In June of 2000 the USFWS released the first EA water out of Lake McConaughy and because of very dry conditions, releases continued throughout most of the summer, usually at a rate of 400 to 550 cfs. The EA release total for water year 2000 (Oct 1, 1999 to Sept. 30, 2000) was 82,810 af. After seepage and evaporation losses were factored in the EA balance at the end of September, 2000, was 44,026 af.

The second project is an enlargement of Pathfinder Reservoir in Wyoming. Water from that project will be managed with a similar objective. The third project is the Tamarack Project in Colorado. The Tamarack Project would take water out of the river during times of excess flows (most often during the winter months) and temporarily store it in shallow alluvial aquifers where it would naturally return to the river at times when flow shortages are most likely (in the summer months). Tamarack is under construction and currently is partially operational, while Pathfinder is still in the planning stages.

The additional 50,000 to 70,000 af necessary to realize the 130,000 to 150,000 af goal for the first increment will be obtained through other projects. These projects will be selected throughout the basin, implemented through out the remainder of the program, and must be acceptable to the representative states.

These projects are most likely to be storage and retiming and/or conservation oriented.

A Draft Water Action Plan which lists the projects now proposed was completed in September, 2000, and will be revised as necessary. Inclusion of projects in the WAP simply means that they will be advanced to the feasibility level of study to undergo further analysis (i.e. economic and social impacts etc.). Changes are likely before final decisions are made. Finally, participation in these projects by entities or individuals is intended to be voluntary and incentive based, so similar to state participation in the program in general, a participant could participate in and/or opt out of projects at their discretion.

Projects proposed for Nebraska at the present time include: (1) small storage and retiming reservoir(s) located on or near the supply canal for Central Nebraska Public Power and Irrigation District (CNPPID) somewhere between Brady and Lexington, (2) water rights leasing, (3) agriculture related water management incentives, (4) management of the Gosper, Phelps and Kearney County ground water mound, (5) drainage cutoffs located in the Tri Basin NRD, (6) Dawson and Gothenburg Canal groundwater recharge in Dawson County, (7) power interference (retaining water instream that would otherwise be released for off season hydropower production, and (8) additional environmental account water from CNPPID's system (attained from conservation measures already being implemented).

Sediment

Flowing water by nature needs to carry sediment. In many storage and retiming type projects the sediment has settled out and the water released is sediment "hungry". This sediment hungry water will then get the required sediment from wherever it can, many times from the streambed and/or bank. There is some concern as to how improving flows to better meet target flows with "new water" or otherwise might impact sediment load and transport, and what (if any) effect that might have on the depth and width of the streambed. Nebraska and the other states will contract for a study to determine what impacts might be associated with augmenting current flows.

Depletion Plan

While the WAP is designed to put "new water" into the river *(water that would not normally be there, **at that time**)*, the Depletion Plan is designed to prevent increased shortages to target flows caused by new or expanded uses of water. New uses that contribute to target flow shortages would be subject to mitigation, either with water or with dollars that could be used to produce water. A new depletion is defined as – new or expanded water related activities begun on or after July 1, 1997, including new or expanded uses of surface water or hydrologically connected ground water which adversely affect Platte River target flows in the Lexington to Chapman reach or which adversely effect at least some water right holders above Chapman. Remember, the overall goal of the program is to reduce shortages to target flows. Each state is responsible for developing it's own depletion plan and Nebraska is still working on it's plan.

Nebraska has undertaken a comprehensive study called the Cooperative Hydrology Study (COHYST), to determine to what extent ground water is hydrologically connected to surface water and how new ground water uses adversely effect the Platte and it's tributaries. The first results of this study are expected to become available sometime towards the end of 2001.

A brief overview of Nebraska's current *New Depletion* proposal follows:

- uses prior to 7-1-1997 would be grandfathered (this is written into the July, 1997 CA document)
- the "State" would assume mitigation responsibility for new uses begun from 7-1-1997 to 12-31-2003
- the user would assume at least part of the mitigation responsibility for new uses begun after 12-31-2003, with the state potentially picking up the remainder
- mitigation would be required on qualifying uses that reduce flows **during times of target flow shortages**
- mitigation would be in water or in dollars which would be used to produce water
- the need to mitigate would be based on "consumptive use" so, replacement wells for similar acres and similar crops would not be "new" uses
- would apply to all new uses: agriculture, industrial, and municipal

Where will mitigation water or dollars come from?
Projections show that some of the WAP projects located in Nebraska should produce more water than Nebraska is proposing to contribute to the "program" water account. To what extent the extra water produced by these projects would be used to offset new depletions for which the state would assume full responsibility (those begun between 7-1-1997 and 12-31-2003) and to what extent this water would be used to offset new depletions begun after 12-31-2003 has not been determined.

Water rights leasing and water banking
Water rights leasing and water banking are a couple of other potential ways to secure water for offset purposes. Legislation does not exist in Nebraska right now for either, but was proposed and probably will again be proposed in a future session. Water leasing is simply what it would imply. One could obtain or transfer the use of or the right to use X amount of water at X price. A water bank would simply be an entity that would serve the same function as the bank you write your checks on – except it would hold (on paper) and do the accounting of water – sort of a water broker. If a party needed offset water for a new depletion, they could go to the water bank and buy water from the bank to offset the new depletion. Deposits into the bank could result from retiring an existing use or reducing a consumptive use. Again, willing participant, in this case willing buyer,

willing seller would be the rule. The water bank could potentially be managed by an NRD, an irrigation district, the state or a newly created institution.

Land Component

Terrestrial 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 terrestrial riverine habitat between Lexington and Chapman. This, however could change as a result of adaptive management. The goal for the first increment of the proposed program would be to develop and/or protect at least 10,000 acres. NPPD's Cottonwood Ranch property located between Overton and Elm Creek (2,650 acres) has been dedicated to the program. This leaves an unmet first increment need of 7,350 acres. This habitat would be acquired from willing participants via leasing, conservation easements, and (as a last option) through purchase. Focus would be placed on riverine and wet meadow type habitat.

The Platte River Whooping Crane Maintenance Trust, the Nebraska Game and Parks Commission, the Nature Conservancy, and the Audubon Society currently own 9,000 to 10,000 acres of potentially eligible habitat. Eventually, those holdings are expected to contribute to meeting the 29,000 acre goal, but they will not count toward the 10,000 acre first increment goal.

NEPA Review

The National Environmental Policy Act (NEPA) requires that any federal agency prepare an Environmental Impact Statement (EIS) when proposing a major action which could cause significant environmental impact. A Draft Environmental Impact Statement for the proposed program is to be released in early 2002. It will evaluate a number of alternatives and identify a *Preferred Alternative*. A comment period will follow (usually around sixty days), and the Final EIS, which must address all written comments, will then be released. The goal for release of the official *Record of Decision* by the Department of Interior is late 2002 or early 2003, it will then be presented to the Secretary of Interior for his or her signature. Each of the three States will also be assessing the proposed program and making a decision whether it should be approved. With this timeline, the States would have a proposed program document to serve as an impetus for related/required 2003 legislative activity. A Cooperative Agreement to implement a program would be signed by June 30, 2003. If required, the Governance Committee could extend the Cooperative Agreement (deadline) an additional six months.

One of the alternatives to be considered in the draft EIS is the proposed "program". Another is called the "No Action" alternative. The No Action alternative is not the "status quo". The USFWS has issued the opinion that the species are "in jeopardy". Consequently, some type of recovery oriented action will be required. The *No Action* alternative is basically no "program" or no basin-wide cooperative recovery effort. Instead of the obligation for overcoming adverse effects resting with the "program", individual citizens and water project operators would have to assume that responsibility under the "no action" alternative. With this comes individual Section 7 consultations on any activities with a federal "nexus". Nexus means connection or relationship. A Section 7 consultation is an evaluation to determine if the action has or potentially could have a negative impact on the endangered species. This would include any projects which utilize federal permits, dollars, expertise or any other type of assistance. Ag programs and irrigation projects could be affected, though the full extent of what may later be determined to have a federal nexus is not now known.

Bottom Line

The states (including Nebraska) have considerable work to do prior to deciding whether to implement a program. Funding availability as well as budget timetables are a common concern and Nebraska needs to finalize it's depletion plan. Affected NRD's will also play a major role in implementation, especially the new depletions plan and the boards of those districts will have difficult decisions to make.

As stated earlier "status quo" is not an option. Recovery efforts will be required by the USFWS. However, until a state officially signs the agreement it is not bound in any sense of the word to the actions outlined in the agreement. Even if a state signs the agreement it may opt out at any time if it concludes that continued participation is no longer in it's best interest. Some important questions to consider include: Are Nebraskans better off participating in a cooperative basin-wide recovery effort? Or would we be better off leaving the decisions to the US Fish and Wildlife Service? What actually will need individual Section 7 consultations if there is no program and how burdensome will the results be? To what extent will groundwater be involved? What impacts will meeting target flows have on sediment loads and ultimately the streambed and/or bank? There are many unanswered questions. The COHYST and sediment studies mentioned earlier will provide some very valuable information but it won't answer all the questions.

Sometime in late 2002 or early 2003, Nebraska will be presented with a "program" document and with a decision about whether to sign on. The best we can do until then is to stay informed, as this program is being drafted and revised continually. For more information on the CA including meeting schedules and locations try the internet at www.platteriver.org or for information and updates on COHYST try www.cohyst.org.

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Does Irrigation Improve Soybean Yields?

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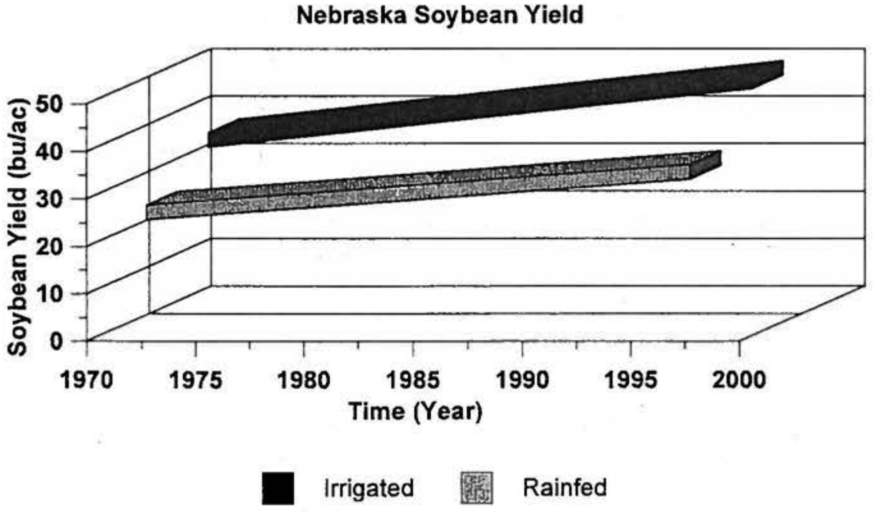
INTRODUCTION

In High Plains, areas once dominated by irrigated corn production are increasingly being replaced by corn-soybean rotations. As a result, soybeans now encompass a region with diverse soils and climate that require different irrigation management strategies.

To begin to answer the question posed by the title of this article, a bit of history may be useful. Research conducted by Specht et al., (2000) suggests an increasing trend in rainfed and irrigated soybean yield for the state of Nebraska (figure 1). Nebraska Ag Statistics data for average soybean yields were regressed for the period between 1972 and 1997.

Figure 1. Trend in Nebraska irrigated and rainfed soybean yields for 1972 -1997.



Note that the yield for irrigated soybeans is increasing at a rate faster than for rainfed conditions. The slope of the line is *0.52 bu/ac/yr* for irrigated soybeans and *0.37 bu/ac/yr* for rainfed conditions.

Though the yield data presented in Figure 1 concentrate on Nebraska results, similar trends have been experienced from Canada to Brazil. Specht et al. (2000) suggest that the increasing trend can be attributed to three factors: 1) an increase in CO_2 content of the atmosphere; 2) improvement in soybean genetics; and 3) improvement in the management of soybean production systems. Top yield claimed in the Nebraska irrigated category in 1997 was 99 bu/ac. They also present evidence that would place the maximum yield potential at about 120 bu/ac. Thus, the upward trend should continue for the foreseeable future.

SOYBEAN STAGE-OF-GROWTH & WATER USE RATES

With determinate varieties, vegetative growth ends at flowering. With indeterminate varieties, the later phases of vegetative growth overlap the early phases of reproductive growth. Though irrigation is usually required only during the mid- to late-reproductive stages, this overlap may mean some water will be applied during the later phases of vegetative growth. To help accurately identify soybean stage-of-growth during the most critical periods, soybean reproductive stages are described in Table I.

Table I. Reproductive stages of soybean plant development (Ritchie et al., 1994).

Stage		**Description**
Beginning Flower	R1	One flower at any node on the main stem.
Full Flower	R2	Open flower at one of the two uppermost nodes on the main stem with a fully developed leaf (nodes with fully developed leaves are those that are below a node with a leaflet unrolled to the extent that its edges are not touching).
Beginning Pod	R3	Pod is 3/16 inch long at one of the four uppermost nodes on the main stem with a fully developed leaf. It is not uncommon to find developing pods, withering flowers, open flowers and flower buds on the same plant.
Pod Development	R4	A pod 3/4 inch long at one of the four uppermost nodes with completely unrolled leaves.
Beginning Seed Fill	R5	The presence of bean seeds (felt when pod is squeezed) in pods at one of the four uppermost nodes with completely unrolled leaves.
Seed Fill	R6	A pod with full-size green beans (bean is full size when it fills pod cavity) at one of the four uppermost nodes with completely unrolled leaves.
Beginning Maturity	R7	One normal pod on the main stem has reached its mature color, normally tan or brown.
Full Maturity	R8	Ninety-five percent of the pods have reached their mature pod color.

The total water use by a fully irrigated soybean crop (evaporation plus transpiration) ranges from 21 to 24 inches per year. About 65 percent of this water is used during the reproductive stages. The average peak crop water use rate, about 0.3 in/day, begins near the full flowering stage and continues through pod development. The average rate during the seed fill stage is about 0.25 in/day. However, daily crop water use rates can reach 0.35 to 0.40 inches under hot dry conditions. Figure 2 presents data that support the need for scheduling irrigation applications. The long-term average curve is smooth, climbing to about 0.3 in/day and then declines as the crop approaches maturity. Actual daily crop water use rates vary considerably from day to day based on the time of year and growth stage.

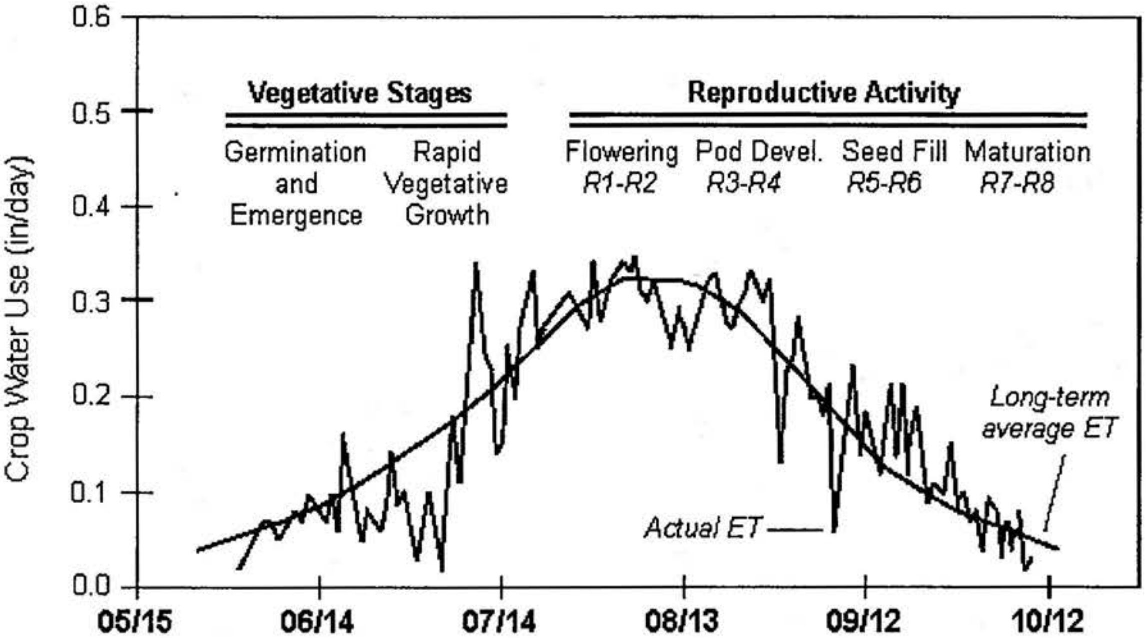


Figure 2. Long term average and actual soybean crop water use (ET) for one year based on day of the year and stage-of-growth.

Irrigation and/or high amounts of rainfall during vegetative growth are not normally beneficial except during periods when soil water levels are extremely low. Excessive water during the vegetative stage stimulates vegetative growth and increases the potential for lodging and fungal diseases with essentially no increase in yield. In some cases, excessive early season precipitation and/or irrigation can lead to yield reductions.

The most important times for soybean plants to have adequate available water are during pod development (R3-R4) and seed fill (R5-R6). Irrigation may also be required during the flowering stage on sandy soils or during very dry years on medium and fine-textured soils. However, if water is applied during flowering, it is important to follow with adequate water during seed fill. Otherwise, more but smaller seeds will develop, reducing yields.

Although soybean roots can reach depths of 5 to 6 feet, the largest concentration of roots and the majority of soil water extraction occur in the top 3 feet of the soil profile. Therefore, irrigation water management should concentrate on the top 3 feet of soil. Soybean produce highest yields on soils with good internal and surface drainage or a more common statement is '*soybeans do not like wet feet*'.

The most convenient way to time soybean irrigation is by using the crop stage-of-growth as an indicator. Stage-of-growth scheduling works well for crops like indeterminate soybean that respond well to water supplied during the later growth stages. However, stage-of-growth scheduling also depends on the capability of the irrigation system to supply sufficient water to the crop. Precipitation during the growing season, stored soil moisture prior to the growing season, and irrigation system capacity combine to furnish water to the crop.

RESEARCH RESULTS

1980's Nebraska Research

Research has shown that indeterminate soybean respond well to delayed irrigation. However, as rainfall and stored soil water decrease from east to west across the region, delayed irrigation can reduce yields when compared to full-season irrigation. To develop soybean irrigation best management practices (BMPs), research in Nebraska has focused on comparing full-season irrigation to stage-of-growth irrigation. In the early 1980's four irrigation treatments were evaluated across Nebraska at Tryon, North Platte, Clay Center, and Mead:

1. **Full-season (Full)**. If necessary, irrigation began prior to flowering to supply water according to the water use of the crop. Irrigations were scheduled in order to maintain the available soil water above the 50% depletion level in the active root zone.

2. **Full Flower (Flower)**. Irrigation began when a flower opened at a node immediately below the uppermost node on the main stem with a completely unrolled leaf *(R2)*.

3. **Pod Elongation (Pod)**. Irrigation began when a pod was 3/16 to 3/4 of an inch long at one of the four uppermost nodes on the main stem with a fully developed leaf *(R3-R4)*.

4. **Rainfed**. Water was applied only if needed for stand establishment.

Figure 3 illustrates the average relative yields compared to the Full-season irrigation treatment for Clay Center, North Platte, Tryon, and Mead based on the stage-of-growth when irrigation was initiated.

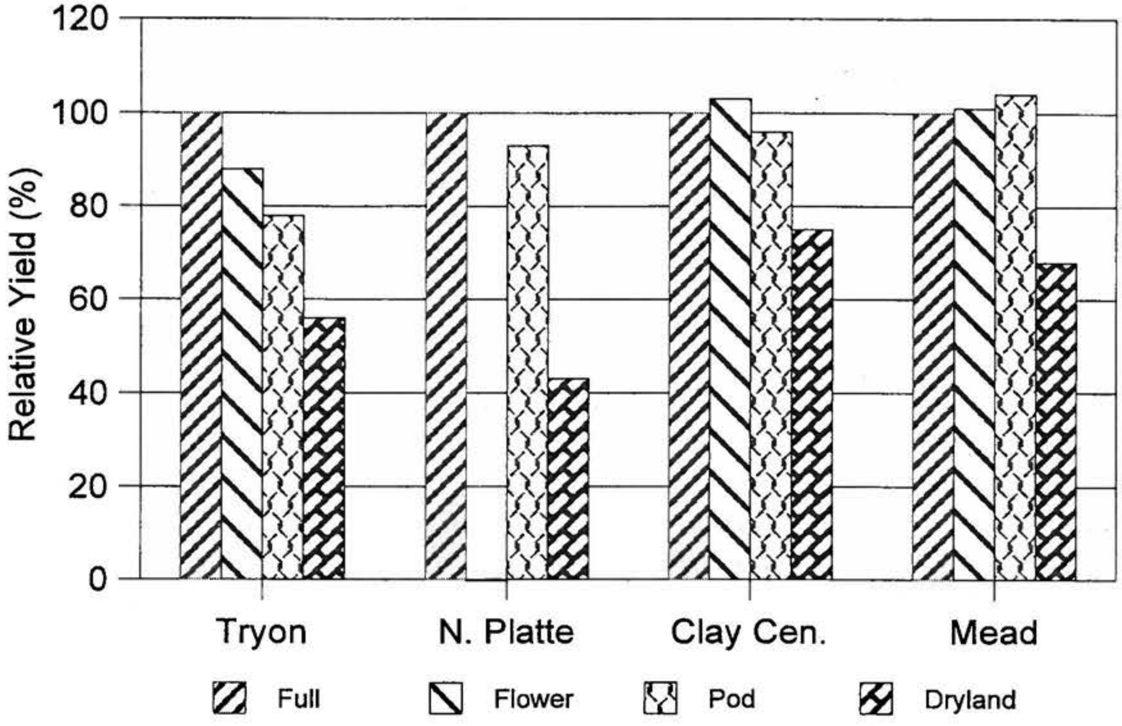


Figure 3. Relative yields for soybean irrigated at Flowering (R2), Pod development (R3-R4), and rainfed with respect to Full-season irrigation (*Full Flower treatment not tested at North Platte*).

Relative rainfed yields were greater at Mead and Clay Center than the two west-central locations. More precipitation before and during the growing season at the eastern locations increased the rainfed yields. Relative yields from the pod elongation treatments decreased from the eastern to the west-central locations. Soil water storage and rainfall were not enough to produce maximum yields from the pod-elongation treatment at the west-central locations; the pod-elongation treatment showed a positive yield response due to late-season water application at all locations. These data suggest that, for eastern Nebraska, a strategy of delaying irrigation until the pod-development stage will result in top yields. However, the data suggest that full season irrigation scheduling is necessary for soybeans grown in West and West Central Nebraska. Averaged across locations, the irrigation water use efficiency was 1.52, 1.35, and 0.95 bu/ac/in for irrigation treatments initiated at pod elongation, full flower, and full season irrigation, respectively.

1980's Kansas Research

Six irrigation treatments were evaluated at Colby,KS in the late 1980's. The approach taken was to replace a certain percentage of the estimated crop water use for the entire range of stage-of-growth. This allowed a range of available soil water contents to be evaluated. Two of the treatments had reduced irrigation during the vegetative stages and full irrigation during the reproductive stages.

The water budgets imposed between 1986 and 1988 for the six treatments were:

1. Full-season, 100% of ET
2. 75% of ET
3. 50% of ET
4. Rainfed
5. 75% of ET in vegetative stages and 100% of ET in reproductive stages
6. 50% of ET in vegetative stages and 100% of ET in reproductive stages

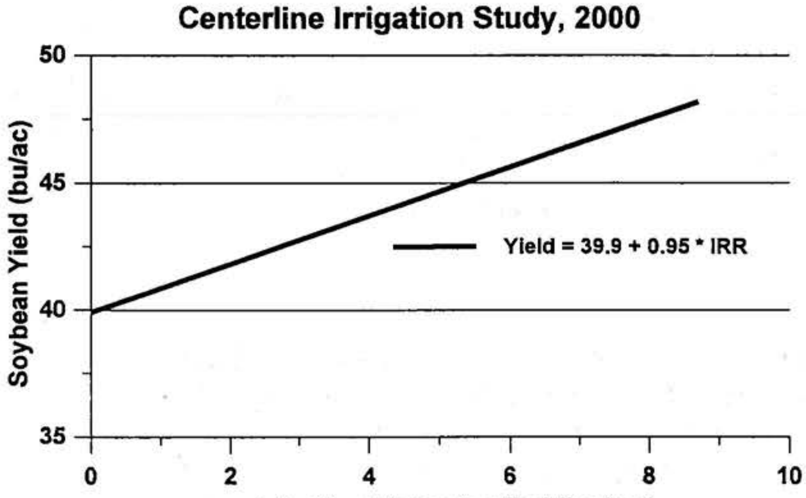
Yields for treatments receiving stress during the vegetative stages were equal or better than the 100% ET replacement treatment in 1986 and 1987 (Table 2). Significant savings in irrigation water pumped result from implementing Treatment 6 (50%/100%). However, in 1988 yields were depressed for both the Full-season and vegetative stage stress treatments. This is likely due to the severity of the stress that occurred in June of 1988. Accumulative ET for June of 1988 was the highest on record for the 17-year period in which estimates have been calculated. This coupled with less than 1.0 inches of rainfall resulted in severe stress.

This research shows that moderate stress during the vegetative stages can reduce irrigation pumping when compared to Full-season scheduling without a corresponding reduction in yield. However, managers must watch soil water contents during the vegetative stages to alleviate severe stress should it occur.

2000 Concord Results

In 2000, soybean irrigation tests were conducted at the Haskell Ag Laboratory near Concord, NE. The test delivered a range of irrigation application from rainfed to fully irrigated. A stationary towline like system was used to apply the water. The soils at the site were in the Nora-Crofton silt loams.

Figure 4. Soybean yield response to irrigation at Concord, NE in 2000.



Irrigation was initiated at the R3 stage of development. Irrigation was initiated to keep the soil water content in plots nearest the towline above the 50% available soil water content. Irrigation water application decreased with distance from the towline to cause water applications that ranged from rainfed to fully irrigated. These treatments would compare well with Treatment 5 of the Kansas research. Yield results are presented in Figure 4.

Yields ranged from 40 bu/ac for rainfed soybeans to 47 bu/ac in plots receiving an average of 8.7 inches of water. The slope of the line is 0.95 bu/ac/in of water. This number agrees well with the Full-season treatment discussed for research conducted in Nebraska in the early 1980's. Obtaining higher irrigation water use efficiencies is a function of the relative maturity of the variety and the growing season characteristics according to Specht et al., (2000). Thus, longer season varieties in the Group III or IV will have larger potential irrigation water use efficiencies than Group II or Group I. Consequently, yield boost expectations should be based on the relative maturity of the variety and how irrigation is managed during the growing season. And some seasons, Mother Nature has a lot to say about soybean yields.

Research Summary

Results of these and many other research efforts indicate that adequate water during the pod development and seed fill stages is critical to boosting irrigated soybean yields. Irrigation water use efficiencies are not as high as for corn and can be less than 1.0 bu/ac/in for shorter season varieties. Growing seasons that do not produce moderate to severe plant stress may not see much of a yield boost from irrigation. However, significant yield increases are possible if irrigation is used to alleviate severe plant stress during the reproductive stages.

RECOMMENDATIONS FOR COARSE-TEXTURED SOILS

Water management for coarse textured soils is more difficult than for medium-textured soils since there is less room for error in timing irrigations. Soils in this classification include fine sands, loamy sands and fine sandy loams. Generally, these soils have a low (less than 1.5 in/ft) available water-holding capacity, and some have root-restricting layers at shallow depths. The combination of low available water-holding capacity and shallow rooting results in a small soil water reservoir. The available water-holding capacity in a 3-foot active root zone will be 2.3 to 4.5 inches (Table 1). This low available water-holding capacity, coupled with the fact that sprinkler systems will likely be the irrigation used, means light, (0.5 to 1.0 inches), frequent water applications are necessary to recharge the limited soil water reservoir.

The general recommendation for water management on coarse-textured soil is to allow no more than 50 percent depletion of the available soil water in the top 2 feet during flowering (R1-R2) and no more than 50 percent depletion in the top 3

Table 2. Summary of soybean response to irrigation water studies from the KSU Northwest Research-Extension Center, 1986-1988.

	Soybean	**Yield**	**(bu/ac)**		
	1986	1987	1988	Mean	IWUE
Full-season	57.7	49.7	64.4	57.3	2.41
0.75 * ET	56.4	48.2	54.3	53.0	3.00
0.50 * ET	39.9	40.3	32.2	37.5	3.41
Rainfed	26.3	29.0	21.7	25.7	------
0.75V - 1.0R	59.7	48.5	55.6	54.6	2.49
0.50V - 1.0R	59.5	51.7	42.9	51.4	2.51
LSD (0.05)	10.7	5.3	9.9		
	Net	**Irrigation**	**(inches)**		
Full-season	15.5	11.1	12.7	13.1	
0.75 * ET	10.2	7.2	9.8	9.1	
0.50 * ET	3.6	3.5	3.2	3.4	
Rainfed	-----	-----	-----	-----	
0.75V - 1.0R	10.8	11.4	12.5	11.6	
0.50V - 1.0R	10.4	9.9	10.3	10.2	

feet during pod elongation (R3-R4) and seed fill (R5-R6). Soil water levels can be determined by combining the appearance and feel method with soil water-balance calculations using reliable evapotranspiration estimates.

RECOMMENDATIONS FOR DEEP FINE-TEXTURED SOILS

These soils (silt loams, silty clay loams, silty clay) generally have an available water capacity of more than 1.5 inches per foot. The available soil water at field capacity is between 4.5 and 6.0 inches in the top 3 feet. Applying irrigation water when the available soil water is depleted to 50 percent in the top three feet of the root zone after the full flower stage (R2) will generally result in maximum yields. The same methods mentioned for the sandy soils can be used to estimate soil water in these soils.

An alternative scheduling approach on deep- and fine-textured soils is stage-of-growth scheduling. This method works if the soil water reservoir is at

9

or near field capacity to 5 feet at planting time. In the eastern half of Nebraska, this usually occurs if the soils were irrigated during the previous season and there was sufficient off-season precipitation to refill the profile.

For soybeans, between 10 and 11 inches of water are required from full flower (R2) to beginning maturity (R7). Therefore, effective irrigation plus rainfall should equal about 3 inches during full flower (R2), 3 inches during pod development (R3-R4) and 4.5 inches during seed fill (R5-R6). With adequate rainfall, optimum yields will be obtained with two, 3-inch net or effective furrow irrigations (typically at full flower or pod development and beginning seed fill). With systems such as center pivots applying smaller amounts of water per irrigation, it will be necessary to make two to four revolutions to apply the desired 3 inches during a particular growth stage. In dry years, an additional 3 to 5 inches of effective irrigation may be required.

If irrigation is started or unusually significant rainfall occurs during the beginning flower stage (R1), it is especially important adequate soil water (50 percent available soil water or greater) be maintained during the remainder of the growing season. If you are limited in the amount of irrigation water you can apply during the season, you will get the maximum benefit of this water if it is applied during the pod development (R3-R4) and seed fill (R5-R6) growth stages. However, when the rainfall is below normal during the vegetative and flower stages, a yield reduction may occur.

With furrow irrigation systems, it is generally not advisable to wait until pod development (R4) before applying the first irrigation, as this will probably cause extremely dry furrow conditions, making it difficult to get water through the field. An earlier irrigation date, perhaps beginning during the full flower stage, is advised. Individual effective irrigation applications should not exceed 3 inches.

Because precipitation decreases from east to west across Nebraska, a full soil water reservoir may not exist at planting time in the western half of the state. In this region, delaying irrigation until pod development may result in yield reductions when compared with full-season irrigation.

SUMMARY

When irrigating soybean in Nebraska:

1. Stage-of-growth irrigation scheduling for soybean should be limited to deep medium- to fine-textured soils. If soil water is at field capacity at planting, irrigation can be delayed until full flower (R2) and perhaps as late as beginning pod (R3).

2. If one or more of the following exists, irrigation should be scheduled according to soil water depletion and depletions should not exceed 50 percent:
    a. Soil texture is sandy loam or coarser
    b. The root depth is impeded (shallow, limits available soil water)
    c. Irrigation system capacity is 1.5 inches per week or less

3. Yield boost to irrigation will range from less than 1.0 bu/ac/in to 3.5 bu/ac/in depending on the relative maturity of the variety and the growing season characteristics.

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LIVING WITH LIMITED WATER IN SOUTHWEST NEBRASKA

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PROJECT SUMMARY

Since 1996, an irrigation management demonstration project has been underway in the Republican River Basin. This demonstration project is based on 30 years of UNL irrigation research in west central Nebraska. The purpose of the project is to demonstrate implications of alternative irrigation management strategies on water use and profitability. Six sites are included in the project. The sites range in soil type from silt loam to fine sand.

Improved management of irrigation may reduce irrigation water use while maintaining or even improving grain yields. Good irrigation management involves knowing crop water needs and making adjustments for the amount of rainfall and moisture stored in the soil. Increased use of stored soil moisture allows for more efficient use of precipitation and is a critical factor in reducing required irrigation water.

There are certain growing season periods, such as the vegetative growth and late grain fill stages where, in general, irrigation amounts can be reduced with little or no effect on grain yield. UNL research and demonstration sites have shown that seasonal irrigation amounts may be reduced by one or more inches per acre with no significant effect on yield. This work also shows, however, that when available water (irrigation plus rainfall plus soil water) is less than the crop's ET demand, yield may be substantially diminished.

Water holding capacity (WHC) of the soil plays an important role in the ability to reduce irrigation amounts without diminishing grain yields. Irrigation water can be reduced to a greater extent (with little or no yield effect) on soils such as silt loams and sandy loams, which have a higher WHC, compared to lower WHC soils, such as fine sands.

This Demonstration Project illustrates that, under certain conditions, there is a potential for reducing irrigation water with little or no decrease in net revenue, especially on silt loams. In many counties in the Republican River Basin, high WHC soils, like loams and silt loams, are prevalent or even dominant. Although over 50% of the soils in Dundy county are low WHC sands, Chase has nearly 50% loams and silt loams, and Perkins' soils are predominantly (over 60%) in the high WHC category. Other counties, such as Frontier, Red Willow, Furnas, and Harlan have over 90% of their soils classified as loams or silt loams.

This demonstration project was funded by the Bureau of Reclamation and Upper Republican Natural Resources District. Support was also given to the demonstration project by the Middle Republican, Lower Republican and Tri-Basin NRDs, the Natural Resources and Conservation Service, and the University of Nebraska Cooperative Extension. This demonstration project will continue through 2001.

PROJECT DESCRIPTION

Sites In 1996, sites near Arapahoe, Dickens and Elsie, Nebraska were selected for the project. Two additional sites were added in 1997 (McCook and North Platte), and one was added in 1999 (Benkelman). Four sites are irrigated with center pivot systems (Arapahoe, Dickens, Elsie and Benkelman) while two are furrow irrigated (McCook and North Platte). These sites have been used to demonstrate corn yield response to different irrigation management strategies. Tillage and cropping practices are those used by the farmer. Timing and amount of irrigation water use are the only variables changed at each of these sites.

Irrigation Management Strategies Four different irrigation management strategies have been conducted at each of these sites: current farmer management (FARM); university best management practices (BMP); late initiation (LATE); and limited allocation (ALLOC). The four strategies are as follows:

1. FARM – irrigation water is applied according to farmer's current management strategy.
2. BMP – includes bi-weekly soil-water monitoring, use of predicted crop water use (ET), and maintaining plant available soil-water (in the active root zone) in the range of 50% depletion and field capacity (minus a rainfall allowance during the vegetative and reproductive growth stages).
3. LATE – emphasizes water application during the crops reproductive growth stage. Irrigation is not applied until two weeks prior to tassel emergence for corn unless soil-water becomes 70% depleted during the vegetative growth stage. Once the crop reaches the reproductive growth stage, LATE is managed the same as BMP.
4. ALLOC – managed the same as LATE except only 10 inches of water per acre are allocated (6 inches for Elsie and Benkelman site). These allocations are applied during a period beginning with the reproductive growth stage and continuing into the grain fill growth stage (approximately five weeks).

For all management strategies, soil-water was monitored to a depth of 10 feet. End of season management targeted 60% depletion of soil-water in the root zone at crop maturity (i.e. black layer for corn).

OVERALL YIELD RESULTS AND ECONOMIC IMPLICATIONS

Table 1 shows average corn yields and irrigation water used at the four project sites with center pivots during 1996-1999 (only 1999 for Benkelman). The annual yields and irrigation water use were influenced by rainfall amounts at the sites. For the four sites, FARM and BMP average yields ranged from 188 to 201 bu/acre. Cooperators at these sites have historically been using amounts of irrigation water at or near BMP levels. This point is important because reductions in water use from BMP levels can significantly affect yields. The All Sites category (in blue) in Table 1 is the average of yields and applied water at the sites during the four-year period. Overall, the LATE strategy shows an average yield decline of 4 bu/acre (from FARM) with water savings of nearly 3 inches/acre. The ALLOC strategy saved over 4 inches/acre of water with an average yield loss of 16 bu/acre.

Figure 1 indicates, in general, how crop yield responds to increasing amounts of applied irrigation water. At lower levels of applied water (e.g. at level A) the response to an extra inch of irrigation water can be large. However, additional water can generate additional yield only to a point. When the curve levels off (applied water level C for the silt loam and D for the sand), yield is at a maximum and does not increase when more water is applied.

This "decreasing extra yield response" is common to all soil types, but the level of applied water use at which the curve becomes flat differs by soil type. This is due primarily to the varying water holding capacities of the soils. Because very sandy soils can store only about one inch of water per foot of soil from rainfall or irrigation, larger amounts of irrigation water are needed to reach maximum yield. The results from the Elsie and Dickens sites illustrate (see Table 1) how yield drops when irrigation water is reduced below ET requirements (e.g. at ALLOC levels). Yield reductions are most dramatic on the Valentine sands at the Dickens site. The Arapahoe site (silt loam), which experienced increases in yield when applied water was reduced, suggests that production under FARM and BMP may have been on the dotted downward section of the yield curve (level D in Figure 1). Reducing irrigation (from level D to C), in this case, increased yield.

A decrease in yield will reduce gross revenue, but the decline in revenue is somewhat offset by a reduction in pumping cost. Table 2 shows an example of the net returns to land, labor, and management for each site and management strategy. These returns were calculated with 1999 average operating costs for southwest Nebraska, a $2.00/bu price of corn, and a pumping cost of $2.50/acre-inch. A black number means the net return for BMP, LATE, or ALLOC is greater than the FARM net return for that site; a red number means net return is less than the FARM net return. Arapahoe and Benkelman, the two sites with the highest water holding capacities (see Table 1), had net revenue gains when applied water was decreased to the levels used for LATE and ALLOC, whereas Elsie and Dickens had net losses.

Also shown in Table 2 are the net returns averaged over the four sites and four years (All Sites). This broader look at the results indicates a net gain of $3.58/acre when BMP management is followed compared to FARM management. Although the LATE management strategy decreases average net return by about $.30/acre, three inches/acre of water are saved. The ALLOC strategy (which cut water use by almost 4.5 inches) reduced net return, on average, by about $18/acre. The net return effects of the ALLOC strategy shows what can happen when crop ET demands are not met. The average net return data in Table 2 are clearly affected by pumping costs and corn prices. For example, a net loss (from diminished yield) will be greater if corn prices rise, and will be less if pumping costs are higher.

SPECIFIC RESULTS FOR CENTER PIVOT SITES

Elsie The soil type at the Elsie site is predominantly a Woodly fine sandy loam with water holding capacity of about 1.5 inches/foot. Corn grain yields and irrigation amounts for 1996 to 1999 for all four irrigation management strategies are shown in Figure 2. Yields for FARM and BMP were similar each of the four years. The amount of irrigation applied to FARM was 0.7 and 0.6 inches more than BMP in 1997 and 1998, and equal to BMP in 1996 and 1999. FARM irrigation management tended to result in more water being applied during the vegetative growth stage while BMP applied more water during the reproductive growth stage. The application of more water during the vegetative growth stage by FARM was done to reduce the risk of crop stress. However, the BMP strategy increased soil-water use, which encouraged more extensive root development.

Yields for LATE and ALLOC were similar to BMP and FARM in 1996. In 1997 to 1999, grain yields for LATE were 10 bu/acre less than BMP and FARM. The savings in irrigation water applied when changing management from BMP to LATE ranged from one inch/acre in 1999 to 3.5 inches in 1996. Grain yields for ALLOC were about 40 bu/acre less than BMP in 1997 and 1998, and 25 bu/acre less than BMP in 1999. Reductions in the amount of irrigation water used for ALLOC compared to FARM ranged from 2 to 7.5 inches.

In 1996, precipitation and small amounts of irrigation during the pollination and grain fill growth stages met ET rates for the crop and no water stress was observed for either LATE or ALLOC. During June of 1996, precipitation and stored soil moisture met crop needs for LATE and ALLOC. Irrigation began in late June and ended during July when precipitation exceeded crop needs. In 1997, precipitation during June was more than crop ET during vegetative growth stage. This caused root development to be limited. Precipitation during July and August was below normal. As a result of these factors, water stress was observed during late August in

ALLOC, and resulted in a larger reduction in grain yield as compared to 1998 and 1999. During 1998 and 1999, little rain occurred during the vegetative and early reproductive growth stages. No precipitation occurred from June 10 to July 25 during 1998 and from July 2 to August 1 in 1999. These periods coincided with the greatest ET for corn. Severe water stress was observed in 1998 prior to tassel emergence for both LATE and ALLOC, while moderate water stress was observed in 1999.

In 1999, most of the LATE management field area yields were similar to BMP and FARM. However, the areas of the field with soil-water-holding capacities lower than the average WHC of the field had decreases in grain yield of 20 to 50 bu/acre. Variability in grain yield increased as water became limited with water management strategies such as LATE and ALLOC.

Benkelman The predominant soil type at the Benkelman site is a Jayem loamy sand with a water holding capacity of about 1.8 inches/foot. Grain yields for the irrigation management strategies in 1999 were 191 bu/acre for FARM, 199 bu/acre for BMP, 183 bu/acre for LATE, and 178 bu/acre for ALLOC. The amount of irrigation applied to each of the treatments was 7.8, 6.7, 5.5, and 3.5 inches/acre for FARM, BMP, LATE, and ALLOC, respectively. A portion of the area (approximately 5 acres) within LATE and ALLOC had a significant reduction in yield. A lower grain yield was also observed in this five-acre area in prior years. Grain yields for LATE and ALLOC were 188 bu/acre when adjusted to exclude the lower yields in these five acres.

Rainfall during June was adequate to meet crop ET. However, there was no precipitation during the first 30 days of July. The amount of soil moisture that was available to the crop was enough to meet ET needs for 18 days, with no crop stress observed for LATE and ALLOC.

Dickens The soil type at Dickens is generally a Valentine fine sand with a water holding capacity of 1.1 inches/foot. Corn grain yields and irrigation amounts for 1996 to 1999 for all four irrigation management strategies are shown in Figure 3. Grain yields and irrigation amounts for FARM and BMP were similar in 3 of 4 years. In 1997, grain yields for BMP were 28 bu/acre less than FARM. This yield loss resulted from not irrigating BMP, LATE and ALLOC at the four leaf growth stage. Water stress during that growth stage resulted in a yield cap (lower maximum potential grain yield) for BMP, LATE and ALLOC.

Grain yields in 1996 were similar for all water treatments. This was due to above normal precipitation during the reproductive growth stages starting in early July. When precipitation is above normal during the reproductive growth stage, reducing irrigation during the vegetative growth stage has little or no impact upon grain yield (although does save on pumping costs). With above normal precipitation in 1996, leaching of nitrogen fertilizer was observed by changes in coloration of the corn crop. After large rains, the vegetation began to appear as a lighter green. To alleviate the nitrogen stress the crop was fertigated, even though irrigation was not required to meet crop water needs. These fertigations applied approximately 2.5 inches/acre of water.

Grain yields for LATE and ALLOC were less than BMP and FARM in 1998 and 1999. Growing season precipitation in 1998 was below normal. Six inches of rainfall occurred in three separate events of 2 inches each. Much of this precipitation was unusable by the crop because of leaching beyond the root zone. With the low water holding capacity of a fine sand, both LATE and ALLOC treatments were under water stress for much of the vegetative growth stage. Irrigation was needed to prevent soil moisture from dropping below 70% depletion and to maintain some crop growth. Yields for LATE and ALLOC were 30 and 50 bu/acre less than BMP and FARM for 1998.

During 1999, precipitation was near normal in June, below normal in July and above normal during August. However, much of the precipitation that occurred in August was unusable since two of the precipitation events were greater than 3 inches. Most of the irrigation water (all treatments) was applied during July (7.4 inches/acre for BMP and FARM; 5.5 inches/acre for LATE and ALLOC). All treatments received an additional 1.5 inches/acre of applied water in May and June and 3.3 inches/acre in August and September. Grain yields for LATE and ALLOC were 10 and 25 bu/acre less than BMP and FARM.

Arapahoe The soil type at the Arapahoe site is a Holdredge silt loam with a water holding capacity of 2.0 inches/foot. Grain yields and irrigation amounts for 1996 to 1999 for all four irrigation treatments are shown in Figure 4. In 1996, grain yields for LATE and ALLOC were more than FARM and BMP. Precipitation during July and August was above normal and leaching of water occurred. Leaching occurred for all irrigation management strategies, but was greater in FARM and BMP because soil moisture was closer to field capacity in mid-July when above normal precipitation occurred. Soil samples were taken in the fall of 1996 for residual soil nitrate levels. Higher nitrate concentrations were found below 6 feet in FARM and BMP, as compared to LATE and ALLOC. Grain yields for all four irrigation treatments were similar for 1997 to 1999. However, irrigation amounts were reduced significantly by delaying irrigation during the vegetative growth stages. During 1997, irrigation water applied for FARM (15 inches/acre) was the highest of the four years. BMP management, with increased monitoring of stored soil moisture, reduced the amount of water applied to 12 inches/acre -- a savings of 3 inches/acre. Delaying irrigation during the vegetative growth stage as with ALLOC utilized stored soil moisture and precipitation more effectively and decreased the amount of irrigation applied by one-third as compared to BMP management.

In each of the four years, delaying irrigation until the reproductive growth stage (LATE and ALLOC) did not reduce grain yields compared to BMP.

SPECIFIC RESULTS FOR FURROW SITES

McCook The soil type at McCook is a Holdredge silt loam with a water holding capacity of 2.0 inches/foot. Irrigation practices at McCook were furrow irrigation with a surge valve. Irrigation management for BMP, LATE and ALLOC was irrigation of every other row with 12 hour set times. Management for FARM was irrigation of every row and a 24 hour set time. Grain yields and irrigation amounts are shown in Figure 5. Hail damage occurred each of the three years. Damage that also occurred in 1999 included green snap resulting in 25 to 40 percent loss of stand and herbicide damage due to the cool spring.

In 1997, grain yields for FARM management were 8 bu/acre more than that of BMP. However, the total amount of water applied on BMP was 12.5 inches less than that applied to FARM. Changing from every row irrigation to every-other row irrigation improved use of precipitation and reduced deep percolation. Reducing irrigation amounts below that of BMP diminished grain yields by 10 to 15 bu/acre, but saved 2.5 and 5 inches/acre of irrigation water for LATE and ALLOC, respectively.

Grain yields in 1998 for all treatments were similar to 1997. However, water savings for BMP compared to FARM were smaller. Water savings by using BMP were 4 inches/acre compared to FARM. Management of FARM was changed from irrigating every row to every other row. Several difficulties have been evident at the McCook site. They include short field lengths, low intake soils and moderate slopes on the field (greater than 1%). With these problems, excessive runoff has occurred. These problems will be addressed in future work.

North Platte The site at North Platte is a University managed research plot. Management treatments are BMP, LATE, ALLOC, and dryland. The soil type is a Cozad silt loam with a water holding capacity of 2.0 inches/foot. Corn grain yields and irrigation amounts are shown in Figure 6. Grain yields for BMP, LATE and ALLOC were similar for 1997 and 1999. This was due to adequate precipitation during the growing season. Higher than normal precipitation resulted in above normal dryland grain yields of 175 and 165 bu/acre for 1997 and 1999 respectively. Precipitation during 1997 was evenly timed and resulted in less water stress. In 1999, no precipitation was recorded during a 30 day time period during July. However, precipitation during August was above normal, as were dryland grain yields.

The greatest difference in grain yields between BMP, ALLOC and dryland occurred in 1998. Grain yields for BMP, ALLOC, and dryland were 216, 204, and 114 bu/acre, respectively. The yield response for the first 6 inches of water applied increased grain yield 90 bu/acre or 15 bu/acre on average for each inch of applied water. The yield response for the next 6 inches of water applied was 12 bu/acre or 2 bu/acre on average for each inch of water applied. In situations where the pumping costs are relatively high, the additional yield gained beyond that of ALLOC may not always pay for the cost of the additional water.

Acknowledgments

The authors of this publication would like to acknowledge their appreciation for the cooperation of the farmers involved in this demonstration project. Without their involvement, this project would not have happened.

Table 1. Four-Year Average of Corn Yields and Water Use by Management Strategy and Site.

			Management Strategy		
	Soil WHC[1]	FARM	BMP	LATE	ALLOC
Site	(in/ft)		Average Yields (bu/acre)		
Arapahoe	2.1"	188	189	198	190
Elsie	1.5"	193	193	184	165
Dickens[2]	1.1"	200	201	184	174
Benkelman[3]	1.8"	191	199	188	188
All Sites[4]		193	194	189	177
		FARM	BMP	LATE	ALLOC
Site			Applied Water (acre-inches/acre)		
Arapahoe	2.1"	8.1	7.4	5.3	4.3
Elsie	1.5"	9.5	9.2	6.6	5.0
Dickens[2]	1.1"	13.0	13.0	10.5	8.7
Benkelman[3]	1.8"	7.9	7.2	5.5	3.5
All Sites[4]		9.8	9.4	7.0	5.5

[1] Soil water holding capacity.

[2] Data for Dickens in 1997 not included due to irrigation error.

[3] Only 1999 data for Benkelman site; average yields for LATE and ALLOC at this site were adjusted as discussed in brochure.

[4] Yield and applied water are weighted by the number of years of data at each site.

Table 2. Average Four-Year Net Returns[1] by Management Strategy and Site.

	Management Strategy			
	FARM	**BMP**	**LATE**	**ALLOC**
Site	**Net Return ($/acre)**			
Arapahoe	**$186.69**	**$191.70**	**$212.69**	**$200.86**
Elsie	**$193.55**	**$193.92**	**$184.68**	**$153.86**
Dickens[2]	**$196.30**	**$198.09**	**$163.08**	**$161.57**
Benkelman[3]	**$193.52**	**$209.61**	**$194.15**	**$199.15**
All Sites	**$191.95**	**$195.53**	**$191.66**	**$173.73**

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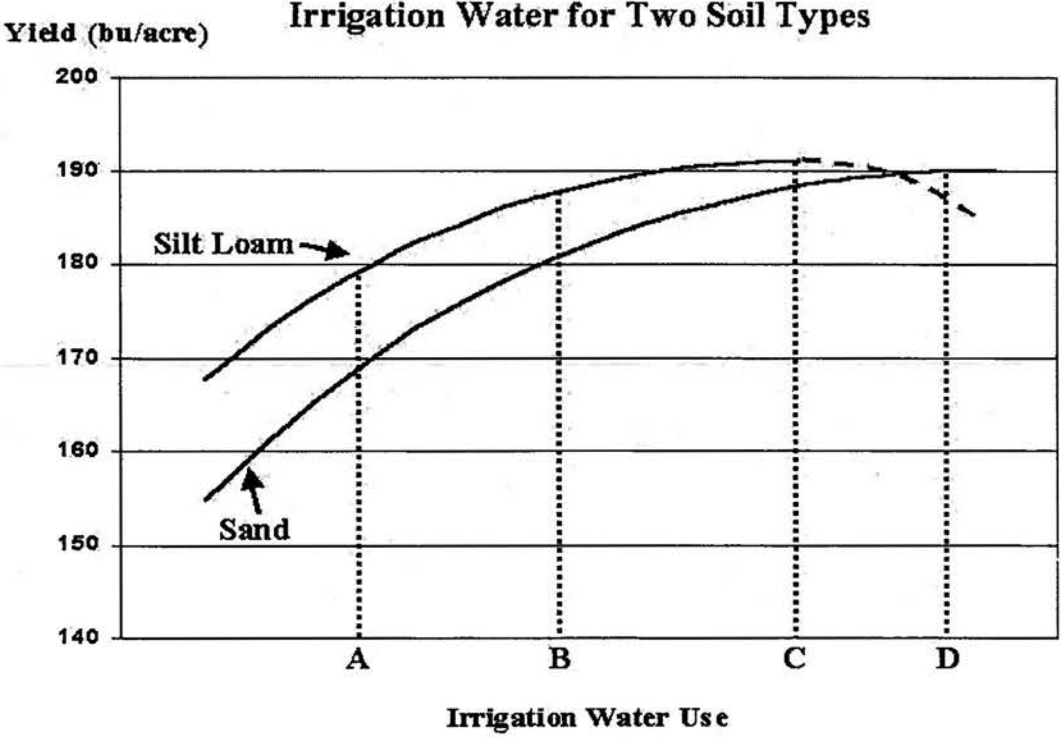
[1] Net returns to land, labor, and management using 1999 average regional operating costs; assumes price of corn is $2.00/bu and pump cost is $2.50/acre-inch.

[2] Data for Dickens in 1997 not included due to irrigation error.

[3] Only 1999 data used for Benkelman site.

Figure 1. Example of Corn Response to Irrigation Water for Two Soil Types



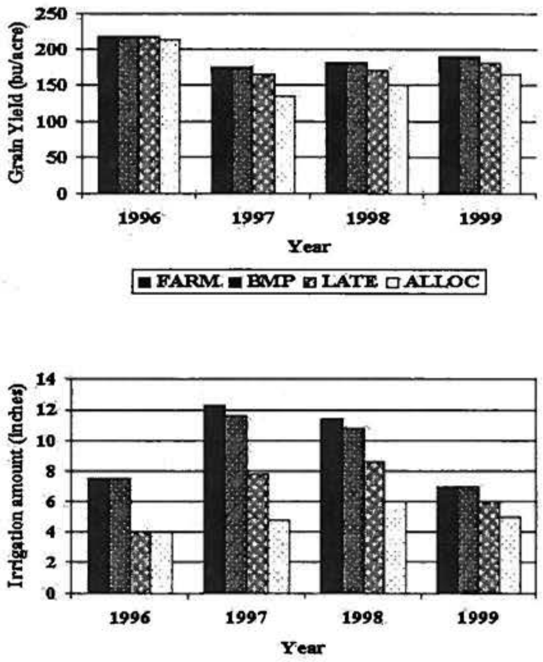


Figure 2. Grain yield and irrigation amounts at Elsie for 1996 to 1999

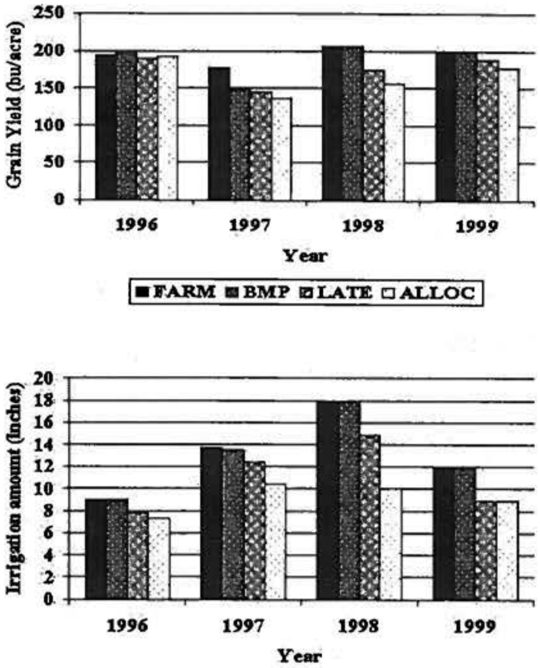


Figure 3. Grain yield and irrigation amounts at Dickens for 1996 to 1999

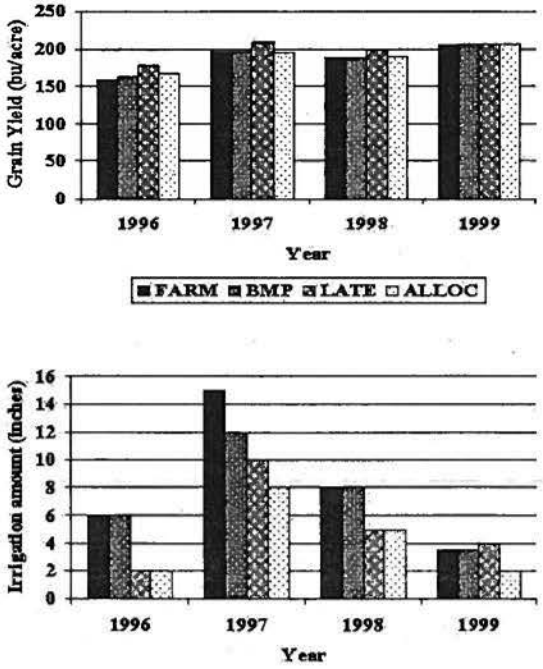


Figure 4. Grain yield and irrigation amounts at Arapahoe for 1996 to 1999

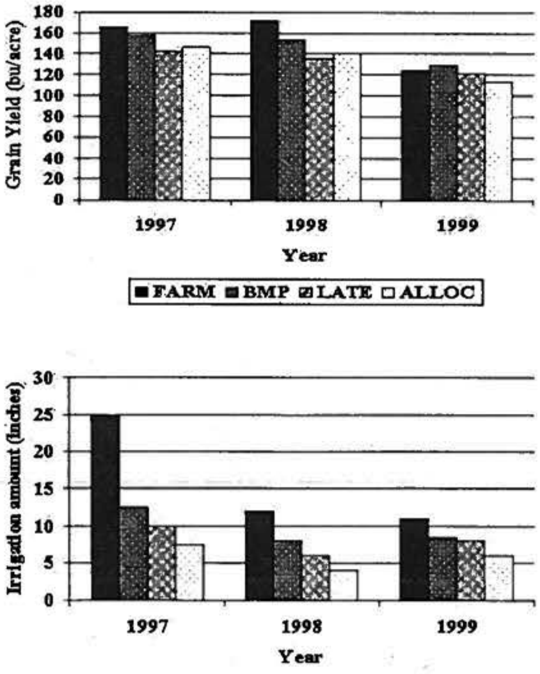


Figure 5. Grain yield and irrigation amounts at McCook for 1997 to 1999

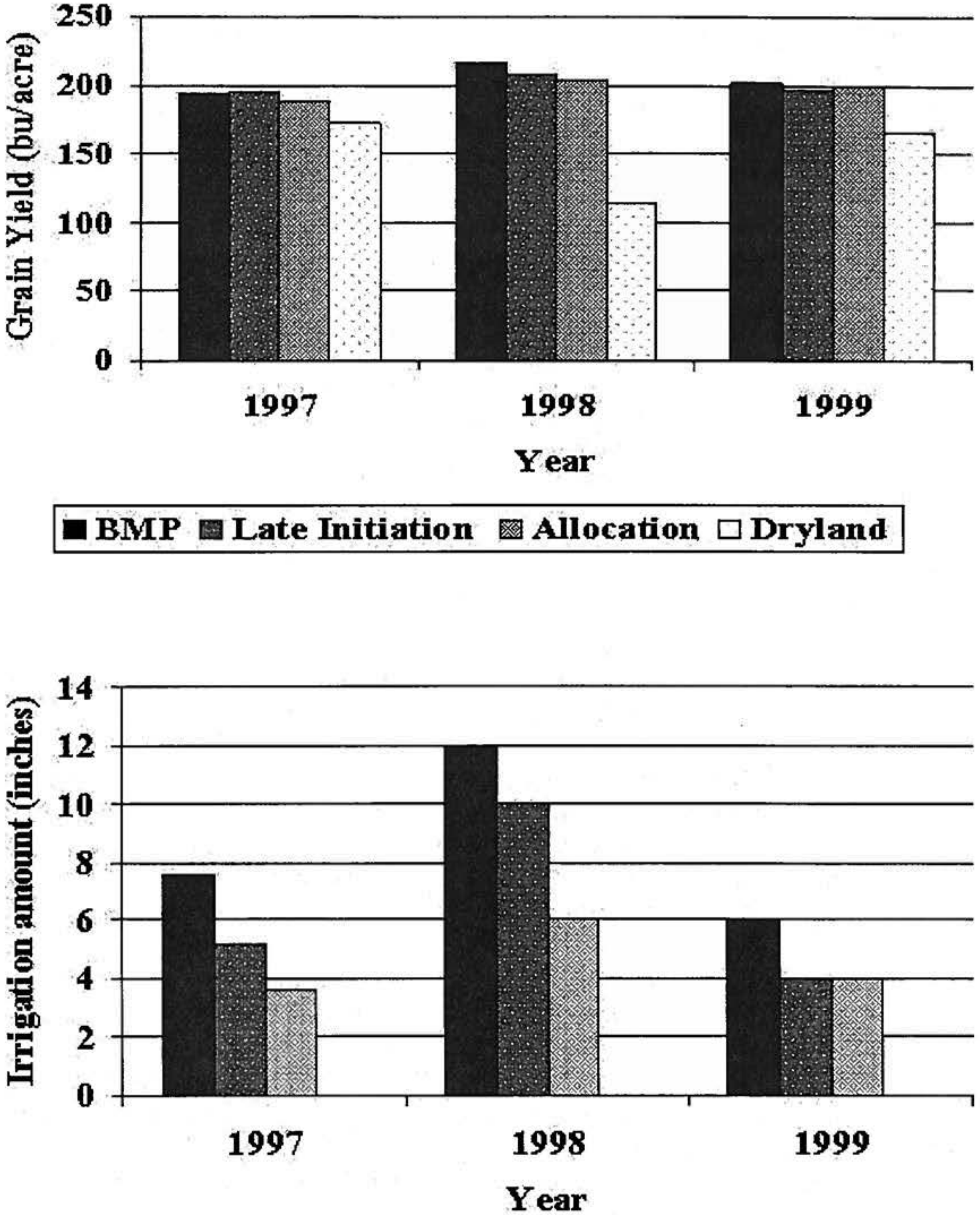


Figure 6. Grain yield and irrigation amounts at North Platte for 1997 to 1999

DESIGN AND MANAGEMENT CONSIDERATIONS FOR SUBSURFACE DRIP IRRIGATION SYSTEMS

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INTRODUCTION

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 so 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.

The intent of this paper is not to show the producer how to step-by-step design and manage their SDI system. Rather, it is to discuss some of the concepts necessary in a properly designed and management system. The hope is this discussion will enable the producer to *ask* the right questions of those designing or selling them an SDI system. As with most any new technology in a region, there are unscrupulous individuals trying to take advantage of unknowledgeable buyers. These SDI systems could easily end in failure. At the same time there are many reputable distributors, sales people and installers that are trying to promote the successful use of SDI technology. System failures hurt all those involved with SDI, the enduser, the industry selling it, and the university and government entities promoting it. *Don't be afraid to ask questions and to seek clarifications. Time spent now will be rewarded down the road.*

HYDRAULIC DESIGN

A schematic of a typical SDI system showing the necessary components is shown in Figure 1. The actual requirements in equipment, their sizes and their location is dependant on the actual design, but elements of all these components should be present in all systems.

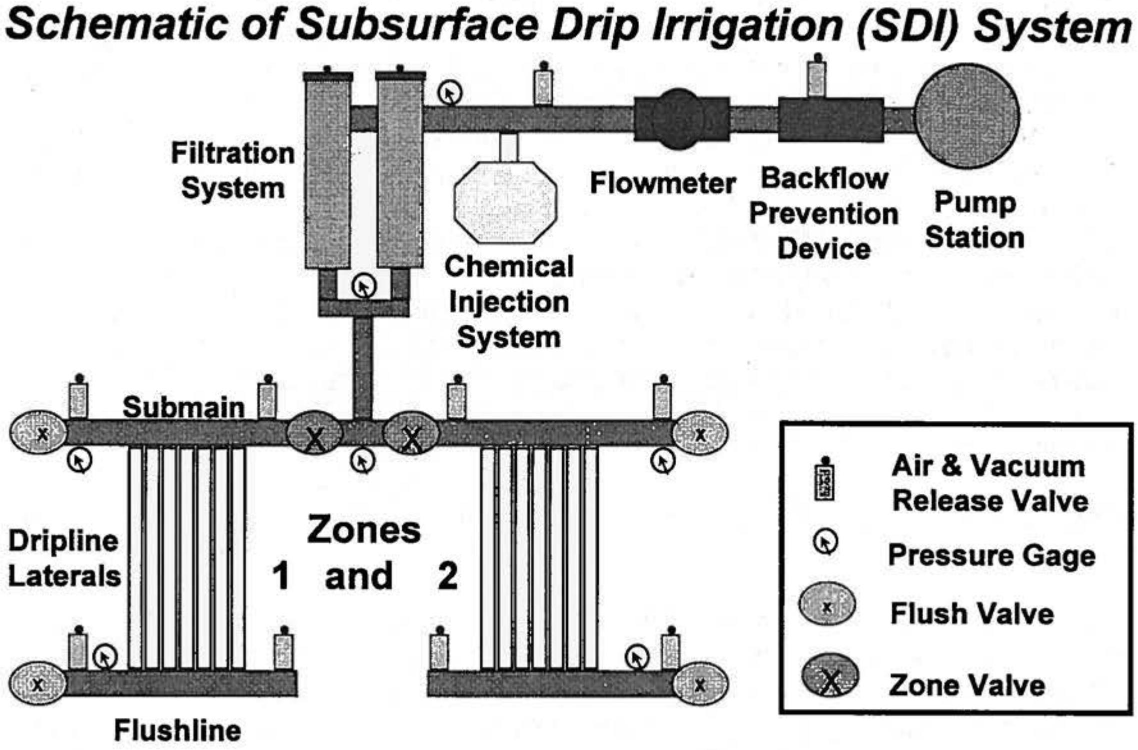

Figure 1. Component requirements of a SDI system.

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. It may be feasible and logical to use a 72-inch dripline spacing for corn planted in 36-inch spaced corn rows. However, this might limit successful use of the system for crops grown in a narrow row pattern. A 72-inch dripline spacing would not be recommended in the Central Great Plains region for corn grown in a 30-inch row culture even though some dripline installers may recommend this as a way to cut investment costs. Soils that have a restrictive clay layer below the dripline installation depth might 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. There may also be some reduced potential for chemical, biological and root plugging of the emitters for the deeper installations. 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 16-18 inches in KSU studies in western Kansas on deep silt loam soils. Some producers in the Central Great Plains region are opting for installations in the 12-14 inch depth range to give more flexibility in germination. Dripline should probably be installed above any restrictive clay layers that might exist in the soil. This would help increase lateral soil water redistribution. K-State initiated a research study to determine the optimum dripline depth (8, 12, 16, 20 or 24 inches) for long term corn production in 1999. The results are not sufficient to report at this time, but the reader is encouraged to watch for the results of this study in the coming years.

The orientation of driplines with respect to crop rows has not been a critical issue with SDI systems used for corn production on the deep silt loam soils. Traditionally, a parallel orientation is used. This may be advantageous in planning long term tillage, water, nutrient and salinity management schemes. However, K-State research has shown either parallel or perpendicular orientations are acceptable.

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

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

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 (Figure 2). 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). It should be noted that this example is based on 5/8 inch diameter dripline. Longer lengths of run would be obtainable with larger dripline diameters. The industry has responded well to the needs of the producer and now are producing larger dripline diameters. However, the producer is encouraged to carefully compare investment and anticipated management costs for the various dripline sizes before concluding what is the optimal dripline size for their installation. Larger diameters are not always more desirable, as they increase the filling and purging times for the system, which could affect water and chemical application uniformity.

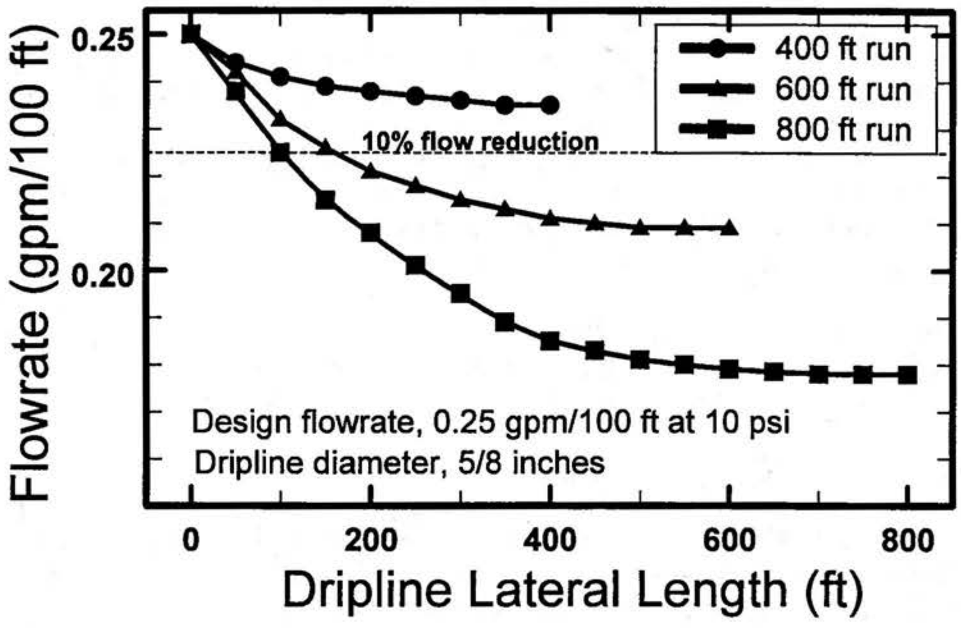

Figure 2. Calculated dripline flowrates on level slopes as affected by length of run. For this example dripline, only the 400 ft lateral length meets the desired criteria of maintaining flow variations less than 10%.

Table 1. Uniformity criteria established by ASAE Engineering Practice EP-405.

	Flow variation, Qvar = 100 x ((Qmax -Qmin)/Qmax)	
Desirable	< 10%	
Acceptable	10 - 20%	
Unacceptable	> 20%	
	Statistical Uniformity, Us	**Emission Uniformity, Eu**
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 3). 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.

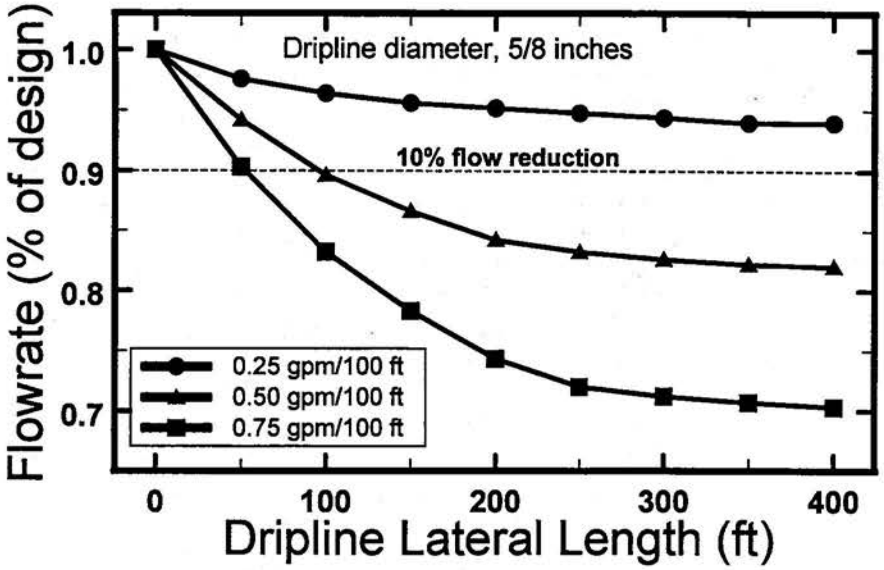

Figure 3. Calculated flowrates on level slopes as affected by dripline capacity. In this example only the 0.25 gpm/100 ft dripline capacity meets the desired criteria of maintaining flow variations less than 10%.

The land slope can have either a positive or negative effect on the pressure distribution along the dripline lateral (Figure 4). 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. If slopes are too great, there is the opportunity to run the driplines cross slope or along the contour. Pressure compensating emitters can also be utilized on greater slopes but may not be cost competitive for relatively low value crops such as corn.

The overall effect on uniformity is specific to the field slope, length of run, dripline capacity and diameter. Many of the manufacturers have computer programs that can quickly compare many design alternatives. The producer is encouraged to utilize this service to determine the overall effect on design his circumstances may dictate.

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.

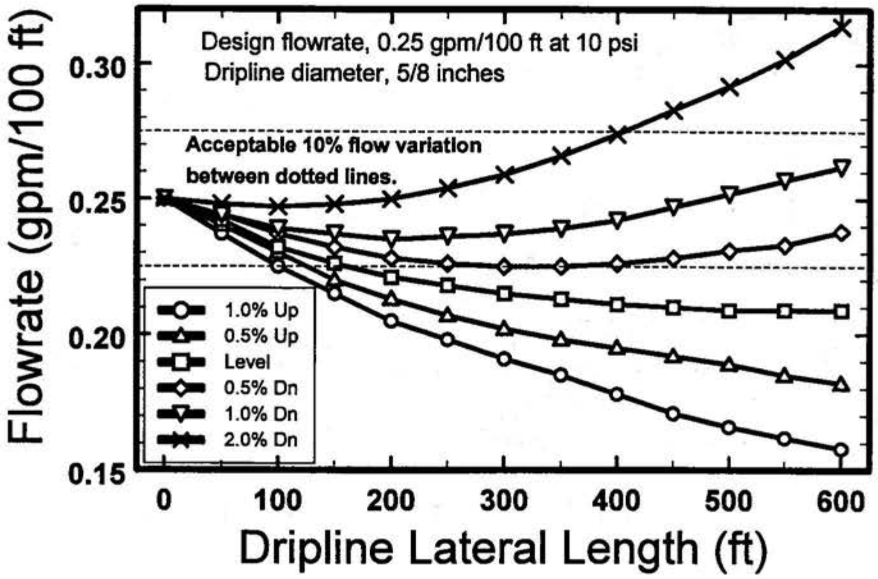

Figure 4. Calculated dripline flowrates as affected by slope. In this example, the 0.5 and 1.0% downslope dripline laterals meet the desired criteria of maintaining flow variations less than 10%.

There are two additional terms to describe system uniformity that can be calculated for a SDI system. They are the emission uniformity Eu and the statistical uniformity Us. 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. A more complete K-State source on this topic is Alam et al. (1999). 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 are eliminated in the filtration process, but injection of chlorine into the driplines on a periodic basis is required to stop the biological activity. The water source and composition will determine, to a large extent, the need for chlorination.

A flushing system is recommended at the distal end of the dripline laterals (Figure 1) 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 that 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. Generally, a minimum flow velocity of 1-2 ft/second is considered adequate for flushing dripline laterals. This flow velocity may often require careful sizing of the mains, submains, flushline mains, and valving.

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 component performance, 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 frequently apply small amounts of water 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, no 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.

K-State continues to develop appropriate methodology for successful utilization of SDI technology in the US Central Great Plains. Much of this technology is summarized on the K-State SDI website which can be accessed by pointing your Internet web browser to **http://www.oznet.ksu.edu/sdi/**

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SUBSURFACE DRIP IRRIGATION FOR ALFALFA IN KANSAS

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ABSTRACT

The result from a two year field study on suitability of using subsurface drip irrigation (SDI) for Alfalfa provided some answers to alfalfa producers of Kansas. The study was set-up in a producer field for demonstration. The soil belongs to Otero-Ulysses complex and sandy loam in texture. The treatments included placement of drip tapes at (a) 1.5 M spacing at 0.46 and 0.30 M depth of placement, (b) 1.0 M spacing at 0.46 and 0.30 M depth, (c) 0.76 M spacing at 0.46 depth, and (d) a center pivot sprinkler irrigated plot seeded to alfalfa. Emergence of seedlings was adversely effected at 1.5 M spacing of drip tapes showing 'striping'. The total yield was reduced for spacing of drip tapes at 1.5 M in both 1999 and 2000. The depth of placement of the drip tapes (0.46 and 0.30 meters) showed no effect on yields.

INTRODUCTION

Alfalfa was grown in 110,000 Ha in western Kansas in 1998 (Kansas, 1999) which, showed an increase of eleven percent from the year before. The net irrigation requirement of Alfalfa exceeds the pumping allocation of 610 mm in most of the years in water short western Kansas. Total diversion need for alfalfa is the highest. A study in California reports 22 to 35% increase in alfalfa yield by subsurface drip irrigation as compared to furrow irrigation (Hutmacher et al., 1992). Alfalfa growth is reduced by water stress which occurs during hay-cutting, drying, and baling. Use of SDI may allow irrigation to continue below the surface during harvest or right after harvest to help start a quick regrowth. The critical stage of water need for alfalfa is after harvest when the crop starts regrowth. Immediate regrowth of alfalfa helps compete with any surface germinated weeds. Subsurface drip irrigation reduces surface wetting which helps cut down the competition from annual weeds that may germinate due to surface wetting from sprinkler irrigation. Alfalfa yield can also be improved by eliminating scalding of leaves that may occur from water left ponded on the surface of the alfalfa leaves after sprinkler irrigation during hot weather (Henggeler, 1995).

Kansas State University research has shown advantages of SDI and its suitability for field crop like corn. The application of water is uniform and efficient eliminating losses. These researches indicate that it is possible to save 25% of total water in a season by using SDI (Lamm et al,. 1995). Subsurface drip irrigation, however, is an emerging technology for the Great Plains of the USA. This technology need to be studied for it's suitability to raise alfalfa crop. The objective of this study was to,

- ☐ Demonstrate the use of Subsurface Drip Irrigation for Alfalfa in a cooperator's field
- ☐ Measure alfalfa dry matter yields at various SDI spacing and depths
- ☐ Compare to nearby sprinkler irrigated alfalfa yield seeded at the same time, and
- ☐ Measure soil water content at the midway between drip tapes to observe the spread of water.

METHODS AND MATERIALS

Subsurface drip irrigation for alfalfa was established at a grower field in the corner of a center pivot sprinkler irrigated corn. The field is located south of Garden City, Kansas, in the sand hills south of the Arkansas River valley. The soil belongs to Otero-Ulysses complex with undulating slopes. The soil texture for this particular field falls in the category of sandy loam. This particular field had been previously leveled for flood irrigation. The drip tubes were plowed in using a deep shank and a tube guide in September 1998. The largest component of the expense for a SDI system is the cost of the drip tube. The closer the drip tapes laterals, the more is the quantity required to cover an acre of ground. The treatments were placement of drip lateral at,

- 1.5 m spacing by 0.46 m depth
- 1.5 m spacing by 0.30 m depth
- 1.0 m spacing by 0.46 m depth
- 1.0 m spacing by 0.30 m depth
- 0.76 m spacing by 0.46 m depth, and
- obtain dry matter yield from nearby center pivot, seeded to alfalfa at the same time

Nelson[1] 7000 path drip tape of 22-mm diameter and 0.61 m emitter spacing was installed in the fall of 1998. The emitter flow rate is 1.4-liter hr^{-1} per emitter at 55 kPa. A 200-mesh rotary disk filter with semi-automatic flush system provided by Rain Bird was installed for filtration.

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[1] Manufacturer and product names are presented for information to the reader and not to imply endorsement of any products by the authors nor criticism to products not mentioned.

Alfalfa was seeded at 0.15 m spacing soon after installation of the system to avoid delay in planting season. The seed-bed was relatively dry and irrigation was applied using drips before installing the flow meters. So, actual amount could not be recorded. Later, Fluidyne vortex flow meters operated by 12 volt DC battery were installed along with a solar panel for continuous recharging. The meters were installed soon after and an application of 19mm additional water was recorded during the fall. Seed germination showed distinct lines indicating where the drip tapes were buried in the plot, especially for the wider spaced drip placements. A rain amounting to 7mm in late September helped germination of the remaining seed. However, some of these late seedlings failed to survive since they were not well established before the winter. As a result, a 'striping' effect was visible. The owner of the field re-seeded in early spring of 1999. There may have been some benefit for the lower end of the field, but no significant change of plant stand was visible.

Four samples of one square meter each were cut to obtain dry matter yield results form each plot. The harvest samples were hand clipped. The harvest spot was randomly selected across the block.

The 1999 season started with a relatively wet spring. Earlier growth was supported by rainfall. Irrigation was started on 1st of July. Gypsum block soil water sensors were installed at mid point between two laterals to represent the furthest point from the wetted line. The depth of placement was at 0.30 m, 0.60 m, and 0.90 m below the soil surface. This midpoint location was chosen to represent the worst case scenario from the standpoint of water reaching the furthest point which would provide an idea on the spread of water.

Results

1999

The total water account from July 1 through September 29 amounted to.

- Irrigation by
  - SDI : 343 mm
  - Sprinkler: 503 mm
- Rainfall: 152 mm
- Estimated modified Penman ET: 526 mm

Dry matter yield for 1999 are presented in Table 1.

Table 1: Alfalfa yield of subsurface drip and sprinkler irrigated plots.

	Date of Harvest, Dry Matter Mg/ha^{-1}					
Treatment	**22-6-99**	**23-7-99**	**27-8-99**	**1-10-99**	**Total**	**Total B***
1.5 M space(S) by 0.46 M depth(D)	4.25	1.38	2.56	2.12	10.31	4.68
1.5 M (S) by 0.30 M(D)	3.38	2.06	3.06	2.12	10.62	5.18
1.0 M (S) by 0.30 M(D)	3.88	2.34	2.81	2.31	11.34	5.12
1.0 M (S) by 0.46 M(D)	3.69	2.38	2.69	2.81	11.57	5.50
0.76 M(S) by 0.46 M(D)	3.31	2.24	1.94	2.5	9.99	4.44
Sprinkler (Center Pivot)	---	---	2.31	1.69	---	4

* Total B - Total for last two (2) harvests.

First two harvest for center pivot is missing. The comparison for corresponding total yields for last two cuttings indicate a lower yield for sprinkler irrigated field. The highest yield was 11.57 Mg^{-1} ha for the treatment of 1.0 meter drip lateral spacing with 0.46 m depth of placement.

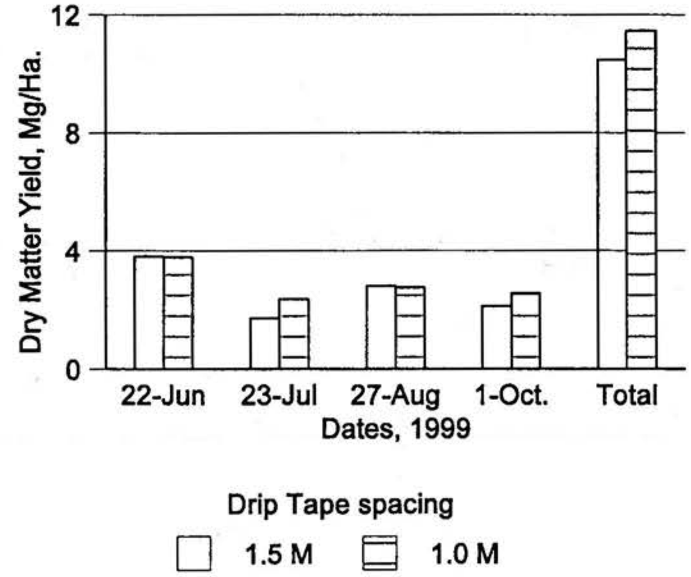

Fig. 1 Dry Matter Yield as affected by spacing

Figure 1 shows the dry matter yield as effected by spacing. Spacing of drip laterals at one meter showed a slight advantage over one and half meter spacing in this study. The differences between two was 0.98 Mg ha^{-1}in 1999.

The depth of placement of the drip laterals were similar for dry matter yield, Fig. 2. Yield for both depth were about 11 Mg ha^{-1}.

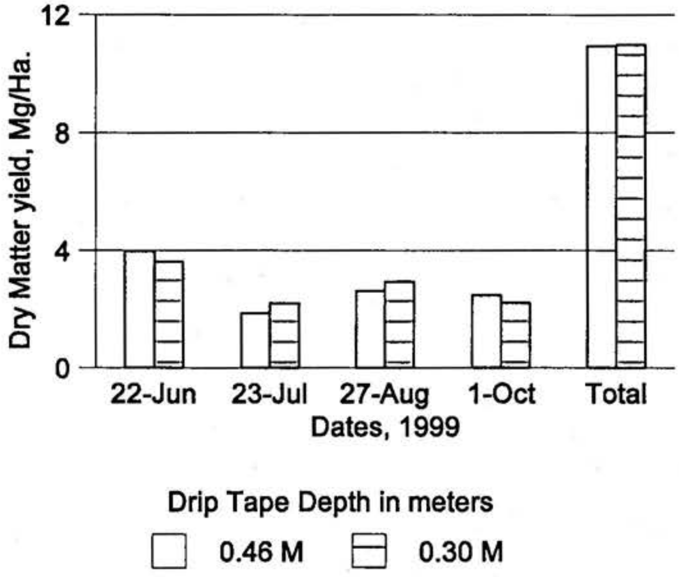

Fig. 2 Dry Matter Yield as affected by the depth of drip tape placement

Gypsum block readings for soil water distribution to the mid-point between drip tapes at 1.5 M spacing placed at 0.46 M below the surface are presented in Fig.3 for 1999.

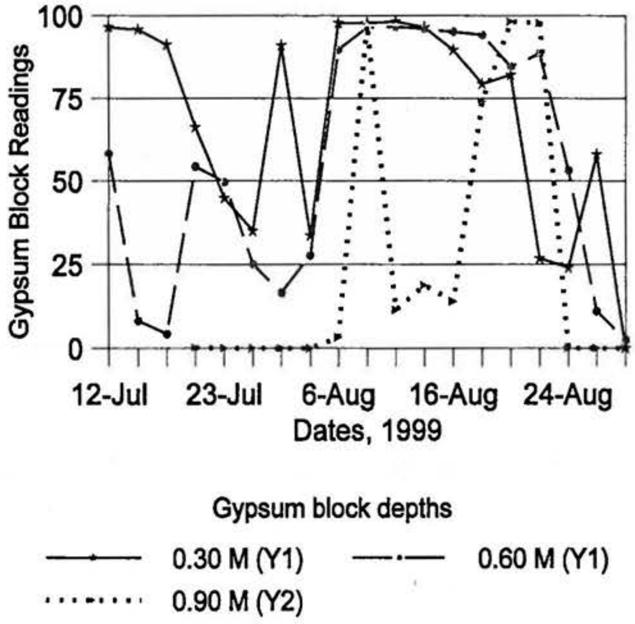

Fig.3 Gypsum block readings at mid-point between drip tapes at 1.5 M spacing

Soil water was always low at the midpoint between two drip tapes for the plot with drip spacing at 1.5 m and the yield was lower. A "stripping" appearance was visible for the 1.5 spacing during the growing season as well. Water distribution from the 1.5 spacing did not reach the midpoint between the tapes at the 0.90 m soil depth until a rain of 50 mm on early August, Fig. 3. However, tape placement at 0.30 m depth for the 1.0 spacing provided a better water distribution for soils at 0.30 m and 0.60 m depths from the beginning of the season, and improved for soils at a 0.9 m depth within a short period (Fig. 4). Irrigation application amount was maintained at the same level for all treatments.

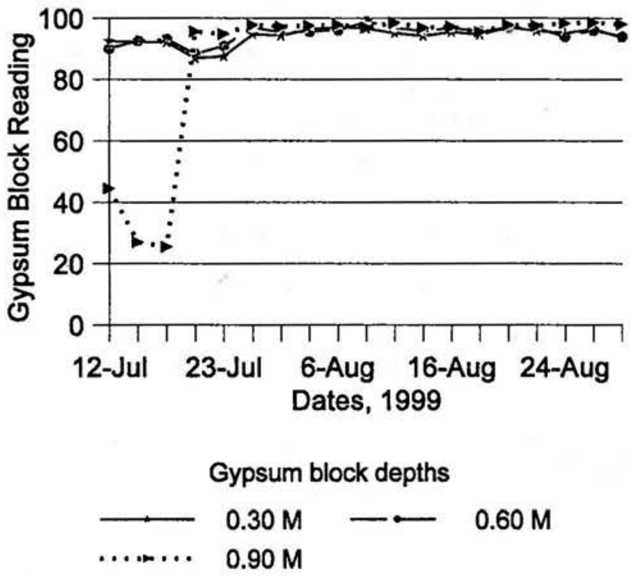

Fig. 4 Gypsum block readings at mid-pont between drip tapes at 1.0 M spacing.

Results for <u>2000</u>

Water applied May 10, 2000 through September 21, 2000

- Irrigation by
  - SDI: 493-635 mm
  - Sprinkler: 644 mm
- Rainfall: 140 mm
- Estimated modified Penman ET: 1060 mm

Dry matter yields of individual harvests within the season including those from the sprinkler-irrigated center pivot field are presented in Table 2 for 2000.

Table 2. Dry Matter yield of subsurface drip and sprinkler irrigated alfalfa for 2000.

	Date of Harvest, Dry Matter Mg/ha^{-1}					
Treatment	**22-5-00**	**23-6-00**	**28-7-00**	**25-8-00**	**26-9-00**	**Total**
1.5 M space (S) by 0.46 M (D) depth	5.25	3.51	4.11	2.56	2.48	17.9
1.5 M (S) x 0.30 M (D)	4.88	3.26	3.19	2.53	2.24	16.1
1.0 M (S) x 0.46 M (D)	5.4	4.26	3.9	3.14	2.71	19.4
1.0 M (S) x 0.30 M (D)	5.86	3.65	4.61	3.10	3.02	20.2
0.76 M (S) x 0.46 M (D)	6.06	3.62	3.55	2.91	2.85	19.0
Sprinkler (Center Pivot)	3.65	4.47	4.32	3.56	2.84	18.8

Dry matter yield as affected by spacing and placement depth of the drip tapes for the year 2000 are presented in Fig.5 and 6. The results are similar to the previous year. The drip tape spacing of 1.0 M yielded about 3 tons ha^{-1} more when compared to drip tape spacing of 1.5 M. The depth of placement at 0.30 or 0.46 M produced similar yield.

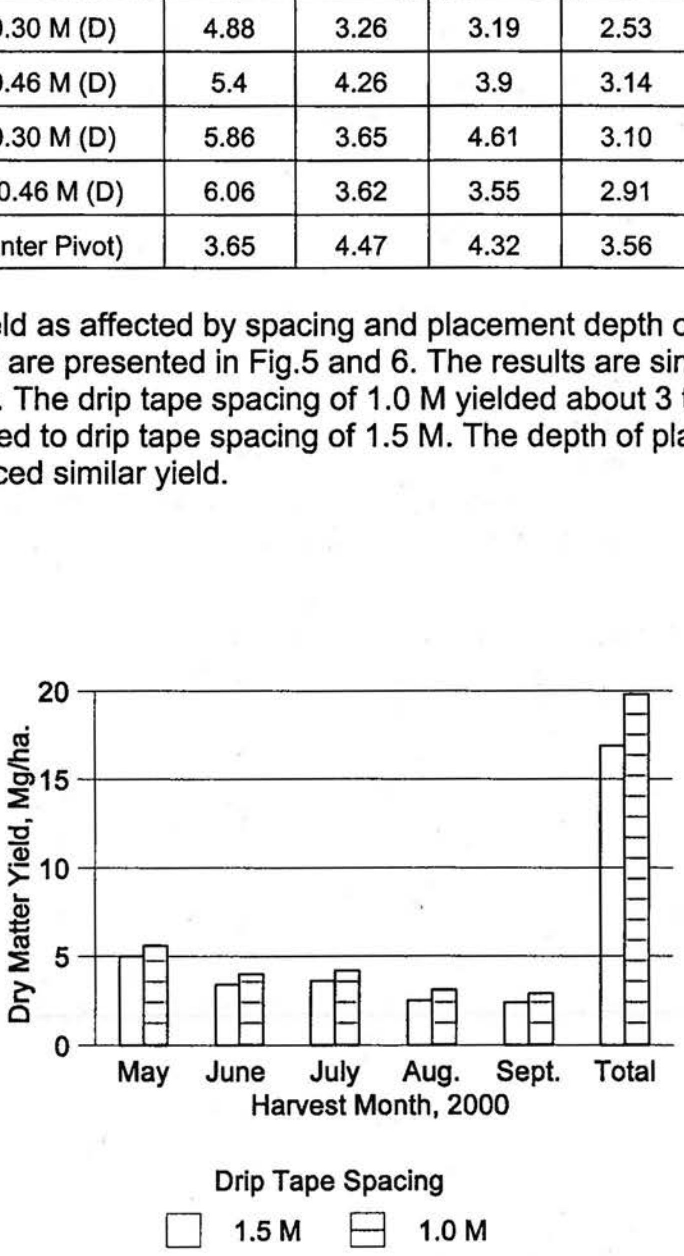

Fig. 5 Dry Matter Yield s affected by drip tape spacing.

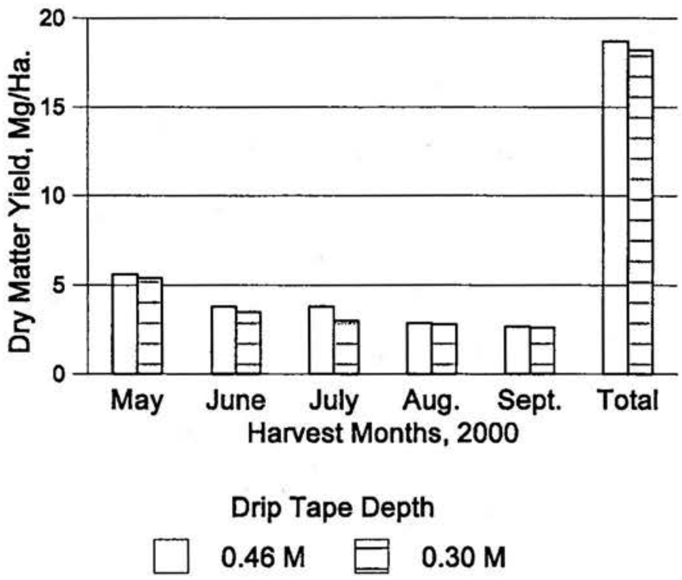

Fig.6 Dry Matter Yield as affected by drip tape placement depth

A similar pattern of water distribution is observed in the year 2000. (Figs. 7 and 8). Distribution somewhat improved for 1.5 m spacing with the increase in frequency of irrigation starting mid July. The hot and dry summer necessitated the increase of frequency of irrigation to 3 times a week.

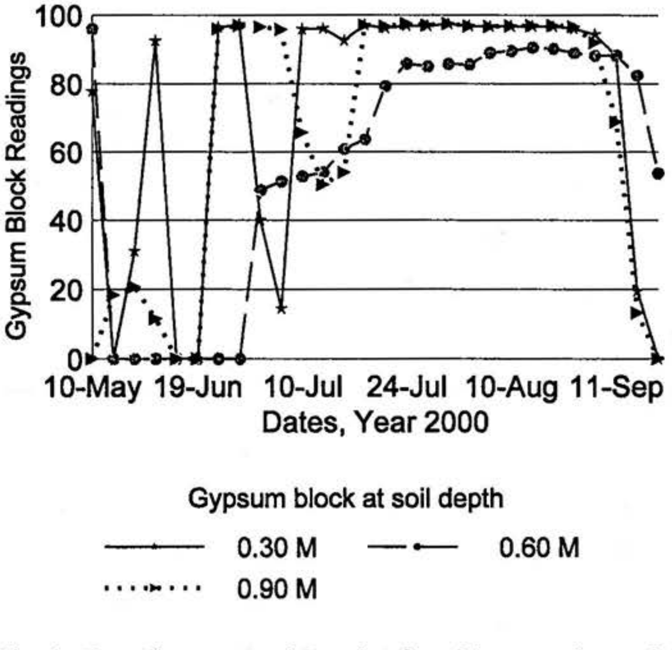

Fig.7 Gypsum Block Readings at mid-point for drip spacing of 1.5 M

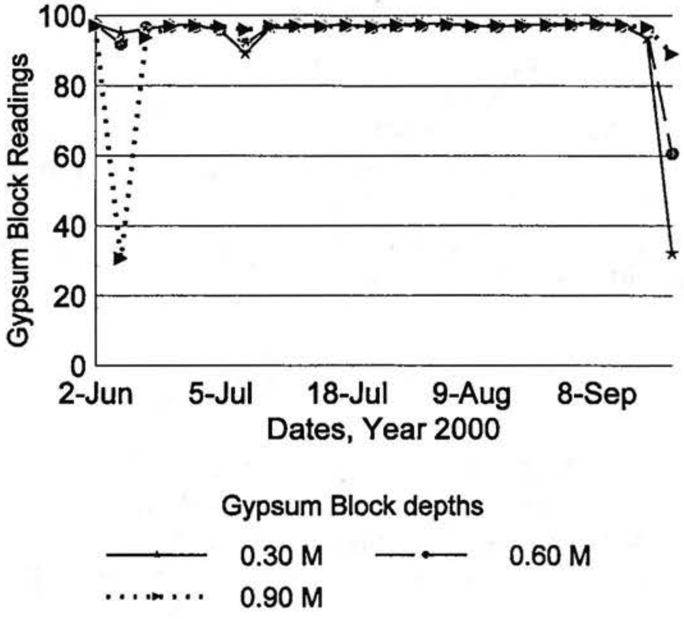

Fig. 8 Gypsum Block Readings at mid-point drip tapes at spacing of 1.0 M

Data presented in the figures for soil water status are the readings of the meter. A reading of zero indicates zero available soil water or a depletion of 100%. The meter readings are presented for simplicity to show the seasonal changes of soil water content and replenishment from irrigation and rainfall. A chart of conversion is given at Table 3 for interpretation of the meter readings in terms of soil water status.

Table 3: Interpretation of Meter Reading to Soil Water

Meter Reading	Available soil water %	Comments
99 to 95	100 to 85	0 to 15% depletion
95 to 85	85 to 70	15 to 30% depletion
85 to 75	70 to 60	30 to 40% initiate irrigation for light soils
75 to 60	60 to 50	40 to 50% initiate for heavy soils
60 to 40	50 to 40	50 to 60% caution
40 to 20	40 to 20	60 to 80% dry
20 to 0	20 to 0	80 to 100% depletion
Negative numbers	None available	Block may lose soil contact

CONCLUSION

Alfalfa seedling emergence was affected adversely at the 1.5 m spacing for this sandy loam soil. We observed some "striping" at emergence in the first year during the establishment period. Yields were reduced slightly for the spacing 1.5 m. Depth of placement of drip tapes did not affect the yields; they were similar for depths of 0.30 and 0.46 m. The second year observation showed similar results, although increasing the frequency of irrigation by SDI reduced striping appearance.

ACKNOWLEDGMENT

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ADVANCES IN SOIL MAPPING FOR IMPROVED IRRIGATION MANAGEMENT

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INTRODUCTION

With increasing concerns about environmental impacts of irrigated agriculture and the continual economic pressures due to rising energy prices and declining water supplies, many producers are looking at various alternatives for reducing or at least minimizing the increase in irrigation costs. One option is improving irrigation management which can be defined generally as applying the right amount of water at the right place and at the right time. Over the past 30 years, research and on-farm studies have shown that savings of 20-30% in the amount of water applied and significant reductions in nitrogen leaching, are possible using soil water budgeting techniques for irrigation scheduling at the field level. Because nitrates move readily with water in the soil profile, water and nutrient management are closely tied together. Currently, researchers and some progressive minded producers are investigating the use of precision agriculture concepts to improve water and nutrient management. Regardless of the management level used, it is necessary to account for differences in soil conditions within a field with better and more detailed information.

Traditionally, soil scientists have used aerial photography maps, field observations of topography, soil texture, and other soil parameters along with well documented descriptions of reference soil pedons, to make soil maps. The USDA-NRCS has mapped nearly all of the agronomically significant areas within the U.S. to aid producers in their crop production practices. Generally, NRCS soil survey data or data obtained from soil sampling at a few selected sites in each field, have insufficient detail about water holding capabilities and consequently are marginally adequate for managing irrigations under average field conditions.

Some producers have opted to take many more soil samples usually in some sort of a grid pattern, to get a better understanding on soil variability in a field. The increased cost for the improved accuracy depends mainly on the sampling density. The accuracy of the generated maps is also affected by the interpolation method used to create a continuous mapped surface from the actual field data points.

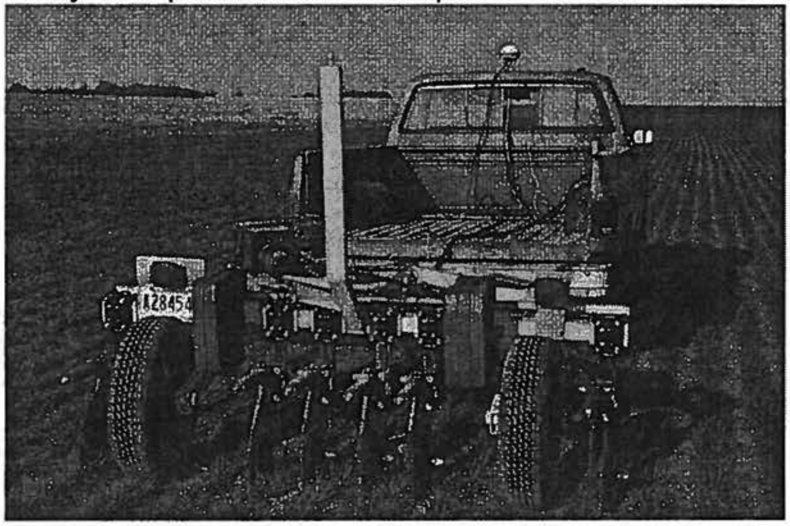
Since it is not possible to physically measure leaching below the root zone for an entire field, physically based simulation models are often used to estimate environmental impacts from agricultural practices. These models mathematically describe the physical processes occurring at a point so spatial variability is accounted for by running the model at the various points in a field using appropriate input values. Since greater accuracy of the input parameters usually instills greater confidence in the model results, it is desirable to have parameter values as good as economically possible. Obtaining the necessary data using labor-intensive field sampling is not economically justified so other less expensive approaches are needed. An affordable approach for improving the accuracy of soil mapping is to use electrical conductivity (EC) measurements as a surrogate measurement for several soil parameters.

MEASURING ELECTRICAL CONDUCTIVITY

Electrical conductivity (EC) is a measure of the ease that electricity can move though a soil. Since it is influenced by a number of factors such as salinity, porosity, amount and composition of soil colloids, organic matter, and moisture content, it is a surrogate measurement for several different soil parameters important for irrigation management. The relationship for a particular field depends on the presence and magnitude of the various parameters. In the absence of saline conditions, percentages of sand, silt, and clay sizes that define soil texture, usually correlate very well with EC. EC values for clay soils are higher than sandy soils because the clay size particles have charged surfaces, and hold larger amounts of water. Useful information for irrigators includes the water holding capacity (WHC), infiltration rate, and the presence of any soil layer that impedes water flow. WHC is usually highly correlated with soil texture and organic matter (OM). Since it is relatively inexpensive to map large areas with these technologies, one goal is to relate various soil parameters with EC in order to generate maps for improving water management decisions.

Two types of equipment are commercially available to measure EC. The Veris 3100 equipment (Figure 1a) applies a constant electric current through the soil, and measures the voltage between two commutators in contact with the ground. EC is measured for 2 depths; 0 – 1 ft (0 to 0.3 m) and 0 – 3 ft (0 to 0.9 m). The Geonics EM38 (Figure 1b) unit utilizes a magnetic transmitter coil to induce a small electric current through the soil. A receiver coil picks up the attenuated current. Changing the orientation of the transmitter and receiver coils changes the depth of sampling. This equipment samples to a depth of about 2 ft (0.75 m) in the horizontal orientation and 5 ft (1.5 m) in the vertical orientation. Although the EM38 equipment was originally designed for hand-carrying through the field, it can be mounted on a custom-built non-metallic carriage and pulled through the field as well. Either of these units can be pulled at a speed of approximately 8-10 mph (13-16 kph) data collection rate was 12-16 ha per hour. With a sampling interval of 1 sec, the sample interval is about 8-12 ft (2.5-3.5 m) in the direction of travel. The swath width is 50 ft (17 m) perpendicular to the direction of travel resulting in approximately 75 readings per acre.

Both systems can be interfaced with Global Positioning System (GPS) equipment to provide geographic locations (i.e. latitude and longitude values) for every data point taken. Examples of the EC data are shown in Figure 2.



a. Veris 3100 unit

b. Geonics EM 38 unit

Figure 1. Commercially available equipment for measuring soil electrical conductivity.

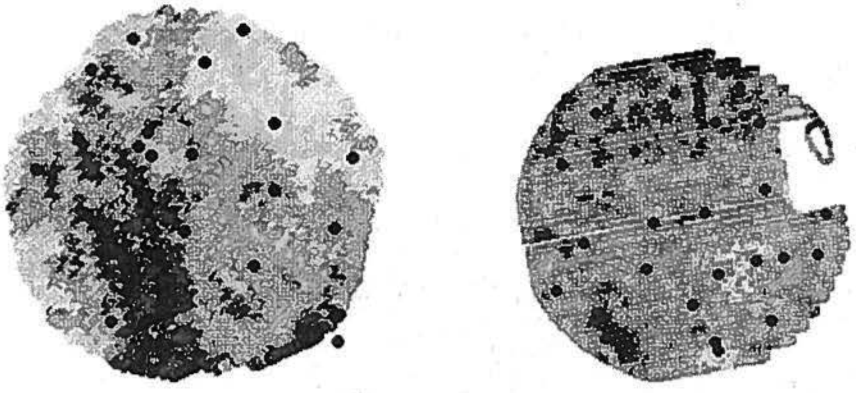


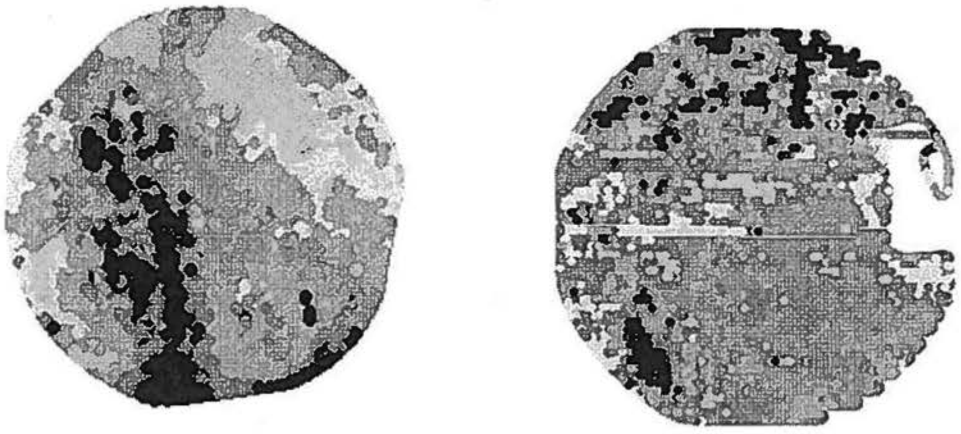
Figure 2. Maps of EC (0-1 ft depth) with soil sampling sites (dots).

ANALYSIS

To date our work has focused on collecting EC data on different soil types, in order to determine how the soil factors affect EC measurements. Two fields (northeastern Colorado and south central Kansas) were chosen where soils were quite variable and soil salinity was not a factor. Both fields were pivot irrigated and soils ranged from sandy loam to silty clay loam.

Although both types of equipment were used successfully on both fields, only the Veris data were used in this analysis. The 10000+ EC data points for each field were screened to eliminate obvious erroneous readings that sometimes occur if there is poor electrical contact between the commutators as the unit crossed deep pivot tracks or other ruts. Statistical software developed by the United States Soil Salinity Lab in Riverside, CA was used to select 20 sites per field where soil cores are taken to a depth of 4 ft (1.2 m). The selected sites are spread over the range of measured EC values as well as spatially distributed across the field to ensure that soil data collected are taken from statistically sound locations. Soil moisture contents were determined at 1 and 3 feet (0.3 and 0.9 m) with gravimetric sampling and the oven-dry method. The soil cores were logged by soil horizons. Samples were sent to a commercial lab for analysis of pH, CEC, OM, salts, % sand, % silt, %clay.

A statistical technique called **cluster analysis** was used to partition the entire EC data set into subsets called clusters that display the smallest within-cluster variation and the largest between-cluster variation. Three pieces of information were associated with each data point in the field. The shallow Veris reading is an integrated value for 0 to 1 ft depth. The deep Veris reading is an integrated value for the 0 to 3 ft depth. Subtracting the shallow reading from the deep reading gives an EC value for the 1 to 3 ft depth. For the combined Colorado and Kansas data set, 5 clusters (classes) gave sufficient separation between classes without being too complex. Three general ranges of EC values were identified for the 1-3 ft depth and three general ranges for the 0-1 ft depth. The low range for the 1-3 ft depth was subdivided into medium and high ranges at the 0-1 ft depth. The medium range for the 1-3 ft depth was subdivided into low and medium ranges at the 0-1 ft depth. The fifth class included the high ranges for both 0-1 ft and 1-3 ft depths. These 5 clusters (classes) are mapped below in Figure 3.



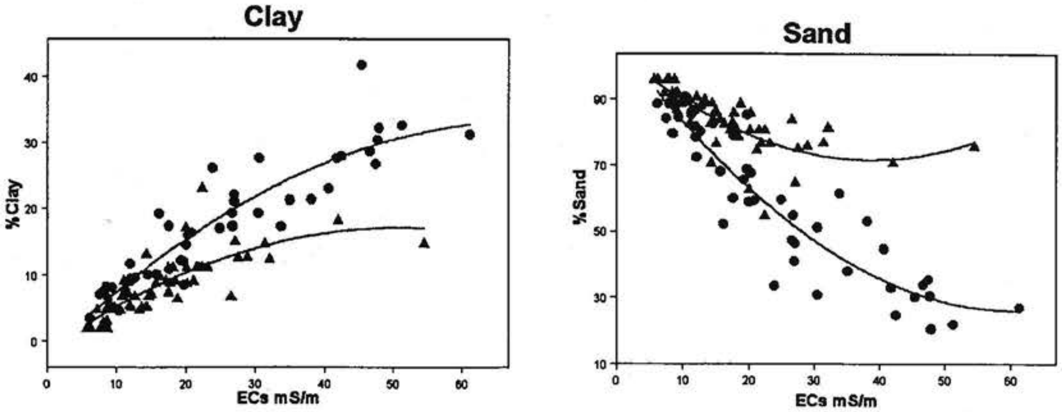
Colorado

Kansas

Figure 3. Maps of 5 clusters at two locations.

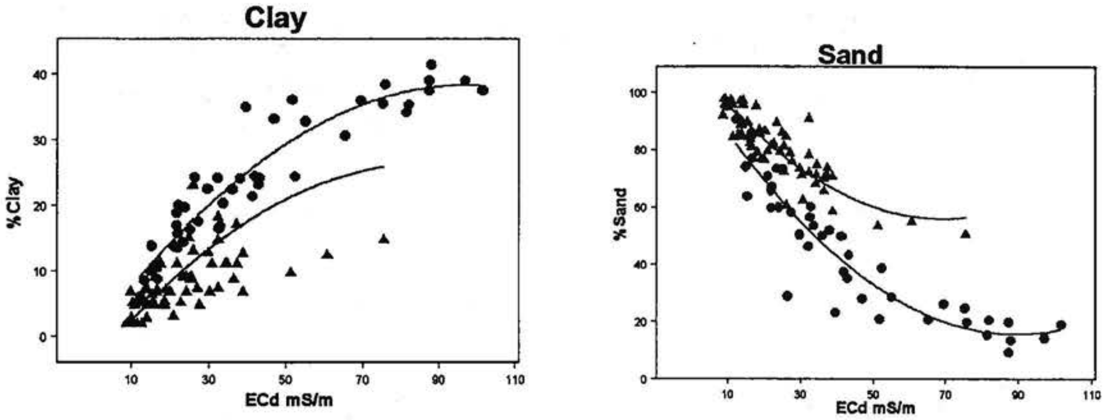
Soil samples to a depth of 4 ft (1.2 m) were taken by soil horizons at sites located in each cluster. These samples were analyzed for soil texture (%sand, %silt, %clay) in a commercial soil lab using standard lab procedures. Values for the %sand, %silt, and %clay for each soil horizon were combined and summarized for two soil layers – 0 to 1 ft (0 - 0.3 m) and 1 to 3 ft (0.3 - 1.2 m). A **nonlinear regression procedure** was used to develop polynomial equations describing the relationships of EC vs. %clay and EC vs. %sand that are shown in Figure 4.

For 0 to 1 ft (0 - 0.3 m)



▲ for Colorado, ● for Kansas

For 1 to 3 ft (0.3 - 1.2 m)



▲ for Colorado, ● for Kansas

Figure 4. Plots of EC vs. %clay and EC vs. %sand for 2 depths).

The **regression procedure** of Saxton et al. (1986) was used to relate the soil texture expressed as %sand, %silt, and %clay to a water holding capacity in in./in (mm/mm). The functional form of the equation is:

$$\text{Water content (\%)} = \exp[(2.302 - \ln A) / B] \text{ where}$$

$$A = \text{fn}\,[(\%\ \text{clay}), (\%\text{sand})^2],$$
$$B = \text{fn}\,[(\%\text{clay}), (\%\text{sand})^2, (\%\text{clay})^2]$$

Water holding capacities were computed for both soil layers and combined to give a total depth for a 4 ft (1.2 m) soil profile that are shown in Figure 5. These maps indicate interesting patterns and significant differences in the water holding capacity of the various soils within a field. They could be very useful in identifying the critical areas that need to be monitored for irrigation scheduling. In the future, if it makes sense to variably apply water, some 'smoothing' of the boundaries would be necessary depending upon the capabilities of irrigation system.

Colorado Kansas

Figure 5. Maps of water holding capacities (4 ft depth) for Colorado and Kansas locations.

DISCUSSION

Additional analysis was done for the Kansas location for verification and to compare the maps generated from EC data with the existing USDA-NRCS soil survey maps. A smoothing algorithm was used on the map in Figure 3 to produce the map shown in Figure 6 with cleaner and more usable delineations between the 5 clusters.

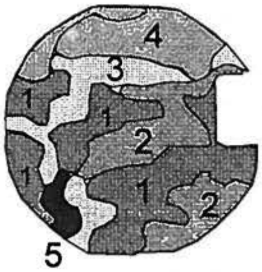
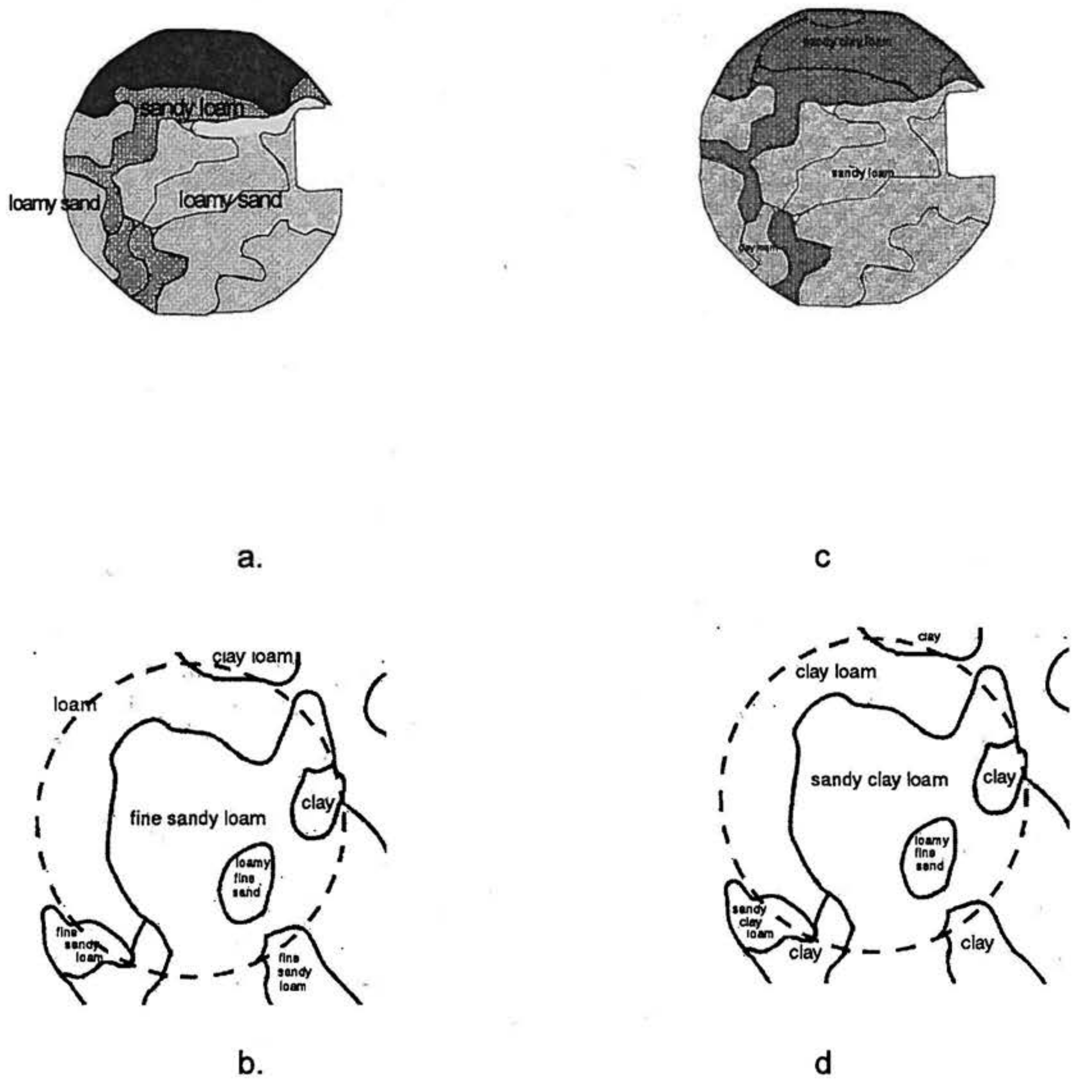


Figure 6. Delineations of soil textures by cluster analysis of EC data

Average values for the sand, silt, and clay fractions of the soil horizons where cores were taken within each of the 5 classes were classified according to the USDA soil texture triangle and are shown in Table 1. The texture classifications for the 0-1 ft depth are displayed (in different colors) for the 5 clusters (from Figure 6) to produce Figure 7a. The soil texture map shown in Figure 7b is developed from the published USDA-NRCS county soil survey map. The same process was repeated to produce the maps for the 1–3 ft depth shown in Figures 7c and 7d.

Table 1. Values of soil texture for 2 layers.

Cluster	0 to 1 ft depth				1 to 3 ft depth			
	%sand	%silt	%clay	texture	%sand	%silt	%clay	texture
1	82	8	10	loamy sand	79	8	23	sandy loam
2	86	7	7	loamy sand	69	17	14	sandy loam
3	65	22	13	sandy loam	52	30	18	loam
4	52	30	18	loam	54	25	21	sandy clay loam
5	67	17	16	sandy loam	34	34	32	clay loam



a.

c

b.

d

Figure 7. Comparison of soil maps from EC measurements with published USDA-NRCS.

This example is not intended to show the superiority of one approach over another. Rather, it illustrates that with new and economical technology we may get a different view of how soil varies across a field. Knowledge about the spatial variability of soil texture can help producers make better water management decisions, but it is important to understand the strengths and weaknesses of the processes used to obtain the information.

Since this approach to mapping is not being done commercially (to my knowledge), I do not know what the costs would be. The EC data could probably be collected for $1-3 /ac and of course the costs for lab analysis of the soil samples would depend on the number and detail of testing desired.

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SPATIAL DISTRIBUTION OF WATER AND NITROGEN APPLICATION UNDER CENTER PIVOT SPRINKLERS

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INTRODUCTION

For most management decisions, water application from center pivot systems is usually assumed to be uniform. However, significant variability of both water and chemigated chemical distribution can occur with both field location and time.

Water application depth under a center pivot system can vary because of improper (or worn) nozzle sizes, changes in pump performance over time, pressure changes caused by end-gun operation, or changes in topography across the field. Most sprinkler package designs are based upon level fields, and many systems are in operation without pressure regulators installed. If the field is not level, the flow of water out of each sprinkler will be less than design, where the elevation is higher, or greater than design where the elevation is lower. In either case, the result is uneven water application. These problems can be solved to a certain degree by using pressure regulators.

If a center pivot is used for fertigation, of if the water supply contains significant nitrate, the nitrogen will not be uniformly distributed either (Evans, 1995; Duke et al, 2000). In addition, there will be some variability of the nutrient concentration due to the effect of line pressure on the injection pump operation. Moreover, nitrogen contents vary through soils and, accordingly, may require different application rates of nitrogen.

Variability in the irrigation and nitrogen application as well as variability in the available soil water holding capacity create the potential for variability in leaching around the field. Unless excessive amounts of both water and nitrogen are applied, this leaching may affect the yield.

Researchers and farmers alike are beginning to recognize that fields are not uniform in terms of optimum input requirements and that there may be both economic and environmental benefits to differential application of water and nitrogen fertilizer rather than uniform application over entire field. These concepts of precision farming are growing rapidly, and there is little scientific evidence to back them up.

In order to apply precision farming principles to leaching reduction, yet maintain optimal yield, resource managers need cost-effective tools to identify areas that are potentially vulnerable to leaching so that management plans can be implemented to reduce the potential pollution problems.

Computer models are among the most cost-effective tools for analyzing water resources problems, and are widely used for estimating the impact of natural resources management decisions. Some of the limitations of models, however, include the requirement for large amounts of input data, and sufficient sampling to account for spatial variability and heterogeneity that are often present. Producers are seldom able to invest the money and time required to adequately sample and characterize the variabilities of interest. For this study, we have used such models, together with GIS tools, to assess the amount of variability in application of both water and nitrogen fertilizer under two farmer-operated center pivot systems typical of those irrigating the sandy soils common to many areas of the central Great Plains. Such an analysis should give us an idea of the most productive improvements in sprinkler design or management to save costs of water and fertilizer, maintain optimum yields, and protect water quality.

APPROACH

Water control is one of the most important variables in irrigated crop production. Different types of soil have different water holding capacities, therefore require different water application depths and rates to reach field capacity and to minimize runoff and deep percolation. Because of this possibility of deep percolation which can carry nitrogen fertilizer beyond the reach of roots, water management is equally important to nitrogen management.

Precision farming is a tool that may provide potential for better management of these resources. Precision farming has been used primarily for preseason nutrient application and for mapping of harvest yields; only limited attention has been given to differential application of water and chemicals in irrigation crop production. The use of GPS and GIS technologies and advances in computer simulation have made the precision farming approach practical. This presentation is limited to determining the spatial and temporal variability variability of irrigation water and of the various sources of nitrogen fertilizer available to the crop during the growing season.

Experimental Site

This study focused on two center pivot irrigated corn fields in 1999, one of 170 ac, the other 130 ac. Results from the second of these fields, located northeast of Wiggins, Colorado in Morgan County will be shown in this presentation. The soils are coarse textured Valentine and Valentine-Dwyer sands and Bijou loamy sand.

This field has about 26 ft difference in elevation, as shown in Figure 1.

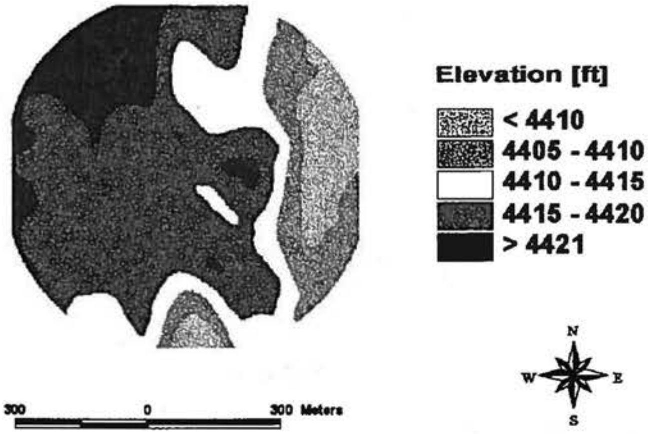

Figure 1. Elevation surface of center pivot field.

Irrigation System

A USDA developed center pivot evaluation and design program, CPED (Heermann and Spofford, 1998), was used to estimate spatial water application by the irrigation system. This program was used to compute the sprinkler hydraulics at radial intervals of 10 ft along the pipeline and at 5° increments of azimuth. The program accounts for the topography along each radius, end gun operation at that angle, and pipeline and pump hydraulics. Computed irrigation depths were compared with results of a catch can analysis to assure accuracy of the computer simulation. This analysis created a data set in polar coordinates. A CAD program was used to create an array of polygons, 25 ft in length at each 5° increment.

This set of polygons was spatially joined within the GIS program with the water application array, and the average depth of water applied computed from the CPED-estimated points falling within each polygon. Irrigation history was collected both manually and by data loggers which queried the computerized pivot panels at 15 minute intervals. This log of operating speed, position, and sprinkler line pressure was used as input to CPED to compute spatial and temporal seasonal depth of water applied.

Chemical Application

Approximately one-half the total available N was applied by fertigation during the growing season. Fertigation injection rate was determined at 15 minute intervals during application by logging the depth of liquid in the UAN storage tank (Figure 2).

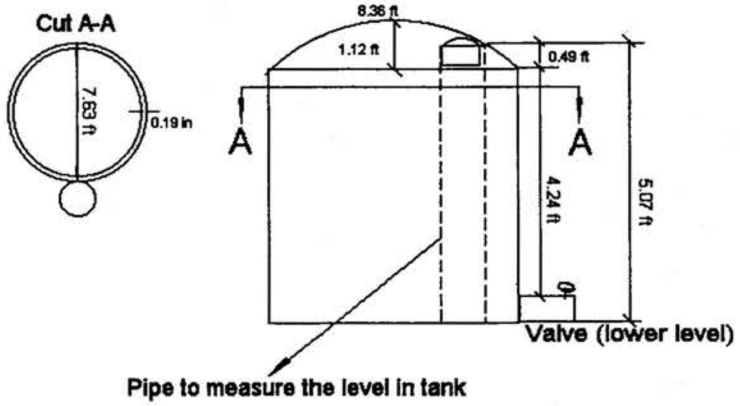

Figure 2. Diagram of tank level UAN solution measurement.

The pivot was equipped with an electric powered injection pump, which was expected to pump at a more uniform rate than the pressure-dependent water powered pump. Both line pressure and sprinkler lateral position were also logged at 15 minute intervals. Samples of concentrated UAN and water/UAN solutions were collected periodically for lab analysis to verify N concentration.

RESULTS AND DISCUSSION

The seasonal irrigation application under the center pivot during the 1999 season is showing in figure 3. The mean weighted (by area) seasonal depth of irrigation was 20.5 inches for the season. The uniformity coefficient was 0.89, which has historically been considered quite uniform. However, this uniformity coefficient still requires that 20% more water that the crop actually uses must be applied to deliver sufficient water to the dries quarter of the field!

As we can see from figure 3, the topography of the area (Figure 1), plays an important role in the spatial distribution of water under the pivot. The higher areas have lower water application, as we can see in the north and southeast areas of the field. The lower areas have higher water application as we can see in the northwest area.

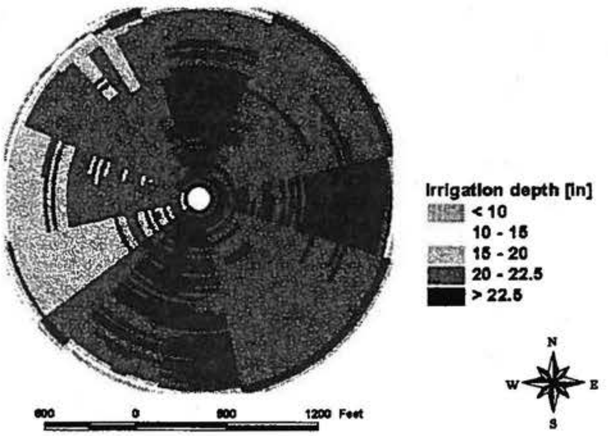

Figure 3. Seasonal irrigation distribution under center pivot - 1999.

The effect of topography is accentuated by turning the end gun on and off. When the end gun is turned on, the pressure in the system is reduced and the sprinkler heads apply less water. On the other hand, when the end gun is off, the pressure in the system increases and more water is applied. This phenomenon can be seen in Figure 3; when the end gun is off (between 35-50, 100-115, 165-175, and 315-330 degrees) there are segments with higher application, and lower application when the end gun is on. The rings of lower and higher application in the edge of the center pivot (figures 3), are due to improperly sized nozzles and improper angle settings on the end gun.

The spatial distribution of nitrogen from all significant sources was evaluated for the 1999 season on a 250 x 250 foot grid. Preseason soil samples were collected to determine the residual N. The average N carryover in these coarse soils was 31 pounds per acre. Preplant and starter fertilizer added 75 pounds per acre N. Soil organic matter was determined for each grid and used to estimate in-season mineralization of N, averaging 28 pounds per acre. The average concentration of nitrate N in the groundwater during the season was 5 ppm, which resulted in an additional 23 pounds per acre.

Figure 4 shows the seasonal spatial nitrogen application (lb/ac) by fertigation under the pivot. Comparing Figure 4 with Figure 3 shows that the behavior of the nitrogen application is not exactly the same as that of water application. There is high nitrogen application was under the north area, where elevations are low (Figure 1) and water application high (Figure 3). We can also see the effect of the end gun turning on and off. In the high elevation areas (from 130 to

230 degrees) the high pressure in the mainline reduces the injection rate. Even so, we have less water applied in those areas, and less nitrogen application. This variability in nitrogen application affects the nitrogen uniformity application with a reduction of the uniformity from the 0.89 (uniformity of the water application) to a value of 0.76. This value of nitrogen uniformity requires that the total N applied be 45% more than the crop needs just to assure that there is enough N to meet crop needs in the average of the 32 acres of the field receiving the least amount (Duke, et al, 1991). Thus, it is important that the uniformity of water application be quite high if the system is to be used for fertigation. The use of pressure regulators may help achieve a uniform water application when there is significant topographic variation or when an end gun is used.

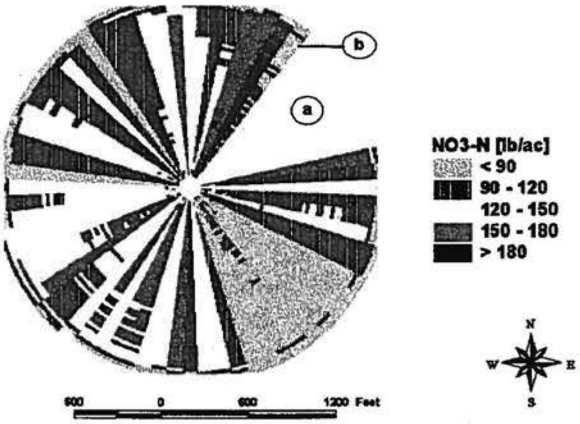

Figure 4. Spatial nitrogen application (lb/ac) by fertigation in 1999.

The available nitrogen from each source, as shown in Table 1, was summed for the season for each of the 250 x 250 ft grid cells. Figure 5 shows the distribution of total N available to the crop during the 1999 growing season.

We can used the water and nitrogen spatial application to match with soil properties in order to adjust the amount of water and nitrogen spatially applied. Using the spatial distribution of water and nitrogen in conjunction with scheduling of irrigation and fertigation could be useful to optimize the water resources and may reduce ground water contamination by nitrogen.

Before the 2000 irrigation season, the pivot was renozzled using pressure regulators. As a result, the uniformity coefficient was increased to 0.96, which reduces the necessary overapplication of water from 20% to 6%. This improvement in water uniformity will not alone improve the N fertigation uniformity by a like amount because the total water flow is still reduced when the end gun is turned off. The fertilizer injection rate is not correspondingly reduced, however, resulting in a higher concentration of fertilizer in the water, and greater application per unit area. Thus, additional changes in management are necessary to achieve uniform fertigation. Although additional testing under various conditions is necessary, the concept of use precision approach to optimize the water and nitrogen resources applied appears to be very workable.

Table 1. Sources of N available to the crop during the 1999 growing season.

Source	Pounds per acre	
	Mean	Std. Dev.
Residual	31.4	9.3
Preplant	50.0	-
Starter	25.0	-
Mineralization	28.1	3.9
Irrigation Water	23.1	2.6
Fertigation	118.7	31.3
Total	276.4	35.1

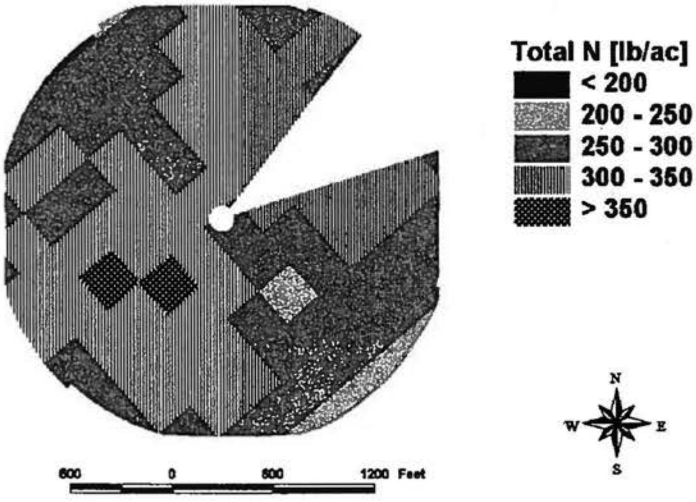

Figure 5. Distribution of total available nitrogen during the growing season.

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USING ULTRASONIC FLOW METERS IN IRRIGATION APPLICATIONS

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University of Nebraska

INTRODUCTION

Irrigation is no different from any other crop production input; to be managed effectively and economically it must be measured accurately. Several devices exist to measure water flow in pipelines. A relatively new alternative is the ultrasonic flowmeter (USFM). The USFM is a non-invasive device that can be used to measure both flow rate and volume. Clamp-on transducers eliminate in-line installation, allowing one meter to be used at many locations (Figure 1). Exterior installation eliminates pressure losses and prevents leaking that can be associated with in-line meter installations.

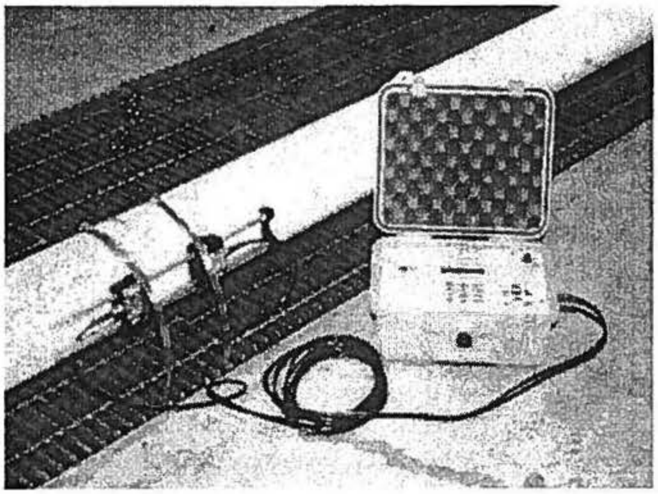

Figure 1. Transit-time ultrasonic flow meter.

The transmission, or transit-time, ultrasonic flowmeter operates on the principle of phase shift. Two transducers act alternately as transmitter and receiver as two paths of sonic beams travel back and forth across the pipe (Figure 2). One beam travels downstream while the other moves upstream. The motion of the fluid causes a frequency shift in both waves. This shift is related to the velocity of the fluid. Research has shown that, when installed properly, USFM accuracy ranges from +/- 1 to +/- 5 percent of full scale.

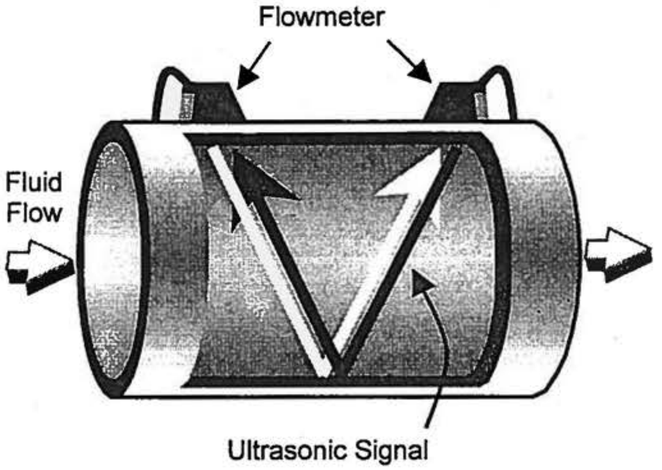

Figure 2. Transit-time ultrasonic flow meter measurement technique.

When measuring fluid in a pipeline, proper flow meter installation is one of the most important requirements for accurate flow measurement. This is true for any type of meter. As water passes through valves, pumps, reducers, tees, and elbows, it is agitated and sometimes sent into a swirling motion. It is difficult to accurately measure water that is agitated and swirling. To ensure that fluid flowing past the measuring location is "well conditioned" (*undisturbed*), meters should be installed with a sufficiently long section of straight, unobstructed pipe upstream from the meter location. Unobstructed upstream distances are often measured in terms of pipe diameters, Dp (Figure 3). For example, if one were measuring flow in an eight-inch pipe, 5 Dp (five pipe diameters) equals 40 inches. Table 1 shows a range of pipe sizes and the corresponding lengths for several values of Dp.

Most common meter location recommendations call for a *minimum of five to ten* straight Dp free of obstructions upstream from the meter and *at least one* straight pipe diameter free of obstructions downstream from the meter. If these requirements cannot be met, the piping conditions are "*non-ideal*" for flow measurement. A common problem found in irrigation-well meter installations is that the upstream unobstructed, straight pipe length recommendation cannot be met and metering is often done in a non-ideal piping configuration.

The popularity of ultrasonic flowmeters is due in large part to their portability and ease of use, they can be installed almost anywhere. Nonetheless, the need to adhere to proper installation guidelines remains. The purpose of this NebGuide is to report on recent research that will help ultrasonic flow meter users adjust inaccurate flow rate measurements that, because of preexisting conditions, are collected under non-ideal piping configurations.

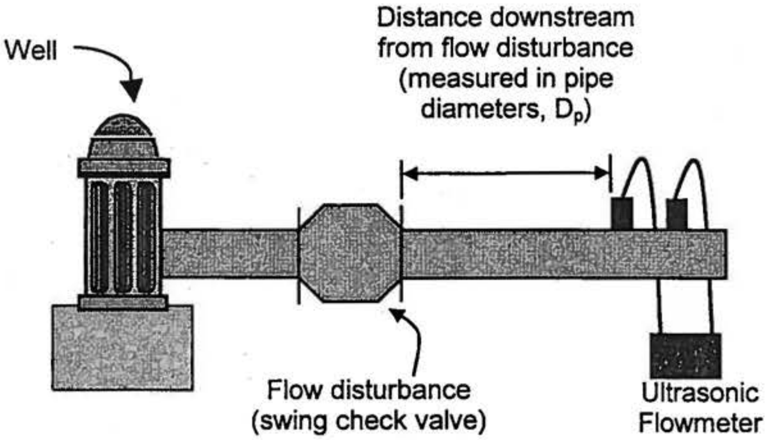

Figure 3. Schematic illustrating a typical irrigation system piping configuration.

Table 1. Dp (pipe diameters) lengths for the range of pipe sizes commonly found in irrigation systems.

	Pipe diameter (in.)			
	4	6	8	10
Pipe Diameters (Dp)	Distance (in.)			
2	8	12	16	20
4	16	24	32	40
6	24	36	48	60
8	32	48	64	80
10	40	60	80	100
15	60	90	120	150
20	80	120	160	200
30	120	180		
40	160			
50	200			

***Distances greater than 200 inches intentionally omitted**

ULTRASONIC FLOW METER PERFORMANCE RESEARCH

For this research three flow disturbing devices were used, a 90° elbow, a spring-loaded swing check valve, and a butterfly valve. These devices were arranged to produce five different flow-disturbing configurations (Table 2). Table 3 shows the tested combinations of the pipe material, diameter, and flow disturbance. The 6-inch steel and 6-inch PVC pipe were used to evaluate the extremes of pipe roughness normally found in irrigation systems. For comparison purposes, four flow rates typically found in irrigation systems (220, 440, 660, and 880 gpm) were evaluated. A Polysonics Model ISTT-P portable transit-time USFM was used for this experiment. Flow rate measurements were taken at 2, 4.5, 10, 22, and 50 Dp downstream from the flow disturbance.

Table 2. Test configurations.

Abbreviation	Configuration, Flow disturbing device
SEL	Single Elbow
2EL	2 Elbows in different planes*
CHK	Swing Check Valve
BV5	Butterfly Valve, vertical axis 50% open
BH5	Butterfly Valve, horizontal axis 50% open

* Used to simulate the transition from an underground supply line to the upright of a pivot riser.

Table 3. Tested combinations of flow disturbance devices, pipe sizes, and pipe materials.

		Tested pipe sizes and devices				
Material	Diameter (in.)	SEL	2EL	CHK	BH5	BV5
PVC	6	x	x	x	x	x
PVC	8	x	--	--	--	--
Steel	6	x	x	x	x	x
Aluminum	6	x	--	--	--	--

As a part of this research, two components of accuracy were evaluated – bias and precision. Figure 4 illustrates the concepts of bias and precision. Bias is that portion of the overall accuracy of a given measurement that is the result of some systematic error. An example of bias would occur if you installed tires on your car that are too small. Since the speedometer is based on the rate of tire revolution, the smaller tires will cause the speedometer to systematically register higher than it would otherwise. Locating a meter too close to a flow disturbance can cause a systematic error.

Precision is that portion of the overall accuracy that is the result of random errors that are out of the user's control. As users of the ultrasonic meter, we can do little to correct for random errors, it is simply a measurement uncertainty that must be acknowledged. Recall that previous research has shown that, when installed properly, (i.e. with no systematic installation bias) ultrasonic flow meter accuracy ranges from +/- 1 to +/- 5 percent of full scale.

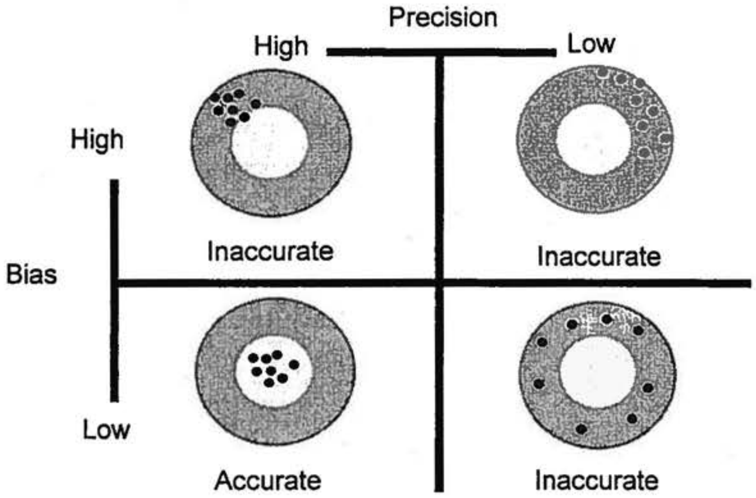

Figure 4. Illustration of the two components of accuracy, bias and precision.

ULTRASONIC FLOW METER PERFORMANCE

To characterize ultrasonic flow meter performance an accuracy or performance envelope was developed. The performance envelope incorporates both the bias and precision associated with the tested configurations of flow disturbance, pipe material and flow rate. The performance envelope documents USFM performance from 2 to 50 PD downstream from a given flow disturbance, Figure 5. By convention, because bias can be either negative (under prediction) or positive (over prediction), performance envelopes are drawn around the axis of perfect accuracy – zero percent inaccuracy. Figure 5 illustrates that when using the USFM at 2 Dp downstream from the type of flow disturbance evaluated here, the inaccuracy can be as much as +/- 36 percent.

Examining Figure 5 more closely, the bias at 2 Dp is a negative 15 percent. In other words, the ultrasonic flow meter systematically under predicted the actual flow rate by some 15 percent. The imprecision at 2 Dp was +/- 21 percent. That means that the range of measurements was +/- 21 percent of the average USFM measurements collected at 2 Dp. As one might expect as distance downstream from the flow disturbance increases, USFM performance improves. At 50 Dp the USFM exhibited essentially no directional bias and the overall accuracy had improved to less than +/-2 percent. Based on these results, its clear that meter location is critical to measurement accuracy. But what if meter locations are restricted to positions very near a flow disturbance? Using the bias and precision data just illustrated, a flow measurement correction approach was developed.

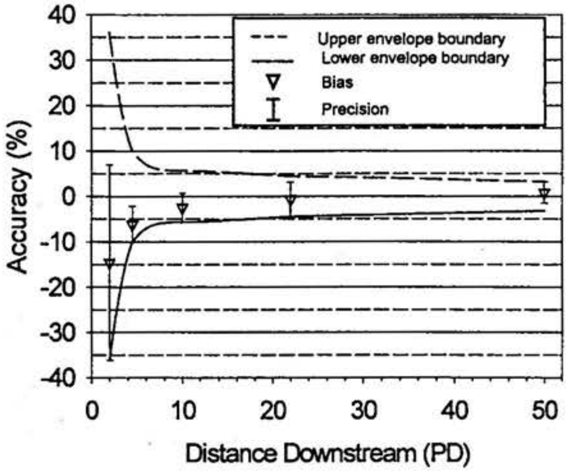

Figure 5. Ultrasonic flow meter performance envelope.

CORRECTING FLOW RATE MEASUREMENTS

To correct for the negative bias shown in Figure 5, a bias-correcting multiplier was developed. Figure 6 shows the multiplier relationship as it varies with distance downstream from a flow disturbance. The equation shown in Figure 6 can be used to predict a bias-correcting multiplier at any downstream measurement location between 2 and 50 Dp. Even after the bias of a particular flow measurement is corrected, a certain level of imprecision due to random error remains. That degree of uncertainty is characterized in Figure 7, which shows the corresponding accuracy for an ultrasonic flow meter reading after the bias-correcting multiplier has been applied. Developed from Figures 6 and 7, Table 4 contains multiplier and accuracy values for some specific Dp values. The following example shows how to use Table 4 to adjust inaccurate USFM measurements.

In this example, assume the USFM is mounted 6 Dp downstream from the flow disturbance, in this case a swing check valve. If this system were plumbed using 8-inch pipe, 6 Dp would be equal to 48 inches (Table 1). The distance between the spring check valve and meter is measured from the downstream flange of the check valve to the upstream USFM transducer. For this example assume that the USFM reads 837 gpm. If we look in Table 4 for Dp = 6, the multipler equals 1.05 and the accuracy equals +/- 3%.

Applying the bias-correcting multiplier to the USFM flow reading gives the *Adjusted Flow Rate.*

$$\text{Adjusted Flow Rate} = 1.05 \times 837\,\text{gpm} = 879\,\text{gpm}$$

Applying the accuracy value for Dp = 6 (+/- 3%) gives an adjusted measurement accuracy range of 850 to 907 gpm. The design flow rate for the irrigation system measured in the example was 880 gpm. This example and two others are shown in Table 5.

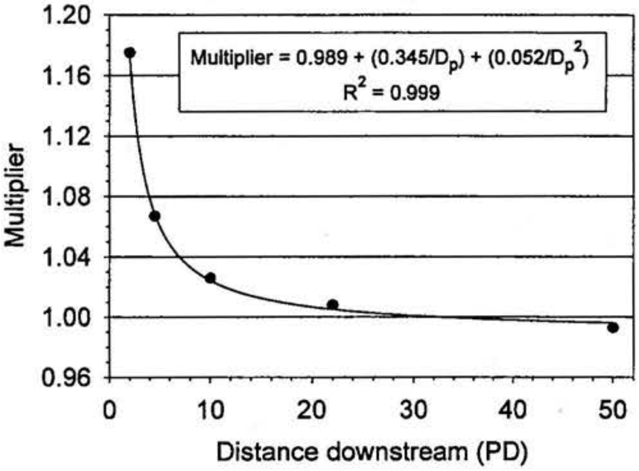

Figure 6. Bias-correcting multiplier.

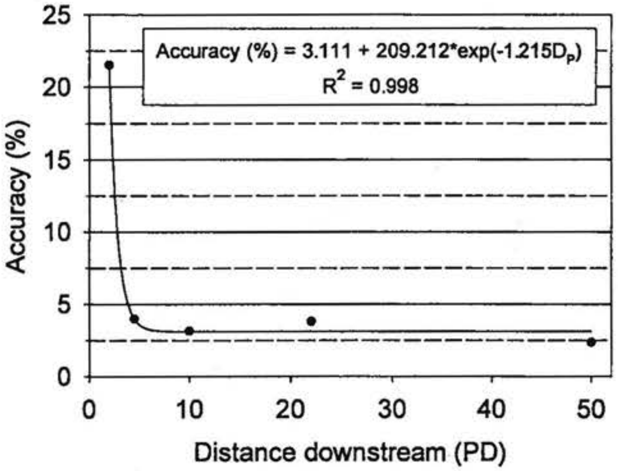

Figure 7. USFM accuracy with bias removed.

Table 4. Multiplier and accuracy values at selected pipe diameters (Dp)

Distance Downstream from Flow Disturbance (D_p)	Multiplier (dimensionless)	Accuracy after adjustment (+/-, %)
2	1.15	20
3	1.10	9
4	1.07	5
5	1.06	4
6	1.05	3
7	1.04	3
8	1.03	3
9	1.03	3
10	1.02	3
15	1.01	3
20	1.01	3
30	1.00	3
40	1.00	3
50	1.00	3

Table 5. Example of ultrasonic flow measurement adjustment and accuracy.

Measured Flow Rate (gpm)	Location (PD)	Accuracy pre-adjustment (+/-, %)	Multiplier	Adjusted Flow Rate (gpm)	Accuracy post-adjustment (+/-, %)	Accuracy range of adjusted flow rate (gpm)
758	2.0	35	1.15	872	20	1046 – 697
795	3.5	19	1.08	859	7	919 – 799
837	***6.0***	***7***	***1.05***	***879***	***3***	***905 – 852***

CONCLUSIONS AND RECOMMENDATIONS

For the flow disturbances evaluated here (Table 2), the USFM consistently under-predicted the actual flow near the flow disturbance and became more accurate as the distance downstream from flow disturbance increased (Figure 5). Based upon these results, we recommend, if at all possible, the USFM should be installed with at least 10 Dp of straight, unobstructed pipe upstream from the measurement location. In circumstances where the USFM must be installed closer than 10 Dp, the bias-correction method presented here can be used to find a more accurate flow rate and assess the accuracy of that adjusted measurement. *The reader should note that the correction multipliers presented here apply only to those flow disturbing devices listed in Table 2.*

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ANNUALIZED COST OF AN IRRIGATION SYSTEM

For Central Plains Irrigation Shortcourse,

February 5 & 6, 2001 Kearney, Nebraska

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WHY COMPUTE THE ANNUALIZED COSTS?

A number of management decisions are based on the annualized costs of owning and operating an irrigation system. Before developing land for irrigation the first decision should be whether the irrigation system will be economically feasible, (will the returns more than offset the costs?). After deciding to proceed with irrigation development, one is faced with many alternative design choices. Sometimes there are offsetting costs and benefits associated with choices; e.g. lower initial cost for one distribution system vs. another may result in higher labor costs and/or lower irrigation efficiency which may increase operating cost and partially or completely offset the initial savings. Aside from development and design considerations, on rented land, an estimate of ownership and operating costs is necessary when negotiating a fair rental arrangement between the landowner and tenant.

Economic Feasibility Studies

Following a dry year like 2000, there is increased interest in developing irrigation. The question is: Will the return in higher yields over the life of the system more than off-set the cost of ownership and operation plus the additional crop input expenses for irrigated vs. dryland production? The only way to truly answer this question is to do a thorough economic feasibility analysis.

Irrigation systems have many components, each of which has a different expected useful life, anticipated repair costs, and different estimates for labor for normal operation and maintenance. Component costs, service life, maintenance repair, and energy costs all can differ under the same operating conditions depending on the design choices made.

If one has a set of financial records and has been irrigating in the past, they may have a pretty fair estimate of the expected out-of-pocket costs for operation and maintenance for an irrigation system. Out-of-pocket expenses only account for a portion of the total costs, however. When conducting an economic feasibility study, one must consider both the costs associated with ownership and the cost of operation.

Comparing Choices

The annualized cost of an irrigation system is dependent on the design choices made. Different systems have different costs. For example: A center pivot sprinkler system will likely have a higher initial cost and a higher cost per inch of water delivered than a gated pipe system (because of higher system pressure) but probably will require less gross water applied to meet crop needs and fewer hours of labor for operation. The question is, will the savings offset the higher costs over the life of the system?

The energy required for irrigation pumping is dependent on both the quantity pumped (acre-inches) and the total head (lift plus pressure) the pump is working against. In a given situation, the lift component of the head cannot be changed but the pressure required does change from one type of system to another, resulting in different fuel costs per acre-inch delivered.

There are four energy sources typically used for pumping irrigation water. They are: Diesel, Electricity, Natural Gas, and Liquid Propane (LP) gas. Different energy sources can be expected to deliver a different number of horsepower hours of useful work per unit of energy consumed and per dollar spent on energy. When fuel prices change relative to one another, the most economical energy source can change. The energy source selected dictates the type of power unit that must be purchased as well. Different types of power units have greatly different purchase prices and estimated useful service lives.

Crop Share Rental Arrangements

Occasionally, extension staff are asked to help landowners and tenants work out fair crop share rental arrangements. One method used in extension is to sit down with both parties and develop a listing of the monetary value of the contributions each party is making. The landowner needs to receive a fair return on the value of his land and other assets as well as cover his costs for taxes, upkeep and insurance. The tenant needs to receive a fair return on his labor and machinery and cover his variable expenses such as fuel and repairs. Some or all, crop input expenses may be shared in most crop-share arrangements, but how they are shared varies case by case.

When computing a fair crop-share rental arrangement, the procedure is to list all the contributions that are required for crop production in a table (land, irrigation system, machinery, labor, crop inputs, etc.). After each input listed, the contribution each party is making is shown in parallel columns; one for the landowner and one for the tenant. The columns are tallied and the percentage of the total cost that each party is making is calculated. The "fair" rental arrangement would be to divide the crop on the same percentage as the contributions that each party has made. Alternately, after the initial listing is done, changes are sometimes made in the percentage the two parties contribute to certain inputs until contributions match a pre-determined crop share arrangement (e.g. 60/40 or 50/50).

The costs of owning and operating the irrigation system are some of the most difficult to identify when analyzing irrigated crop share arrangements. Much of the total cost of irrigation results from ownership costs and a large percentage of ownership costs are not annual out-of-pocket costs.

A complicating factor in some rental agreements results from who owns the various components. In some cases, the landowner may furnish the entire irrigation system; in other cases the landowner may furnish the well, pump and gear head; while the tenant may furnish the power unit and/or the distribution system. A need therefore exists for the analyst to easily estimate the ownership and operating costs for each major component in various irrigation systems so each party is credited with a fair estimate of the contribution he/she is making.

Examples

The author has developed a computerized spreadsheet which can assist the manager with analyzing the costs described in this paper. Since a picture is worth a thousand words, following are some sample runs. Figures 1 and 2 represent a typical center pivot system in central Nebraska. The difference between these are the energy sources used (diesel vs. natural gas). Figures 3 and 4 both use an electric motor to pump the water, the difference is the distribution system used (center pivot vs. gate pipe with a surge valve). Many other comparisons like these could be made, so long as the prices for the alternative components and energy sources are known.

Summary

As can be seen, this approach can be used to determine the annualized costs when conducting an irrigation economic feasibility study. One can compare the ownership and operating costs for an array of possible irrigation design choices, the result being identification of the most economically feasible choice for a given situation. Finally, it also can be used to help put a value on the assets, labor, expected fuel costs, etc. when analyzing rental arrangements.

This spreadsheet was developed in Corel Quattro Pro v.9 for Windows $_{TM}$. It has been converted using the conversion utility to Microsoft Excel$_{TM}$ v5/v7 format. Interested parties can download these spreadsheets at no cost from the following website: http://www.ianr.unl.edu/ianr/lanco/ag/crops/irrigate.htm . Click on the heading Annualized Cost of an Irrigation System and then right click on the format you want to download. Use the "save link as" feature to save the file to a folder (directory) on your computer. You should then be able to open your spreadsheet program, browse to the file, and open it.

Annualized Cost of an Irrigation System

Figure 1 - Diesel & Pivot

Distribution System Code	1
Acres Irrigated	130
Pumping water level, ft.	125
System Pressure, PSI	35
Gross Depth applied, Inches	12
Fuel Source Code	1
$/Gal Diesel	**$1.000**
Labor Chrg, $/hour	**$10.00**
Irrigation District, $/ac-ft	**0**
Return on Invest. (R.O.I), %	**5**
Drip Oil, $/gal	**$6.00**

Distribution System Codes

Center Pivot = 1
Gated Pipe = 2
Surge Valve = 3
Siphon Tube = 4
Drip System=5

Fuel Source Codes

Diesel = 1
Nat Gas = 2
LP Gas = 3
Electricity = 4
$0.00

Component				**Ownership Costs**			**Operating Costs**			
	Initial Cost	**Life**	**Salvage[1]**	**R.O.I.**	**Insurance + tax**	**Depr**	**Repairs[2]**	**Oper. labor**	**Energy[3]**	**Total**
Irrigation Well	**$12,543**	25	-$627	$316	$125	$527	$163	$16		$1,147
Irrigation Pump	**$10,148**	18	$507	$228	$101	$536	$355	$62		$1,282
Gear Head	**$1,900**	15	$95	$42	$19	$120	$25	$16		$222
Pump Base, etc.	**$1,433**	25	$72	$33	$14	$54	$22	$16		$139
Diesel Engine & Tank	**$11,571**	12	$579	$252	$231	$916	$507	$234	$2,919	$5,060
Center Pivot System	**$33,000**	15	$1,650	$732	$660	$2,090	$1,287	$468	$291	$5,528
	$0	25	$0	$0	$0	$0	$0	$0	$0	$0
										$0
Totals	$70,595		$2,275	$1,602	$1,152	$4,243	$2,359	$811	$3,211	$13,378

	Ownership Costs	**Operating Costs**	**Costs**
Total annual cost	$6,996.79	$6,380.90	$13,377.69
Annual $/ Acre	$53.82	$49.08	$102.91
$/ac-in	$4.49	$4.09	$8.58

[1] End of life salvage value 5% of purchase price except for irrigation well. End of life cost for well = 5% to plug the well

[2] Drip oil added to repair costs. For internal combustion engines, 5% of energy costs added to repair costs for oil, filters, and lube.

[3] Energy Cost assumes operating at 100% of the NPC. Hookup charge added for Electric Units.

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Annualized Cost of an Irrigation System

Figure 2 - LP gas & Pivot

Distribution System Code	**1**
Acres Irrigated	**130**
Pumping water level, ft.	**125**
System Pressure, PSI	**35**
Gross Depth applied, inches	**12**
Fuel Source Code	**3**
$/Gal LP Gas	**$0.850**
Labor Chrg, $/hour	**$10.00**
Irrigation District, $/ac-ft	**0**
Return on Invest. (R.O.I), %	**5**
Drip Oil, $/gal	**$8.00**

Distribution System Codes

Center Pivot = 1
Gated Pipe = 2
Surge Valve = 3
Siphon Tube = 4
Drip System=5

Fuel Source Codes

Diesel = 1
Nat Gas = 2
LP Gas = 3
Electricity = 4
$0.00

Component				**Ownership Costs**			**Operating Costs**			
	Initial Cost	**Life**	**Salvage**[1]	**R.O.I.**	**Insurance + tax**	**Depr**	**Repairs**[2]	**Oper. labor**	**Energy**[3]	**Total**
Irrigation Well	$12,543	25	-$627	$316	$125	$527	$163	$16		$1,147
Irrigation Pump	$10,148	18	$507	$228	$101	$536	$403	$62		$1,330
Gear Head	$1,900	15	$95	$42	$19	$120	$25	$16		$222
Pump Base, etc.	$1,433	25	$72	$33	$14	$54	$22	$16		$139
LP Gas Engine	$4,395	6	$220	$87	$88	$696	$362	$234	$4,502	$5,969
Center Pivot System	$33,000	15	$1,650	$732	$660	$2,090	$1,287	$468	$449	$5,686
	$0	25	$0	$0	$0	$0	$0	$0	$0	$0
										$0
Totals	$63,419		$1,917	$1,437	$1,008	$4,023	$2,262	$811	$4,951	$14,493

	Ownership Costs	**Operating Costs**	**Costs**
Total annual cost	$6,468.18	$8,024.53	$14,492.71
Annual $/ Acre	$49.76	$61.73	$111.48
$/ac-in	$4.15	$5.14	$9.29

[1] End of life salvage value 5% of purchase price except for irrigation well. End of life cost for well = 5% to plug the well

[2] Drip oil added to repair costs. For internal combustion engines, 5% of energy costs added to repair costs for oil, filters, and lube.

[3] Energy Cost assumes operating at 100% of the NPC. Hookup charge added for Electric Units.

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Annualized Cost of an Irrigation System

Figure 3 - Electric & Pivot

Distribution System Code	1
Acres Irrigated	130
Pumping water level, ft.	125
System Pressure, PSI	35
Gross Depth applied, Inches	12
Fuel Source Code	4
$/kW.h Elec	$0.040
Labor Chrg, $/hour	$10.00
Irrigation District, $/ac-ft	0
Return on Invest. (R.O.I), %	5
Drip Oil, $/gal	$8.00

Distribution System Codes

Center Pivot = 1
Gated Pipe = 2
Surge Valve = 3
Siphon Tube = 4
Drip System=5

Fuel Source Codes

Diesel = 1
Nat Gas = 2
LP Gas = 3
Electricity = 4

Annual Electric Hookup Charge $1,650.00

Component				**Ownership Costs**			**Operating Costs**			
	Initial Cost	**Life**	**Salvage[1]**	**R.O.I.**	**Insurance + tax**	**Depr**	**Repairs[2]**	**Oper. labor**	**Energy[3]**	**Total**
Irrigation Well	$12,543	25	-$627	$316	$125	$527	$163	$16		$1,147
Irrigation Pump	$10,148	18	$507	$228	$101	$536	$403	$62		$1,330
Gear Head	$0	15	$0	$0	$0	$0	$0	$0		$0
Pump Base, etc.	$1,433	25	$72	$33	$14	$54	$22	$16		$139
Electric Motor& Switches	$2,900	20	$145	$65	$58	$138	$255	$39	$3,299	$3,855
Center Pivot System	$33,000	15	$1,650	$732	$660	$2,090	$1,287	$468	$165	$5,401
	$0	25	$0	$0	$0	$0	$0	$0	$0	$0
										$0
Totals	$60,024		$1,747	$1,373	$959	$3,345	$2,131	$601	$3,464	$11,873

	Ownership Costs	**Operating Costs**	**Costs**
Total annual cost	$5,677.15	$6,195.40	$11,872.55
Annual $/ Acre	$43.67	$47.66	$91.33
$/ac-in	$3.64	$3.97	$7.61

[1] End of life salvage value 5% of purchase price except for irrigation well. End of life cost for well = 5% to plug the well

[2] Drip oil added to repair costs. For internal combustion engines, 5% of energy costs added to repair costs for oil, filters, and lube.

[3] Energy Cost assumes operating at 100% of the NPC. Hookup charge added for Electric Units.

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Annualized Cost of an Irrigation System

Figure 4 - Electric & Gated Pipe

Distribution System Code	2
Acres Irrigated	150
Pumping water level, ft.	125
System Pressure, PSI	10
Gross Depth applied, inches	15
Fuel Source Code	4
$/kW.h Elec	$0.040
Labor Chrg, $/hour	$10.00
Irrigation District, $/ac-ft	0
Return on Invest. (R.O.I), %	5
Drip Oil, $/gal	$8.00

Distribution System Codes
Center Pivot = 1
Gated Pipe = 2
Surge Valve = 3
Siphon Tube = 4
Drip System=5

Fuel Source Codes
Diesel = 1
Nat Gas = 2
LP Gas = 3
Electricity = 4

Annual Electric Hookup Charge **$1,980.00**

Component				**Ownership Costs**			**Operating Costs**			
	Initial Cost	**Life**	**Salvage**[1]	**R.O.I.**	**Insurance + tax**	**Depr**	**Repairs**[2]	**Oper. labor**	**Energy**[3]	**Total**
Irrigation Well	**$12,543**	25	-$627	$316	$125	$527	$235	$23		$1,226
Irrigation Pump	**$10,148**	18	$507	$228	$101	$536	$581	$90		$1,536
Gear Head	**$0**	15	$0	$0	$0	$0	$0	$0		$0
Pump Base, etc.	**$1,433**	25	$72	$33	$14	$54	$32	$23		$156
Electric Motor& Switches	**$4,761**	20	$238	$107	$95	$226	$399	$56	$3,691	$4,575
Gate Pipe	**$8,745**	15	$437	$194	$87	$554	$394	$1,125	$0	$2,354
Reuse?	**$10,225**	25	$511	$233	$205	$389	$575	$450	$100	$1,951
										$0
Totals	$47,855		$1,138	$1,111	$628	$2,285	$2,216	$1,766	$3,791	$11,798

	Ownership Costs	**Operating Costs**	**Costs**
Total annual cost	$4,024.59	$7,773.63	$11,798.22
Annual $/ Acre	$26.83	$51.82	$78.65
$/ac-in	$1.79	$3.45	$5.24

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[1] End of life salvage value 5% of purchase price except for irrigation well. End of life cost for well = 5% to plug the well
[2] Drip oil added to repair costs. For internal combustion engines, 5% of energy costs added to repair costs for oil, filters, and lube.
[3] Energy Cost assumes operating at 100% of the NPC. Hookup charge added for Electric Units.

Written by: Tom Dorn, Extension Educator UNL-IANR Lancaster County, NE 1/11/01

COMPUTING FIELD LOSSES FOR FURROW IRRIGATION

Brian L. Benham
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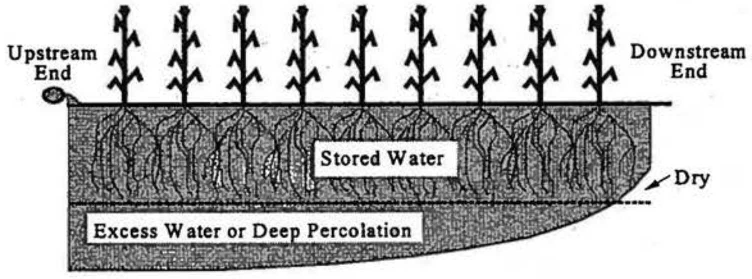
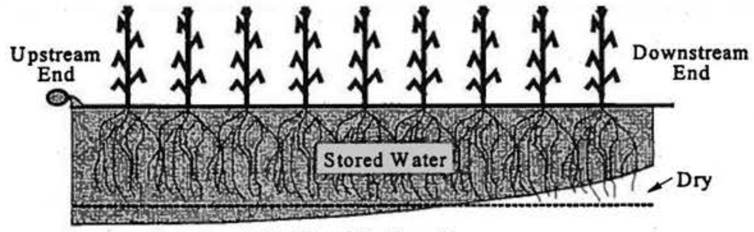
The goal of every irrigator should be to apply the right amount of water as uniformly as possible to meet the crop needs. To do the job right, irrigators need to take into account how much water is applied during irrigation and where the water goes (uniformity). Achieving a uniform water application 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.



1a. Poor Uniformity



1b. Good Uniformity

Figure 1. Infiltration profiles under conventional furrow irrigation.

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.

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: $R_i = 0.617$
$R_p = 0.061$
$R_r = 0.323$

$$Infiltration\,depth\,exceeded\,in\,90\%\,of\;field = 5\,inches\,x\,0.617 = 3.1\,inches$$

$$Depth\,of\;percolation = 5\,inches\,x\,0.061 = 0.3\,inches$$

$$Depth\,of\;runoff = 5\,inches\,x\,0.323 = 1.6\,inches$$

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

$$AE = Application\,Efficiency = \left[\frac{1 - R_r - R_p}{1 - R_r R_T}\right] x\,100$$

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)

$$AE = \left[\frac{1 - 0.323 - 0.061}{1 - (0.323\,x\,0.85)}\right] x\,100 = 85\%$$

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.

SELECTING SPRINKLER PACKAGES FOR LAND APPLICATION OF LIVESTOCK WASTEWATER

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INTRODUCTION

Livestock operations have changed dramatically in the last ten years. For example the number of hog farms has decreased from 600,000 to 157,000 in the last fifteen years. (Harkin 1998) During this same time the overall output of pork has increased. This increase of size also indicates an increased concentration of animals. Problems associated with any traditional livestock production unit are multiplied as the size increases. Management of the wastewater stream becomes a major component of the management strategy. Maintaining the environmental quality for the area of the livestock operation is critical to the overall success.

Livestock wastes may be applied by a number of methods. Tractor towed manure spreaders or slurry wagons are used to apply to the soil surface. Tractor towed slurry tanks with equipment to 'inject' the waste into the soil are used. Another choice is a plow down system where a tractor tows an injection unit attached to a long hose connected to a pump and the lagoon. On-land application units such as fixed head sprinklers, traveling guns or a center pivots are also commonly used.

Decisions on the type of waste application system are important to the economics of the livestock operation. Timing is one issue, which plays a key role in determining application methods (Hardeman 1997). Most of the methods listed above are only viable in the spring before the crop is planted or in the fall after it is harvested. Center pivots are not however limited by whether a crop is present or not as they may be used to apply over an active crop.

Center pivots, due to their characteristics, are considered to have advantages with regards to applying livestock wastes, particularly from a lagoon with large amounts of water to handle. Some of these characteristics include limited labor input required, application uniformity, ease in handling large quantities of effluent and particularly the ability to apply to actively growing crops with minimal negative impact to the crop.

Operators readily invest in major capital improvements and equipment to facilitate the production of meat or milk by providing the best possible environment for the animals. However most producers have a strong reluctance to invest in more than the minimum required to meet existing local, state and federal environmental regulations for disposal of the wastewater. If the investment does not add value to their operation - why make the expenditure?

DISCUSSION

Land application of wastewater with center pivot and linear irrigation equipment has been used for more than thirty years. Until the late 1970's the land application package was easy to select, as the choices were limited to relatively high-pressure impact sprinklers (50psi) or the Valley Slurry Shooter™ using high volume sprinklers (90psi). Since the early 1980's the equipment and techniques for irrigating with fresh water have changed dramatically to the point the pressures at the nozzle inlet may be as low as 6psi. Currently more than five major classes of sprinkler packages are being used with many options within each class – pad styles being the main option. In many cases both water for reuse and fresh water are applied with the same equipment. Midwest Plan Service's MWPS-30 (MWPS, 1999) discusses general principles in sprinkler selection relating to fresh water application but does not attempt to quantify any procedure or specifically look at effluent application. Other publications have provided general discussions without offering a specific procedure – Livestock Waste Facilities Handbook (MWPS, 1993), Liquid Manure Application Systems Design Manual (NRAES, 1998) and Agricultural Waste Management Field Handbook (USDA, 1992)

Then also in today's world one must take into account the issues and public perception of land application systems. Land application of wastes may be imposing in some locations, potentially dangerous conditions relative to environmental quality (Hegde 1997). We must insure any equipment being used for land application meets public scrutiny.

OBJECTIVE

How does one select the optimum sprinkler package for a particular waste water situation?

DISCUSSION

Currently many sprinkler packages are selected by irrigation dealers and customers based on personal experience and preference. Some of these general sprinkler categories are:

type	orifice diameters	pad	pressure
drag hose	4/64 to 24/64in	none	6 to 10psi
fixed pad	4/64 to 24/64in	fixed	6 to 20psi
rotating pad	4/64 to 24/64in	rotating	15 to 30psi
impact	9/64 to 40/64in	n/a	40 to 60psi
high volume guns	0.50 to 0.94in	N/A	45 to 90psi

A systematic approach does not exist to assistance in the decision making process. Experience has taught that "if it worked the last time, it should work again" or "that is what my neighbor's doing".

It is recommended looking at each system individually to make the selection on the best information available.

To begin the process information is required about the particular application:

- Material being applied
  - Estimated solids content
  - Organic material
  - Inorganic material
  - Particle size
- Environmental constraints
  - Ground water wells
  - Neighbors
  - Tile line
- Management issues
  - Operating costs
  - Energy costs
  - Maintenance
- CAFO permit constraints

Then look at how the wastewater stream is handled –

- Collection
- Treatment (if any)
- Storage
- Pump system
- Position of inlet of the pump

We have tried to develop a quantitative approach to the selection of a recommended sprinkler package based on the information collected. To do this we apply the information to a ranking system

First assign 1-5 points for each item based on the headings –

Value to assign	1	2	3	4	5
Item			Range		
1 - Solids content	<0.5%	1.0%	2.0%	3.0%	>4.0%
2 - Particle size	small		medium		large
3 - Pump impeller	closed		semi open		open
4 - Pump inlet	floating				bottom
5 - Labor costs	low		medium		high
6 - Energy costs	high		medium		low
7 - Environment	high		medium		low
8 - Storage	2 stage Lagoon		1 stage lagoon		pit
9 - Collection	flushing				scraper
10 – Pump style	fresh water		slurry		chopper
11 – Uniformity (CU)	85		75		65

Minimum number of possible points – 11
Maximum number of points - 55

This is the range within which to work with the lower the number tending to indicate a wastewater stream, which has limited solids content and small particles. The closer a number approaches 55 the thicker the wastewater and larger the particles.

Some of the items are relatively easy to estimate – others such as the solids content are very difficult. The following table is one way to characterize the solids in a waste stream.

First visualize a bucket with the manure in it. Then start tipping the bucket -

Angle from ground	how it flows	estimated solids
45 degrees above	smooth stream	1 to 2%
30 degrees above	in small globs	3%
15 degrees above	in quarter sized globs	4%
0 degrees, bucket parallel to ground	fist sized globs	5%

45 degrees, pouring down	thick chunks	6%

This table allows a method to roughly estimate the solids content based on how the effluent flows.

Using the point total one goes into the table to select a recommended sprinkler type.

Point Total	Type	Pad	Pressure
10 to 19	low pressure on drops	fixed	6 to 20psi
20 to 29	low pressure on drops	rotating	15 to 30psi
30 to 39	impact	n/a	40 to 60psi
40 to 50	high volume guns	n/a	45 to 90psi

A worksheet was developed to allow a person to 'fill-in-the blank' with the data and information collected. One does the best to estimate and make a selection based o experience and quantitative data if available.

Sprinkler Selection Worksheet

Item
Ranking

1) -Solids content – _____ consistancy _____% ___
2) Particle size _____ inches ___

3) Pump impellor _____ ___
4) Pump inlet _____ ___

5) Labor costs _____ $/hr ___
6) Energy costs _____ ¢/kw-hr or gallon ___

7) Environment _____ issues ___
8) Storage _____ ___

9) Collection _____ ___
10) Pump style _____ ___
11) Uniformity _____ ___

Total Points ___

Ranking	**type**	**pad**	**pressure**
11 to 19		fixed	6 to 20psi
20 to 29		rotating	15 to 30psi
30 to 39	impact	n/a	40 to 60psi
40 to 55	high volume guns		45 to 90psi

Sprinkler package selected – ____________________

Pad type if applicable – ____________________

Pressure selected - ____________________

Testing of the selection process

Example 1 **-** Single stage dairy lagoon, limited labor, no neighbors within two miles, flushing system, wants to pump from bottom, is not nutrient limited. Primarily system to be used for land application and not irrigation.

Item ranking			
1) Solids content –	thick consistancy	4%	4
2) Particle size	3/16 inches (pieces of corn cob)		4
3) Pump style	slurry		4
4) Pump impellor	semi open		3
5) Pump inlet	on bottom of lagoon		5
6) Labor costs	9.25 $/hr		4
7) Energy costs	4.25 ¢/kw-hr or gallon		2
8) Environment	no issues		5
9) Collection	flushing		1
10) Storage	pit		5
11) Uniformity	low		5
		Total Points	42

Ranking	type	pad	pressure
10 to 19		fixed	6 to 20psi
20 to 29		rotating	15 to 30psi
30 to 39	impact	n/a	40 to 60psi
40 to 50	high volume guns		45 to 90psi

Sprinkler package selected
minimum of impact sprinkler, hig volume gun suggested

Pad type if applicable -
Not applicible to impact or volume guns

Pressure selected –
Minimum suggested of 45psi

Example 2 - *two* stage hog lagoon, limited labor, no neighbors within two miles, plug/pull system, wants to pump from top w/ floating pump, wants no problem with plugging and will use for irrigation

Item ranking			
1) Solids content –	thin	<.5%	1
2) Particle size	3/16 inches (trash in lagoon, in-organics		4
3) Pump style	fresh water		1
4) Pump impellor	closed		1
5) Pump inlet	on top of lagoon		1
6) Labor costs	20.00 $/hr		4
7) Energy costs	2.25 ¢/kw-hr or gallon		2
8) Environment	no issues		5
9) Collection	flushing		1
10) Storage	two stage lagoon		1
11) Uniformity	high		1
		Total Points	22

Ranking	**type**	**pad**	**pressure**
10 to 19		fixed	low
20 to 29		rotating	low to medium
30 to 39	impact	n/a	medium to high
40 to 50	high volume guns		high

Sprinkler package selected

From ranking – rotating pad

But customer suggestions wants no problems

A combination system may be the best choice. Utilizing the wider spacing of the sprinklers with rotating pads for the first portion of the center pivot until a larger nozzle size is reached.

SUMMARY

The model has proved to be successful in the actual situations where it has been applied as a decision tool. This is process is not perfect and one must apply reasonable judgement in selecting a sprinkler package. Also the process is only as good as the data which is collected. As with any tool care must be taken to consider all factors and apply appropriately.

In addition center pivots can successfully used to meet requirements for minimizing environmental impact of spray drift and runoff and also meet customer requirement for monitoring and reporting by the selection of equipment options.

Livestock systems continue to evolve. Rations, genetics and housing systems have changed significantly in the last five years. Feeding and manure handling systems continue to change. As production units change the irrigation industry is working on equipment to continue to meet customer's requirements.

Center pivots continued to be an accepted option for land application of wastewater generated from a CAFO particularly if a lagoon or storage reservoir is used. This type of equipment provides the control and monitoring capabilities required by many CAFOs (LaRue 1998).

In many cases the CAFO may have different constraints from traditional farm livestock units. In these cases, alternative treatment such as the Sheaffer MRRS, (Sheaffer, 1998) anaerobic digestion or other methods may need to be utilized to reduce the nutrient, odor and sludge. Once the treatment process is completed, the remaining liquid fraction may be land applied with a center pivot or other system designed to handle large volumes of low nutrient strength water.

As is always the case the operator must be aware and follow local and state regulations.

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USING LIVESTOCK WASTEWATER WITH SDI
A STATUS REPORT AFTER THREE SEASONS

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ABSTRACT

Using subsurface drip irrigation (SDI) with lagoon wastewater has many potential advantages. The challenge is to design and manage the SDI system to prevent emitter clogging. A study was initiated in 1998 to test the performance of five types of driplines (with emitter flow rates of 0.15, 0.24, 0.40, 0.60, and 0.92 gal/hr-emitter) with lagoon wastewater. A disk filter (200 mesh, with openings of 0.003 inches) was used and shock treatments of chlorine and acid were injected periodically. Over the course of three seasons (1998-2000) a total of approximately 52 inches of irrigation water has been applied through the SDI system. The flow rates of the two smallest emitter sizes, 0.15 gal/hr-emitter and 0.24 gal/hr-emitter have decreased approximately 30% during the three seasons, indicating some emitter clogging. The three largest driplines (0.40, 0.60, and 0.92 gal/hr-emitters) have had less than 5% reduction in flow rate. The disk filter and automatic backflush controller have performed adequately with the beef livestock wastewater in all three years. Based on these results, the use of SDI with beef lagoon wastewater shows promise. However, the smaller emitter sizes normally used with groundwater sources in western Kansas may be risky for use with lagoon wastewater and the long-term (> 3 growing seasons) effects are untested.

INTRODUCTION

In response to increasing nationwide concern about problems associated with livestock wastewater generated by confined animal feeding operations, K-State Research and Extension initiated a project to address odor, seepage into groundwater and runoff into surface water supplies. Subsurface drip irrigation (SDI) is a potential tool that can alleviate all three problems, while still utilizing livestock wastewater as a valuable resource for crop production. A study was begun in 1998 on a commercial beef feedlot to answer the engineering question, ***"Can SDI be successfully used to apply livestock wastewater?"***

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Approximately 8 million cattle are on feed in the central and southern Great Plains of the USA; more than 2 million are in Kansas alone. Using the Kansas design parameter of 250 ft^2 per animal, the land area of feedlots in the Great Plains is approximately 45,500 ac, and that in Kansas is approximately 11,400 ac. Perhaps 20 to 33% of average annual precipitation in the Great Plains could be collected as runoff from feedlots. Assuming 20% runoff and an average annual precipitation of 20 inches, approximately 3,700 and 15,000 ac-ft of runoff from feedlots might be available annually in Kansas and the Great Plains, respectively. This feedlot runoff, minus any evaporation from the lagoons, must be disposed of by land application.

Using subsurface drip irrigation (SDI) with this livestock wastewater has many potential advantages. These include, but are not limited to,

- Saves fresh water for other uses
- Reduces groundwater withdrawals in areas of low recharge
- Rich in nutrients, such as N, P, and K, for crop growth
- Reduced human contact with wastewater
- Less odors and no sprinkler aerial pathogen drift
- No runoff of wastewater into surface waters
- Subsurface placement of phosphorus-rich water reduces hazards of P movement into streams by runoff and soil erosion
- Greater water application uniformity resulting in better control of the water, nutrients, and salts
- Reduced irrigation system corrosion
- Reduced weather-related application constraints (especially high winds and freezing temperatures)
- Increased flexibility in matching field and irrigation system sizes
- Better environmental aesthetics

Worldwide, the leading cause of microirrigation system failure is clogging of the emitters. Therefore, it is easy to recognize that prevention of emitter clogging will be the primary design and management challenge of using SDI with this particle-rich, biologically active wastewater. Given that challenge, the objective of this project was to measure the performance of five different dripline types as affected by irrigation with filtered but untreated water from a beef feedlot runoff lagoon.

METHODS

This project was conducted at a beef cattle feedlot in Gray County, KS. The soil type is a Richfield silt loam. As is typical for beef feedlots in the region, precipitation runoff water from beef cattle pens was collected in a single-cell lagoon. Selected wastewater characteristics are shown in Table 1.

Table 1. Selected wastewater characteristics, Midwest Feeders, KS, 1998-2000.

Sampling Date	pH	EC mmho/cm	SAR	N ppm	P ppm	K ppm	TDS ppm	BOD ppm	TSS ppm
Mar. 6, 1998	8.00	2.93	1.8	118	35	336	1875	N/S	N/S
Jun. 5, 1998	7.81	2.56	1.9	92	30	341	1613	N/S	N/S
Jul. 17, 1998	7.84	2.54	2.0	67	30	349	1625	N/S	N/S
Jul. 31, 1998	7.64	2.70	2.0	89	30	383	1728	N/S	N/S
Aug. 21, 1998	7.60	2.90	2.2	51	33	428	1856	N/S	N/S
Sep. 1, 1998	7.90	3.60	2.3	84	32	467	2304	96	190
May 12, 1999	8.20	5.29	2.9	260	39	724	3386	1033	580
Aug. 13, 1999	7.60	4.30	2.9	160	39	672	2739	405	1320
Sep. 10, 1999	8.00	5.30	2.8	140	31	724	3379	255	440
Jun. 23, 2000	7.80	4.90	2.9	240	53	828	3136	998	533
Jul. 13, 2000	8.10	5.20	2.7	250	53	828	3328	834	740
Aug. 25, 2000	8.00	5.10	3.0	210	31	888	3290	228	940

N/S: Not sampled.
Abbreviations: N: nitrogen, P: phosphorus, K: potassium,
TDS: total dissolved solids, TSS: total suspended solids,
BOD: biochemical oxygen demand.

In April 1998, driplines were installed 17 inches deep and on a lateral spacing of 60 inches. Each plot was 20 ft wide (4 driplines) and 450 ft long. Plots were arranged in a randomized complete block design with three replications. There was a border plot (using the 0.40 gal/hr-emitter laterals) at each of the north and south ends for a total of 17 plots. The system installation and testing were completed on June 16. The first wastewater was used for irrigation on June 17. After completion and testing of the system, the lagoon wastewater was the only water that has been applied with the SDI system; no fresh clean water has been used for irrigation, flushing, or dripline chemical treatment. Corn was the irrigated crop in all three seasons.

Five drip irrigation lateral line (dripline) types, each with a different emitter flow rate (and thus different emitter size), were tested (Table 2) to determine the optimum emitter size that would be less prone to clogging with the wastewater. Agricultural designs of SDI in the Great Plains with groundwater typically use lower flow rate emitters. The emitter flow rates and flow path dimensions were obtained from the manufacturers.

Table 2. Selected emitter characteristics for the driplines used in the SDI study using livestock wastewater, Midwest Feeders, KS, 1998-2000.

Emitter flow rate, (gal/hr)	Flow path dimensions, width by height by length (inch)	Flow path area, (inch^2)	Operating inlet pressure (psi)
0.15	*	*	8
0.24	0.0212 by 0.0297 by *	0.000663 **	8
0.40	0.028 by 0.032 by 0.787	0.000896	10
0.60	0.034 by 0.037 by 0.713	0.001258	10
0.92	0.052 by 0.052 by 0.610	0.002704	***

* These dimensions were not available from the manufacturer.

** Flow path was not rectangular, so the area differs from the product of the width X height.

*** This product was a pressure-compensating emitter. Inlet pressure was greater than 30 psi.

The wastewater was filtered with a plastic grooved-disk filter with flow capacity about 25% greater than the filter manufacturer's recommendations for wastewater (1168 in^2 for our maximum flow rate of 120 gal/min). The disks were selected to provide 200-mesh equivalent (openings of 0.003 inches) filtration even though the manufacturers' recommendations for all driplines were filtration of 140 mesh or finer. A controller was used to automatically backflush the filter after every hour of operation or when the differential pressure across the filter reached 7 psi. To help keep bacteria and algae from growing and accumulating in the driplines and to clean lines of existing organic materials, acid and chlorine occasionally were injected simultaneously into the flow stream at injection points about 3 ft apart. Acid was added at a rate to reduce the pH to approximately 6.3. The acid used was N-pHuric 15/49, and the chlorine source was commercial chlorine bleach (2.5% Cl). Flushing (10 dripline volumes) to clean the lines and injections took place on the schedule shown in Table 3.

Generally, daily irrigations of 0.25 to 0.40 inch were made each season from June to early September, except when crop water use did not exceed precipitation or when the irrigation pump was inoperable. Each plot received the same daily application amount, so plot run times varied according to dripline flow rate. Seasonal applications were 21, 15, and 16 inches in 1998, 1999 and 2000, respectfully. The 1998 amount greatly exceeded the crop water requirements but allowed more rigorous testing of the system. Additional flow tests were conducted between growing seasons (Oct. 6-7 and Nov. 17, 1998 and Nov. 3, 2000). In Kansas, few crops require irrigation during the winter months, so the system was allowed to remain idle during the overwinter periods. This stagnation period might increase the potential for system degradation from clogging, but it represents practical operating conditions for this climate.

Table 3. Dates of flushing and injection, Midwest Feeders, KS, 1998-2000.

Date	Flush ?	Injection ?
July 9, 1998		Y
July 27, 1998		Y
August 4, 1998	Y	Y
August 31, 1998		Y
September 2, 1998	Y	Y
September 4, 1998		Y
October 6, 1998	Y	Y
November 17, 1998	Y	Y
June 8, 1999	Y	Y
June 9, 1999	Y	
July 28, 1999		Y
August 5, 1999	Y	Y
August 6, 1999	Y	
August 24, 1999	Y	Y
August 25, 1999	Y	
September 10, 1999		Y
April 28, 2000	Y	
May 3, 2000		Y
June 13, 2000		Y
June 21, 2000		Y
June 23, 2000	Y	
August 1, 2000		Y
August 3, 2000	Y	
August 8, 2000	Y	
August 9, 2000		Y
November 3, 2000	Y	

A blank means the operation did not take place on that day.

The flow rates for entire plots were measured approximately weekly during the season whenever the system was operational. Totalizing flow meters were used on each plot to measure the amount of wastewater delivered during an approximately 30 minute test. Pressure was measured at the dripline inlets during each flow test. To account for the variation due to minor fluctuations of pressures from test to test, the calculated flowrates were normalized to the design pressure (Table 2) using the manufacturer's emitter exponent for that dripline type.

RESULTS AND DISCUSSION

Of the five dripline types tested, the three higher-flow emitter sizes (0.40, 0.60, and 0.92 gal/hr-emitter) showed little sign of clogging (Fig. 1). Flow rates at the end of the test for those emitters were within 5% of the initial flow rates, indicating that very little clogging and resultant decrease of flow rate had occurred. The absence of clogging indicates that emitters of these sizes may be adequate for use with lagoon wastewater.

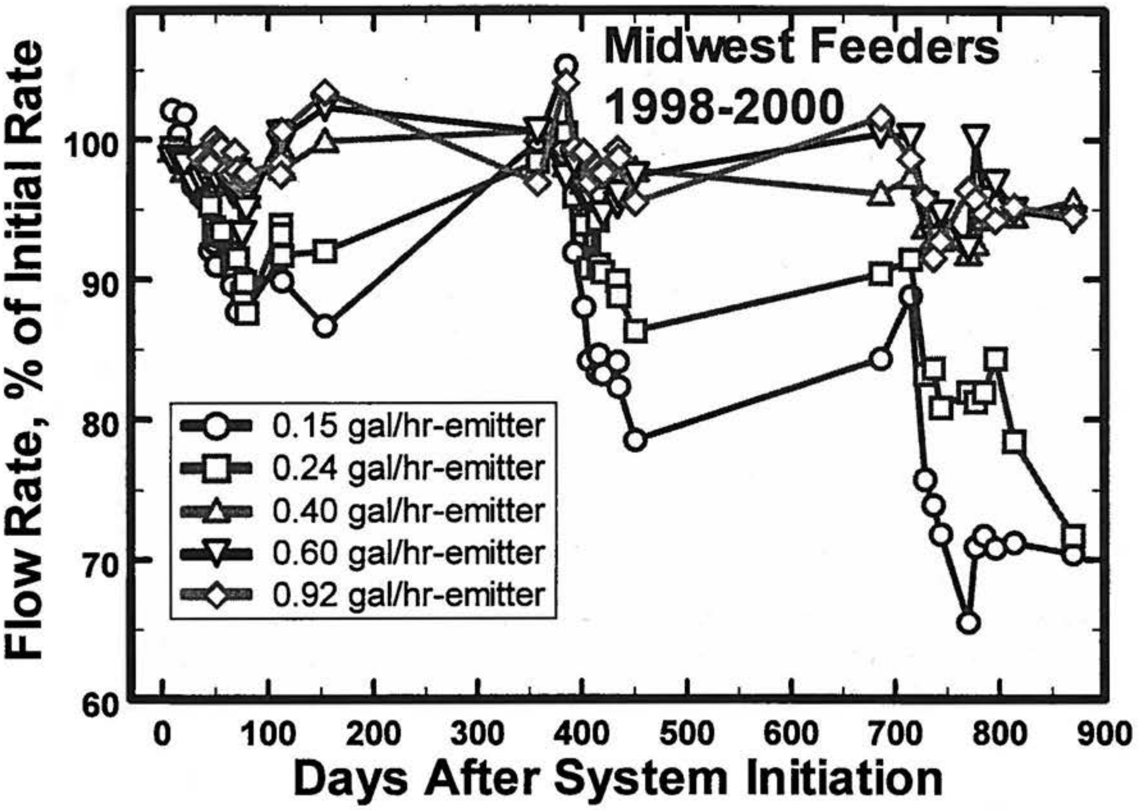

Figure 1. Measured flow rates for five dripline types with different emitter flow rates using lagoon wastewater, Midwest Feeders, KS, 1998-2000.

The two lower-flow emitter sizes (0.15 and 0.24 gal/hr-emitter) showed some signs of emitter clogging (Fig. 1) during all three growing seasons. Within 30 days of system completion in 1998, the flow rates in plots with both smaller emitter sizes began to decrease. The 0.15 gal/hr-emitter plots showed a gradual decrease of flow rate throughout the remainder of the season. By November 17, 1998 (Day 154), the flow rate had decreased by 15% of the initial rate. The 0.24 gal/hr-emitter plots showed a decrease in flow rate of 11% of the initial rate by September 2, 1998 (Day 78). Following harvest and the first (32-day) idle period, flow rates in the 0.24 gal/hr-emitter plots increased approximately 5% over the minimum measured rate. This increase indicates that some cleaning of the emitters had occurred in response to the flushing. The flow rate then stabilized for the rest of 1998 at about 9% less than the initial rate.

Following the winter idle period (Day 368), all flow rates recovered to near their initial flow rates (Fig. 1). Possible explanations for this include (a) the longer time that the acid and chlorine remained in the driplines allowed better control of biological clogging agents or (b) the cooler temperatures during the winter resulted in partial control of the biological clogging agents and the acid and chlorine were then more effective at cleaning up the remaining agents.

The smaller emitter sizes continued to have decreasing flow rates during the 1999 and 2000 growing seasons (Fig. 1), similar to the response in 1998. By the end of the third season (November 3, 2000, Day 870), flow rates had decreased by 30% in both of the smaller emitter sizes compared to the initial (maximum) flow rate.

The disk filter and automated backflush controller operated well in all thee years.

Excavation and visual inspection of dripline samples showed that flushing was effective in removing the accumulations of materials from the driplines. Prior to flushing, a slimy substance probably containing both silt and biological materials was present in the lines. After flushing, the driplines were clean.

Other management procedures might be employed to prevent performance degradation in the lower flow-rate emitters or remediate it after it occurs. Such procedures might include more frequent flushing, flushing with fresh water, and more frequent and concentrated chemical-injection treatments. However, the objective of this study was to compare the different driplines under difficult but identical conditions. Further studies are warranted to determine if the lower flow-rate driplines can be maintained at a higher performance level with more aggressive management.

These results show that the drip irrigation laterals used with SDI have potential for use with lagoon wastewater. However, the smaller emitter sizes normally used with groundwater sources in western Kansas may be risky for use with lagoon wastewater. The dripline performance was similar during all three growing seasons, but questions remain about the long-term, multiseason performance of SDI systems using livestock wastewater. Long-term reliable performance probably will be necessary to justify the high investment costs of SDI systems.

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IRRIGATING WITH SWINE EFFLUENT

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INTRODUCTION

Nebraska swine annually produced manure containing 40 million pounds of nitrogen. The trend toward increased concentration of animals in large production units makes it difficult to find enough available land for economical manure distribution at agronomic application rates. In Nebraska, pigs per farm have increased from 250 in 1982 to 507 in 1997. As the number of pigs per enterprise have increased, there has not been a corresponding increase in the number of acres per enterprise available for land application and crop utilization of the stored swine manure.

The goal of our research was to evaluate alfalfa as a nitrogen sink for swine effluent. Data from our experiment has shown that alfalfa receiving 600 pounds of swine effluent nitrogen per acre removed about 100 pounds more nitrogen per acre than alfalfa receiving no swine effluent. Established, irrigated alfalfa can remove more than 700 pounds of nitrogen per acre in the harvested hay (Table 4). The implication is that producers can reduce the land base for effluent distribution by over 50% when compared to the 200 pound removal rate for corn followed by winter rye (Table 4). This could be beneficial to producers who do not have sufficient land to apply effluent at agronomic rates to corn or other row crops.

Additional advantages to alfalfa are: it covers the ground all year round which reduces the erosion potential; the nitrogen use curve is more constant through the season than for annual crops; uptake of phosphorus and potassium are relatively high; effluent application can occur at times that are not possible in a corn system; and alfalfa is deep rooted and can scavenge nitrogen from deeper in the soil than most other crops grown in Nebraska.

METHODS

A line-source sprinkler system was used to distribute a range of effluent rates to both alfalfa and corn. Figure 1 shows the distribution of the effluent and of fresh water. The experiment was designed so that the distribution patterns of both the fresh and effluent waters produce an even amount of water application. Therefore, only effluent rates changed. Rates of effluent were chosen that provided from 0 to 140% of the predicted nitrogen harvest for the corn-winter rye and alfalfa treatments. Irrigation of each crop could be controlled and was applied based on soil moisture and crop nitrogen needs with the caveat of needing to apply up to 600 lb-N per acre near the centerline.

Laboratory analysis showed that the effluent contained about 90 lbs total nitrogen, 100 lbs K_2O, and 10 lbs P_2O_5 per acre-inch of water (Table 1). The goal was to apply sufficient effluent so that at the end of the growing season both the corn and alfalfa would have plot areas with an excess of applied N. In 1994, soil samples, leachate and crop harvest took place at 6 equally spaced areas across each cropping system plot for a range of 0 to 140 percent of nitrogen application versus estimated harvest removal.

At each sampling site a porous cup extractor was installed 6.5 feet in the ground (Insert, Figure 1). The soil water solution passing the cup was sampled and analyzed for nitrate. Neutron readings were recorded to determine the rate of water flow past the 6.5 foot depth. This information was used to determine the amount of nitrate leaching at each sampling site (Table 3).

The original alfalfa stand was planted in the fall of 1992 and replanted in 1993. In 1996 the corn-rye and alfalfa areas were switched. However, the gradient of increasing levels of swine effluent remained the same. In 1996, a non-nodulating alfalfa variety (Saranac) was planted along with the conventional variety and the number of subplots was reduced from 6 to 5 (Figure 1). Unlike the conventional variety, the non-nodulating isoline could not use atmospheric nitrogen for crop growth needs.

In each year, alfalfa samples were collected from each subplot using a flail-type forage harvester. Sampling protocol was designed to mimic a range of harvest management schemes. Thus, each replicate contained subplots that were harvested 3x, 4x, or 5x times per year. The 3x treatment was harvested at full bloom and the 4x and 5x at tenth bloom. The 5x treatment had the 5th harvest after a killing frost. Plant dry matter was collected from a 30 square foot area and used to estimate total dry matter production for the treatment. Laboratory analysis provided the N content in each alfalfa sample.

RESULTS

In 1994, dry matter production ranged from 9 to 10 tons of alfalfa per acre. Thus, the addition of 560 lb-N resulted in an additional ton of dry matter production (Table 2) and a slight increase crude protein of about 1.5% (data not shown). Yields were highest when the alfalfa was harvested 4 times per season at approximately 10% bloom. Apparently, the harvest after a killing frost reduced yields for the 5x treatment.

Subsurface drainage was greater than would be typical of a field managed using irrigation scheduling techniques (Table 3). This was due in large part due to near normal precipitation and below normal temperatures so irrigation need was minimal. Drainage ranged from 6 inches in plots receiving no lagoon water to 4 inches in plots receiving 560 lb-N. This reduction in drainage is attributed to the additional production (1 ton/ac) resulting from the lagoon water application.

The N concentration of soil water at the 6.5 foot depth had flow-weighted average concentrations that ranged from 4.9 ppm in plots receiving no lagoon water to 37 ppm where 560 lb-N were applied (Table 3). The acceptable N concentration is up for discussion, however, if the maximum contaminant level for drinking water of 10 ppm NO_3-N is used, our data would suggest that approximately 340 lb-N could be safely applied to irrigated alfalfa. We were not in a position to estimate losses of N to the atmosphere during and after application, but published values are typically greater than 30%. Assuming 30% application loss, the actual removal in the alfalfa dry matter would be close to 235 lb-N. This level of utilization agrees with laboratory research from Minnesota that suggests that alfalfa will preferentially fix up to 2/3 of the N removed in the forage. This happened despite N applications that would have met crop needs. Thus, a high percentage of the N contained in the alfalfa forage will continue to be fixed from the atmosphere.

Nitrate leaching losses ranged from 7 to 33 lb-N per acre (Table 3). Though a zero tolerance rule could be applied, these levels are within the range recorded for crops fertilized with commercial fertilizer. Leaching losses would be reduced if subsurface drainage could be reduced by irrigation management strategies that allow plants to lower soil water content near the end of the season. Another beneficial practice would be to leave room in the soil profile for rainfall by accounting for the deep rooting depth of the crop. Both of these practices were not possible during this research due to timely rainfall events and the need to apply 6-7 inches of lagoon water.

In 1996, the non-nodulating alfalfa nitrogen harvest was 70 percent of the nodulating alfalfa at the zero effluent rate, but equal to the nodulating alfalfa at the higher nitrogen rates. Due to it being a crop establishment year, sufficient rainfall, and the use of irrigation scheduling, the maximum nitrogen applied in

1996 was 75 lbs total nitrogen/acre. Actual N removal in the forage was within 10 lb-N per acre for the non-nodulating and nodulating isolines (Table 4).

A severe winter in 1996 caused winter kill in the experiment, so the alfalfa was replanted in 1997. Subsequent work continues to support the notion that non-nodulating alfalfa will produce forage of the same quality and quantity as nodulating alfalfa if N is applied to meet crop needs. Failure to apply sufficient N tends to reduce plant stand by allowing weed competition, and it appears to increase the potential for winter-kill in the isoline we tested. Plant breeding efforts will likely reduce the winter-kill problems.

DISCUSSION

Documenting the environmental effects of swine effluent application is the major objective of this research. Two indicators have been monitored 1) soil nutrient levels in the spring and fall and 2) nitrate leaching.

Using book-values, 9 tons of alfalfa would remove about 500 lb-N, 135 lb-P_2O_5, 540 lb-K_2O per acre. In 1994, laboratory analysis of the dry matter indicated that about 700 lb-N were removed in the forage. Field data indicate that alfalfa can remove more applied N than a more traditional crop like corn. Thus, the lagoon water can be distributed over fewer acres of land when alfalfa is used as a scavenger crop.

Soil samples taken in the spring of 1997 indicated that a buildup of both phosphorus and potassium at the higher application rates was occurring (Table 5). The phosphorus levels are increasing despite removal at rates up to 50 lb-P_2O_5 per acre greater than the application rate. Research evaluating the long term impacts of manure applications have suggested that manures high in NH_4-N can change soil pH sufficiently to allow additional phosphorus to enter the available pool from the organic pool. In addition, increased microbial activity tends increase P mineralization rates. Both of these factors are likely present in fields where swine lagoon water is applied. Thus, long term application of swine lagoon water may need to account for the additional P in the management plan.

Potassium application was in excess of the removal rate so buildup was anticipated. However, continued buildup of soil potassium could cause soil structure problems in the future. At some point, effluent might need to be reduced until potassium levels decrease.

Leaching of nitrate may occur when drainage through the soil profile occurs. When irrigation scheduling techniques are used correctly, drainage is held to a minimum. When rainfall is greater than crop use, drainage is inevitable. Research using commercial fertilizer applications tends to suggest that off-season losses are a definite concern in Nebraska. So even if good irrigation management is practiced, over application of N may lead to leaching losses.

This is of particular significance where manure storage capacity considerations necessitate land application regardless of soil water availability, thus, increasing the risk of a drainage and N leaching event.

Application of swine effluent to alfalfa shows considerable promise based on the results of this research. Alfalfa uses large amounts of nutrients contained in animal manures and provides ample opportunities to spoon feed applications in much the same was as commercial fertilizers. Further development of the non-nodulating alfalfa isolines will enhance the value of alfalfa as a crop suitable for use in crop rotations used by animal producers.

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Table 1. Nutrient concentrations of monthly water samples collected from the swine lagoon in parts per million. Concord, NE.

Year	No. Sample	Total N	NH_4-N	P_2O_5	K_2O	S	Zn	Na	Ca	Mg
		-------	-------	-------	ppm	-------	-------	-------	-------	-------
1993	12	400	310	9.8	401	4.1	0.13	103	59	23
1994	12	420	371	12.8	554	2.1	0.14	114	65	26
mean		410	340	11.3	472	3.1	0.13	108	62	24

Table 2. Mean dry matter yields as affected by swine effluent application in1994. Concord. NE.

Effluent N Rate	Alfalfa Harvests per Season 3x	4x	5x	Mean
kg N / acre	-------------------	tons DM per acre	-------------------	-------------------
0	8.5	9.3	8.9	8.9
90	8.3	9.7	9.1	9.0
210	8.4	10.4	9.5	9.4
340	8.4	10.0	9.7	9.3
450	8.7	10.7	10.0	9.8
560	8.8	10.1	10.3	9.7

Table 3. Total nitrogen harvested after irrigation with swine effluent as alfalfa hay and in a corn/rye system. Concord, NE.

Year	Alfalfa type	Nitrogen	Crop	Nitrogen
		lbs/acre		lbs/acre
1993	Nodulating	230 - 250	Corn/rye	154
1994	Nodulating	680 - 745	Corn/rye	213
1995	Nodulating	337 - 520	Corn/rye	162
1996	Nodulating	270 - 383	Corn	205
1996	Non-nodulating	189 - 396		

Alfalfa was established in 1993 and 1996.
Rye cover crop did not survive winter in 1996.

Table 5. Effect of swine effluent application on drainage, leachate nitrate nitrogen and nitrate nitrogen leached. 1994. Concord, NE..

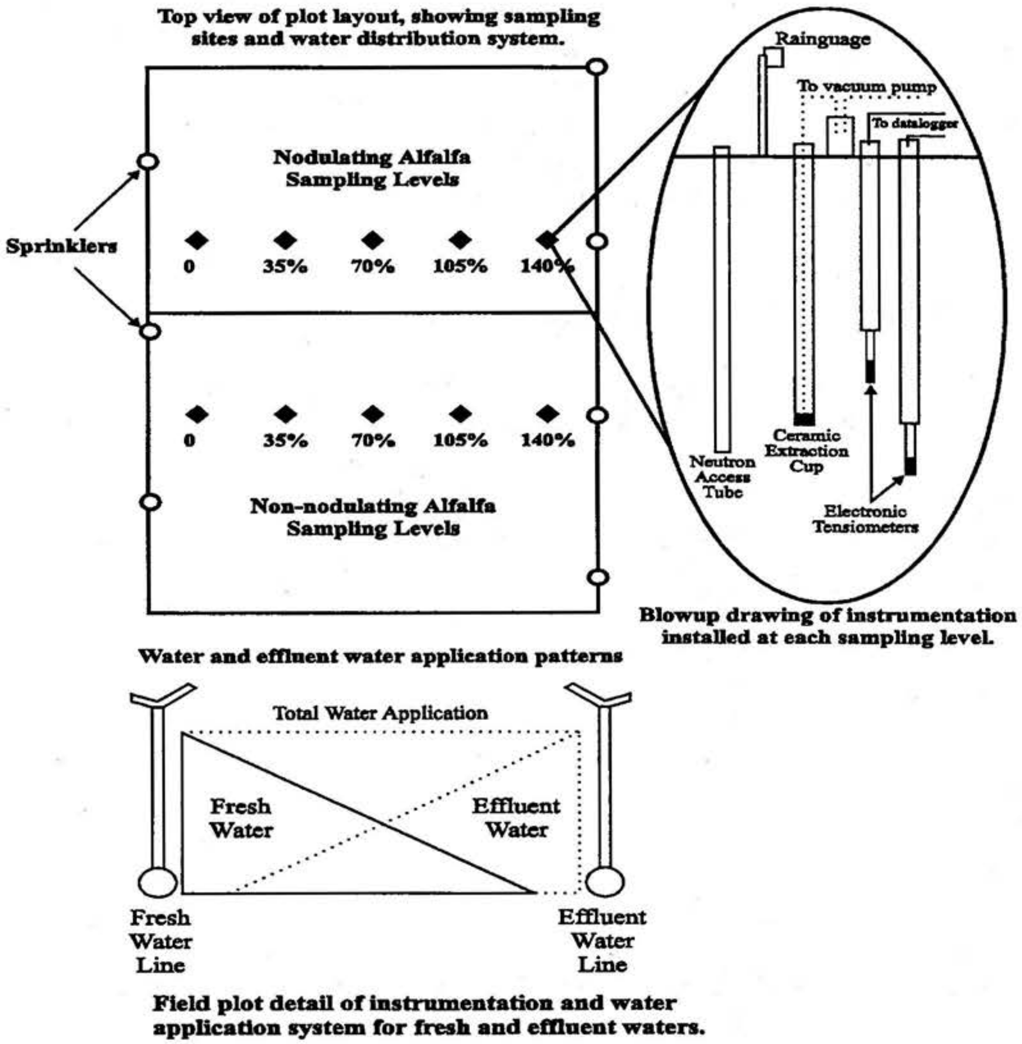
Effluent N-Rate	Drainage	Nitrate-Nitrogen Concentration	Nitrate-Leaching
(lb/ac)	(inches)	(ppm)	(lb/ac)
0	6.3	4.9	7.0
90	5.7	8.2	10.6
210	5.5	8.2	10.2
340	6.3	10.0	14.2
450	4.7	19.9	21.2
560	3.9	37.1	33.1
Mean	5.4	14.1	16.0

Table 4. Effect of lagoon water on soil phosphorus and potassium after four years of irrigation with swine effluent. Concord, NE.

Swine Effluent Application Intensity	Soil P	Soil K
% of estimated N removal	----------ppm	------------
0	31	188
35	42	213
70	51	306
105	70	383
140	66	364

Soil sampled spring 1997; corn grown 1996-97 and alfalfa 1993-95.

Figure 1. Field layout, water distribution and porous cup installation. Concord. NE.



Field Scale Evaluation of Center Pivot Systems

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The three states of Kansas, Nebraska, and Colorado have over fourteen million irrigated areas, of which eight million are irrigated by sprinkler irrigation systems. In the past decade, center pivot systems became the dominant sprinkler system type in the region. The growth of center pivot irrigated acreage is due to conversion of existing surface irrigated land to center pivot irrigation. A number of factors contribute to this conversion trend. Possibilities include:

1. Desire by irrigators to reduce irrigation labor requirements,
2. Desire by irrigators to conserve water through improved irrigation efficiency
3. Desire by irrigators to adopt reduced or low to no tillage production systems, and/or
4. Desire by irrigators for chemigation capability.

One of the underlying assumptions by irrigators regarding center pivot packages is that the water is being uniformly distributed across the field, so that all plants have an equal opportunity to the irrigation water applied. Irrigators have recognized that differences in irrigation efficiency exist between various sprinkler packages. Sprinkler package efficiency differences are due to a variety factors including differences in drift losses and canopy evaporation and the potential runoff.

In general, center pivot sprinkler packages are designed, installed and operated without much field verification of performance, either initially or over-time. Systems equipped with flow meters and pressure gauges can indicate that the systems are operating at design flow and pressure and, if so, are assumed to be operating at design specifications. While flow and pressure monitoring is a good and recommended best management practice, monitoring alone does not assure the over-all system performance is good.

Numerous center pivot nozzle devices and installation configurations have been developed along with use recommendations. However, testing of the performance along an entire full sized field center pivot system has been relatively infrequent for a variety of reasons; some of which are certainly the labor requirement and the wet messy condition for data collection immediately following irrigation in a field.

In 1995, irrigators from south central Kansas requested assistance from K-State Research and Extension personnel to establish a long-term project to promote adoption of best irrigation management practices with special emphasis on ET-based irrigation scheduling. The irrigators also wanted a major educational component of the project to include demonstrations using on-farm field sized irrigation systems. A research trial was also established at the Sandyland Experiment Field that had goals complimentary to the on-farm demonstration sites.

Irrigation scheduling is a process by which the timing and amount of irrigation water application to meet a specific management goal is determined. A parallel in today's business philosophy context for resource and product inventory control is "just enough, just in-time". In irrigation scheduling, control is in reference to water.

One concern to the irrigator is that the individual plants within a crop have equal access to water. This is especially important for high-yielding, full-irrigation scenarios. Therefore, part of the demonstration project and research study effort was directed towards evaluation of the sprinkler package performance in terms of irrigation distribution uniformity.

Sprinkler package uniformity evaluation involves catching of the applied water along the center pivot or lateral move irrigation system. The collection interval is determined by the distance between nozzles. The collection devices are positioned so that there is no interference by the crop canopy. The tests are usually done before or early in the growing season to avoid canopy interference. Measurement of the catch must be accomplished quickly after collection in order to minimize evaporation losses from the catch device.

Large diameter black feed pans were purchased and used to test the linear move sprinkler system at the Sandyland Experiment Field. A second catch was made simultaneously using large white-painted coffee cans. The sprinkler package had just been retrofitted with 6 psi LDN nozzles, spaced at 6 feet and positioned approximately at canopy height of fully grown corn. The initial purpose of the test was to verify the distribution uniformity of the new sprinkler package, which was assumed to high since it was a new, pressure-regulated package, designed and installed to the manufacturers recommendations. The test was also conducted to compare the results of the performance evaluation between the two catch can devices. The white coffee cans meet or exceeded ASAE catch can criteria, while the black feed pans did not. However, the black pans were preferable to the white cans because they could be nested together for better transport and storage efficiency. This was an important consideration in preparation for testing of multiple full size systems where the devices would have to be hand carried into and out of field.

The surprise from the evaluation, as shown in Figure 1, was that the new package did not result in high uniformity. The range of application depth was from one-half to nearly twice the average. However, the results between types of catch cans were similar, as is shown in Figure 2. The comparison included various pan spacings, catch can devices and application rates. The flowrate from each nozzle was caught separately and verified that each nozzle was discharging at the proper rate. Figure 2, as with other test data not shown, indicated that consistent performance evaluation occurred regardless of whether the can or the pan was used.

Based on this information, black pans were used when field scale evaluations were performed. However, the results of evaluation raised some concern since low pressure LDN nozzle packages are popular in the region.

The field evaluation of uniformities have resulted in discovery of a number of package deficiencies. Figure 3 represents a system that did not have the overhang portion of the package installed according to the design. One nozzle has been omitted and several other nozzle orifices were undersized. This resulted in an application depth in this portion of the system at only about one-half of the reminder of the system. The deficiently watered portion of the field represented approximately 20 acres. Yield losses due to the reduced water could potentially be as much as 40 bushels/acres. Annual losses due to the non-uniformity could exceed $1,600. The cost to correct this deficiency would be minimal.

A second example is shown in Figures 4a and 4b. This is a system package which included an end gun. The end gun was known to have an operational problem and during the test it was rotating 360°. This, of course, resulted in additional water being thrown back onto water pattern of the end tower. As seen in Figure 4a, excess application was being applied to the outer end of the system. This is an example of how an operational or maintenance problem can impact uniformity.

The same system was evaluated with the end gun off and shows the end portion of system has a defective application pattern (Figure 4b). Examination of the nozzle package revealed that during installation the series of nozzles for the two outside spans of the system had been reversed. The repair of the end gun and switching of reversed nozzle orifices would greatly improve uniformity of this system.

This system is equipped non-pressure regulated sprinkler package on a field with a large elevation charge. The system was tested on a relatively flat portion of the field. An additional evaluation on a sloped portion would be useful in evaluating the impact of elevation on the uniformity.

Figures 5a-c represent uniformity evaluations conducted on three center pivot irrigation systems all equipped with low pressure LDN nozzles, and nozzled for approximately the same system capacity. All were pressure regulated, and had drop nozzles of similar height. The major difference was the nozzle spacing.

The system shown in Figure 5a had a nozzle spraying of 5 foot and had a distribution uniformity of 90 percent, noted as CU on the graph which stands for coefficient of uniformity. Ninety percent is considered an acceptable industry standard. The system in Figure 5b had a CU of 84 percent. It had a nozzle spacing of 8 feet. The system in

Figure 5c had a CU of 87 percent with a nozzle spacing of 10 feet. The variable CU values for these three systems are consist with other research results that indicate nozzle spacing can have a large but somewhat difficult to predict impact on uniformity. Certainly a single snapshot of three systems should not be the sole basis altering system package design criteria. They do illustrate that each type of nozzle device have unique characteristics and operating constraints. These systems had been designed within recommended ranges, but at the lower end of the recommended operating pressure range. In this case, the low operating pressure made the nozzle distribution package very sensitive to the nozzle spacing. A complex relationship exists between uniformity and design parameter such as discharge rate, pressure, spacing and nozzle height. A large change of uniformity can occur due to changes in the overlap of nozzles with either small increases or decreases in nozzle spacing. The design complexity magnifies enormously when the best combination of nozzles needed for a center pivot lateral is considered since discharge rate requirement varies along the lateral.

As additional research and performance testing adds to the database, package design criteria should be improved. The effect of non-uniformity on yield also needs further examination. Non-uniformity of yields in wide spaced in-canopy systems have been noted. However, with increasing use of systems for chemigation, non-uniform water distribution would directly affect the chemical distribution applied through the water. The main point for the irrigator is that good sprinkler package design may not necessarily be the "popular" sprinkler package. Hopefully the manufacturers, dealers, researchers, etc can continue to identify and provide the best possible design. The irrigator also needs to make certain the design is properly installed, operated, and maintained.

Although the black pans were effectively used to evaluate a number of systems, the job was still a messy and labor intensive activity. Another problem associated with the irrigation demonstration projects which had sites spread out over a thirteen county area, was how to get good ground data on irrigation and rainfall when the sites were only visited periodically. What was needed was an inexpensive measuring device that would not lose caught water to evaporation. They needed to be inexpensive because of the large number of demonstration sites and the large number needed to do a center pivot distribution evaluation.

This need lead to the development of the Irrigage as shown in Figure 6. Irrigages are constructed using thin-wall low pressure drainage pipe and cap and some type of plastic bottle. The pipe is used as a sharp edged collector but the colleted water drains into the storage bottle below through a small hole. The collected water now has little opportunity to evaporate and losses are minimal; only a few percentage points in a week. An irrigator with multiple systems can use the Irrigage to catch rainfall events at the various sites and have a good reading even with a day or more delay in reaching the catch.

A second use of the Irrigage could be field verification of applied irrigation water. This would require the use of at least three irrigages being placed under the system. A great deal of variation can occur even in center pivots with good uniformity (Figure 5a) so an average of at least three readings are needed to obtain good average application estimate. If the group of three or several groups of three are moved periodically, the application depth along the entire system could be monitored over time.

Irrigages are also useful for full scale pivot evaluations. Since a large crew was required to rapidly measure catch data in order to minimize evaporation losses, a time had to be scheduled when the irrigation crew and field conditions would all allow a test. This was often a difficult scheduling problem and also usually resulted in irrigation water being applied that was not needed. The use of Irrigages addresses these problems.

First they can be installed at the evaluators convenience since they are placed on a stake and are not likely to be moved by wind. Once installed, they remain in place until an irrigation occurs. The irrigation event can be a regular event. Without a waiting crew, there is no need to run a light application to save time. In traditional evaluations, usually only the outer half of the system is tested. Since no one is waiting, the entire system could be measured if desired, if sufficient Irrigages are available.

Second, they do not have to be read immediately after an irrigation, since there is no immediate evaporation loss. Data collection can be delayed until all water is infiltrated and the surface is dry so the measurement and removal of the Irrigages can be done on firm soil. A single individual can also effectively conduct an evaluation.

Field evaluation of center pivots have indicated a need for a system review process. These evaluations can be a cost effective way to catch design, installation or maintenance errors that adversely affect center pivot irrigation system efficiency and uniformity.

Development work will continue on field evaluation of center pivots. In addition to the proto-type design of the Irrigage, a spread sheet for calculation of CU has been prepared. Guidelines for placement, measurement data entry, and other procedural issues need to be refined so that any evaluation conducted will provide an irrigator with consistent and quality information.

Figure 1.

South Central Kansas Irrigation Management Project

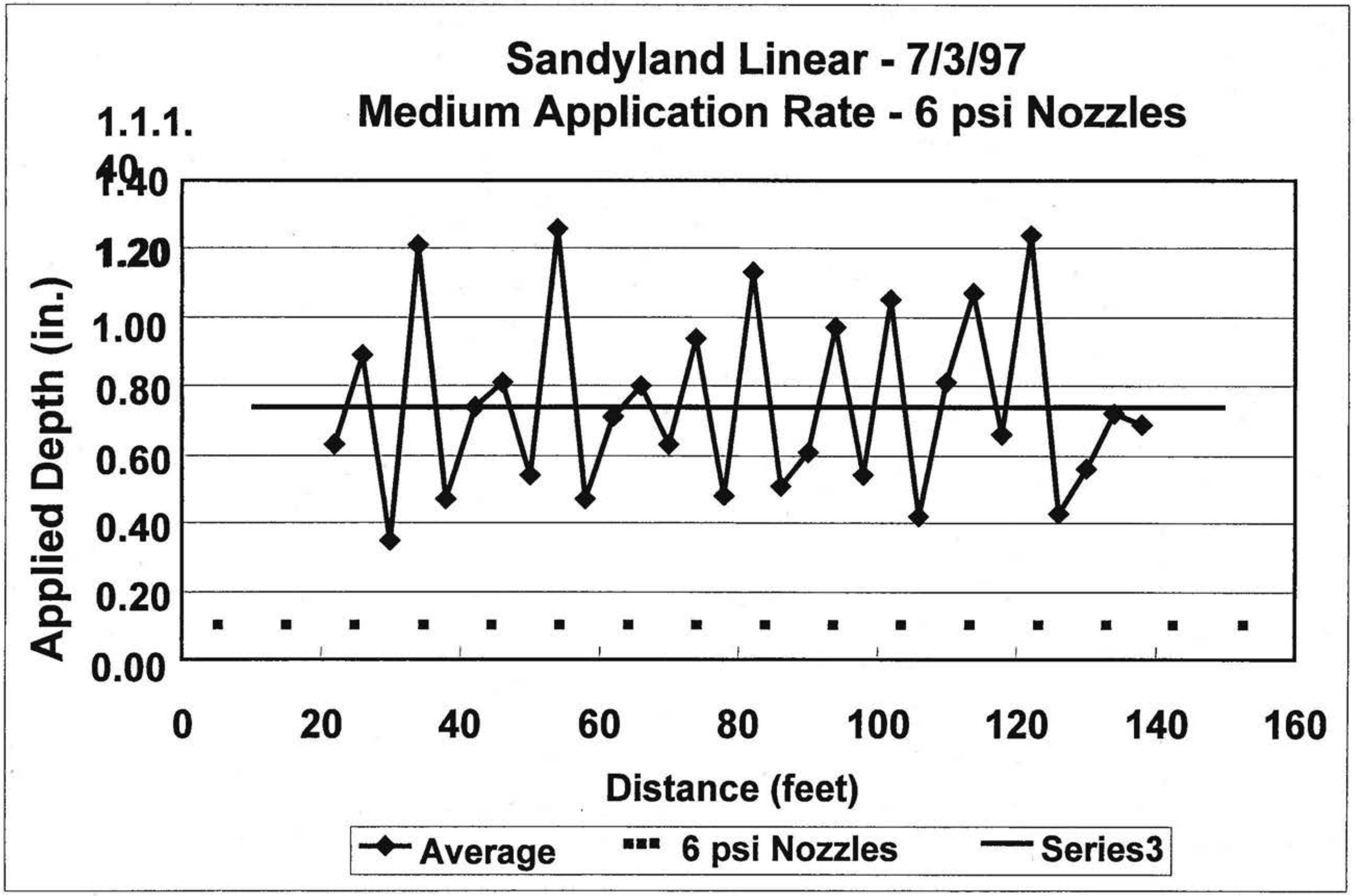
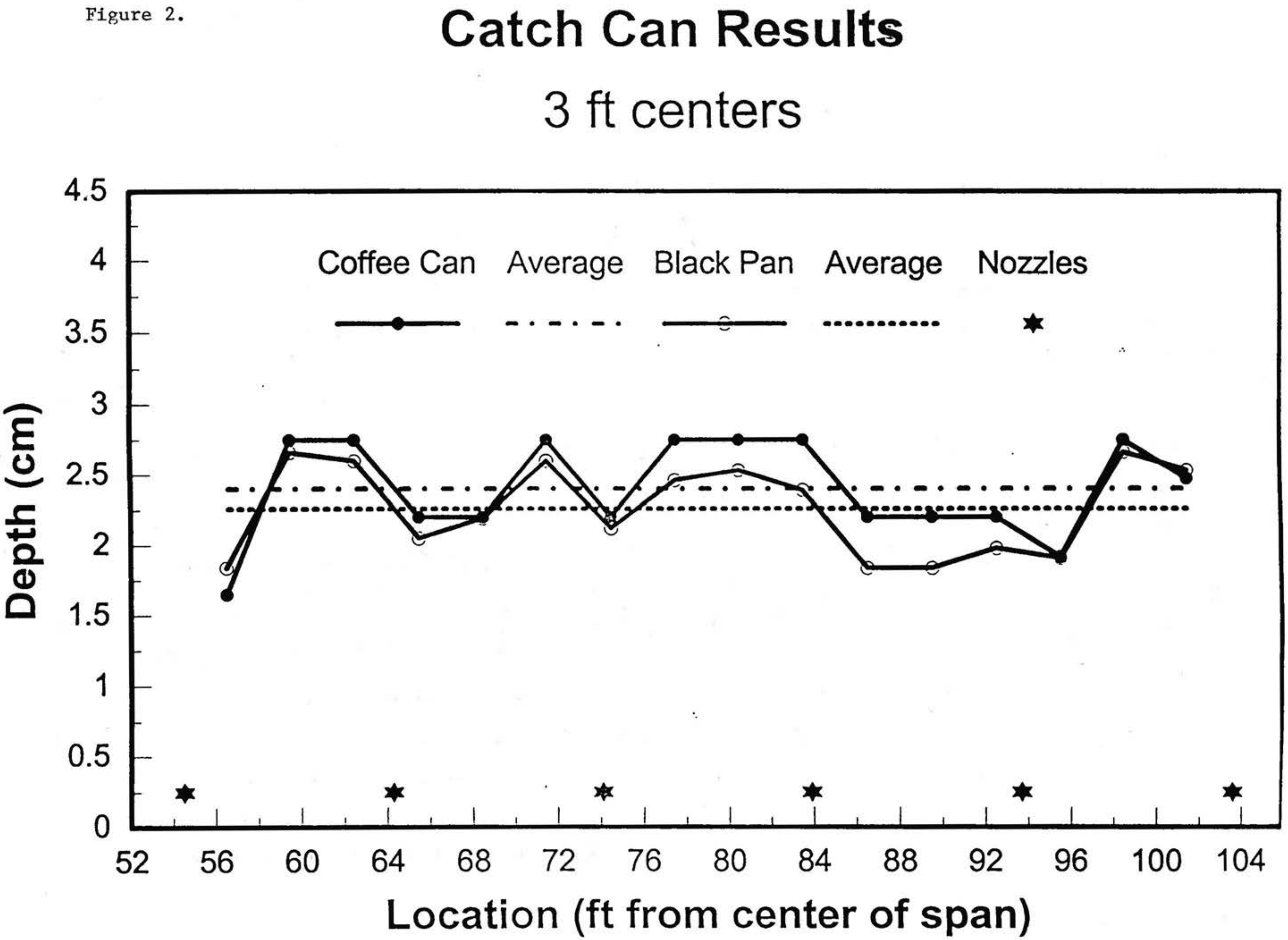


Figure 2.



Sandyland - 7/03/97

High Rate

Figure 3. Center Pivot Distribution Uniformity – System PR01.

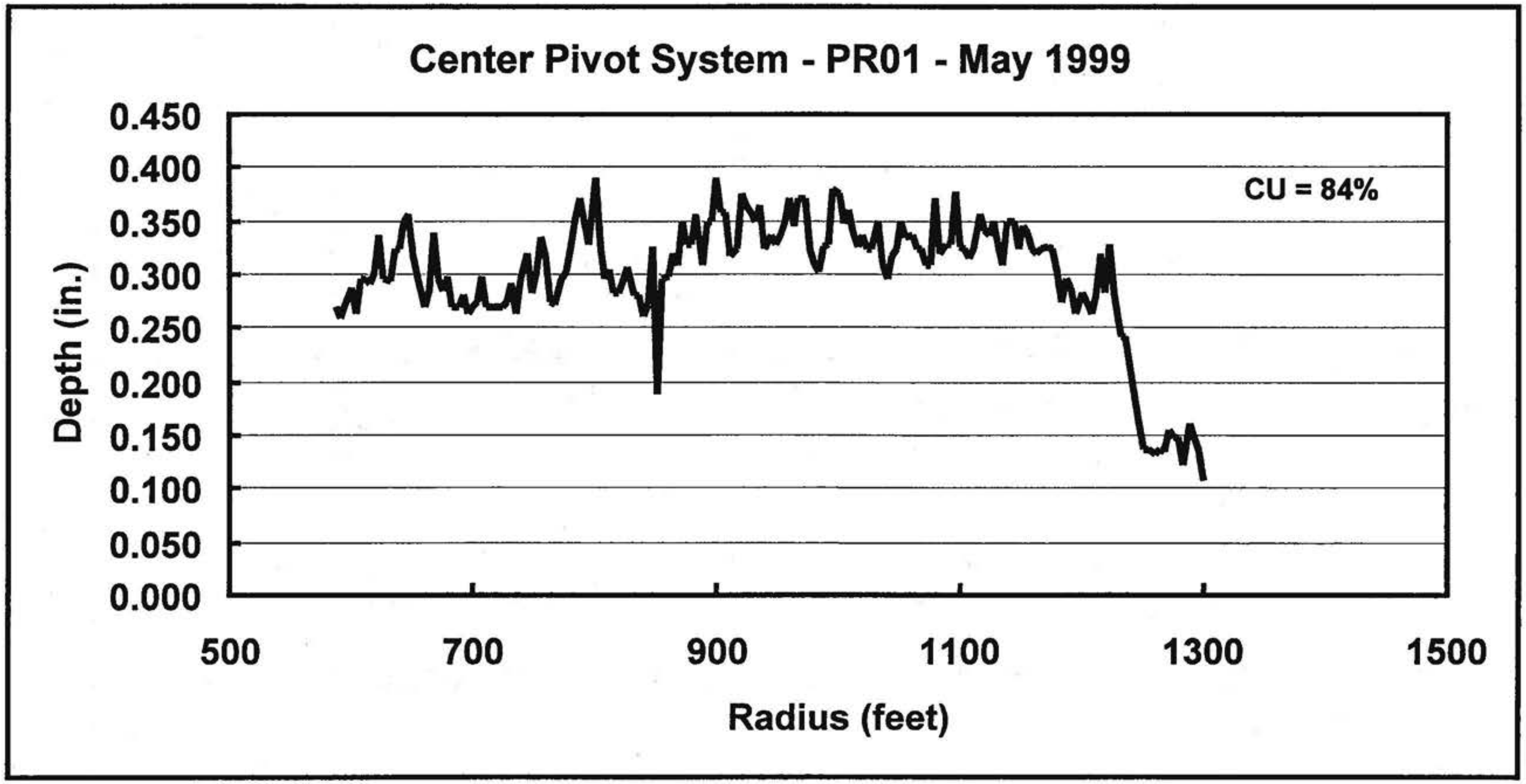


Figure 4a. Sprinkler uniformity with End-gun 'ON'
Farm No. 1, Finney County, Kansas

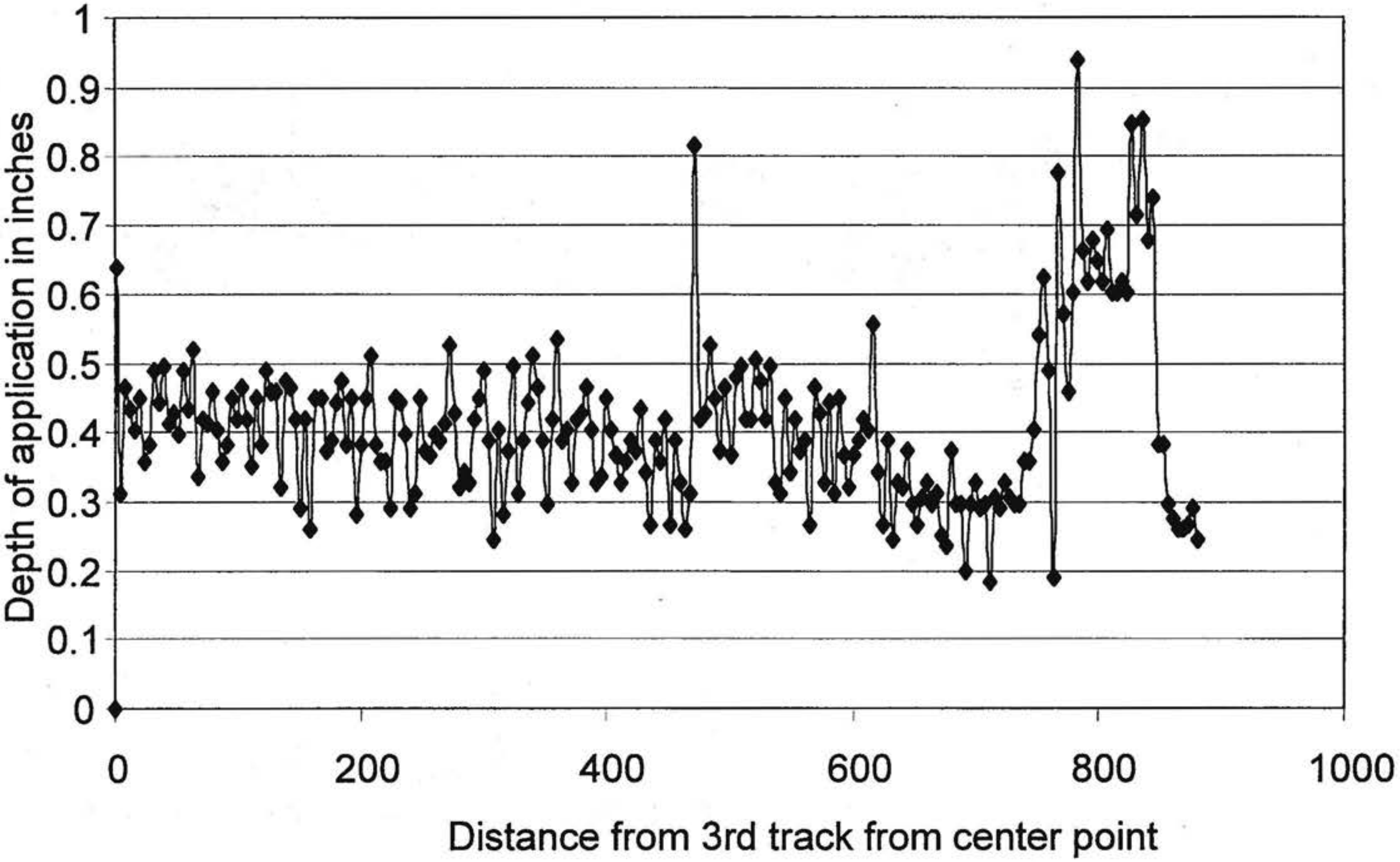


Figure 4b. Sprinkler uniformity with End-gun 'OFF'
Farm No. 1, Finney County, Kansas

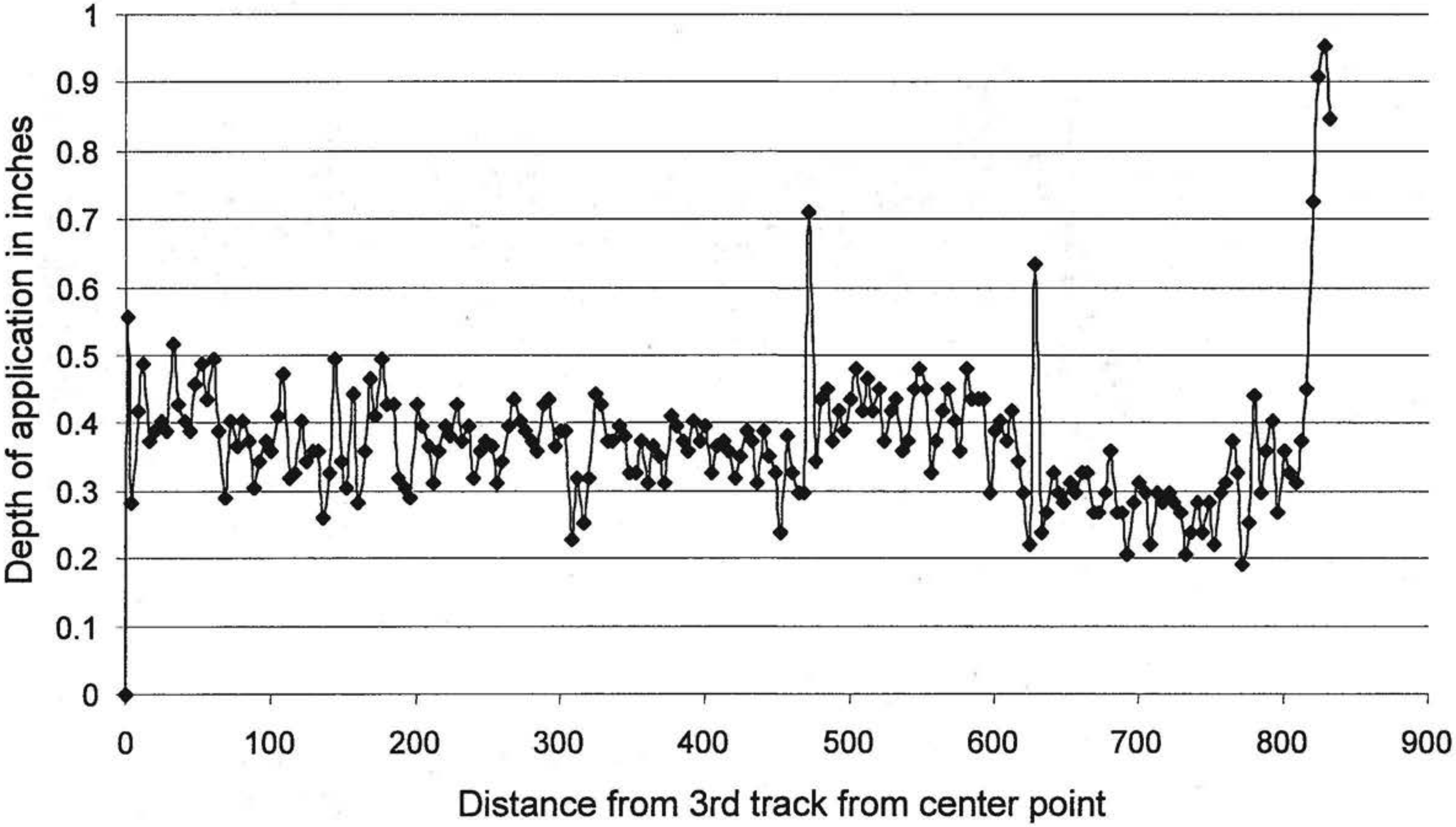


Figure 5a. Center Pivot Distribution Uniformity – KI01.

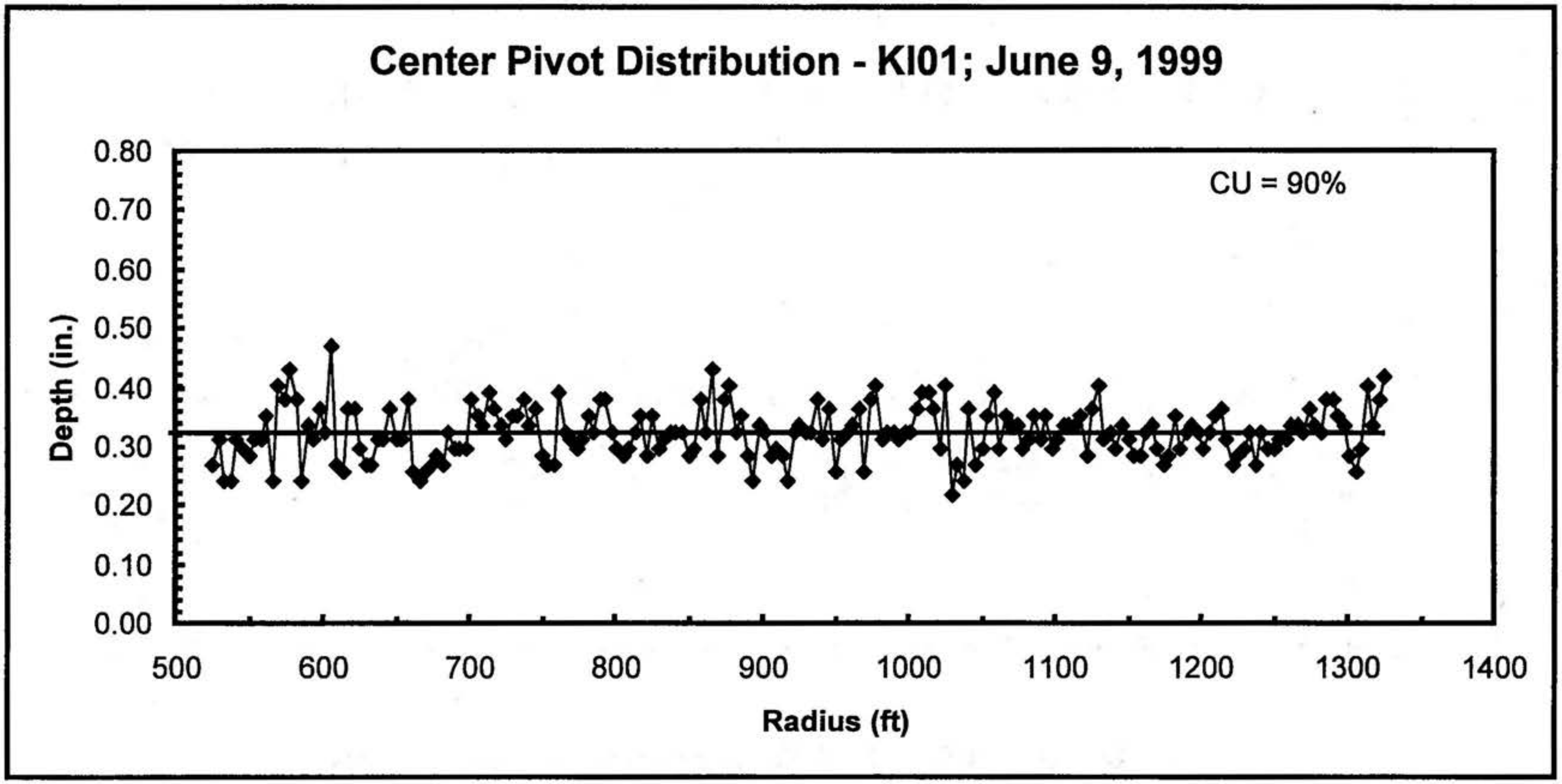


Figure 5b. Center Pivot Distribution Uniformity – System ED01.

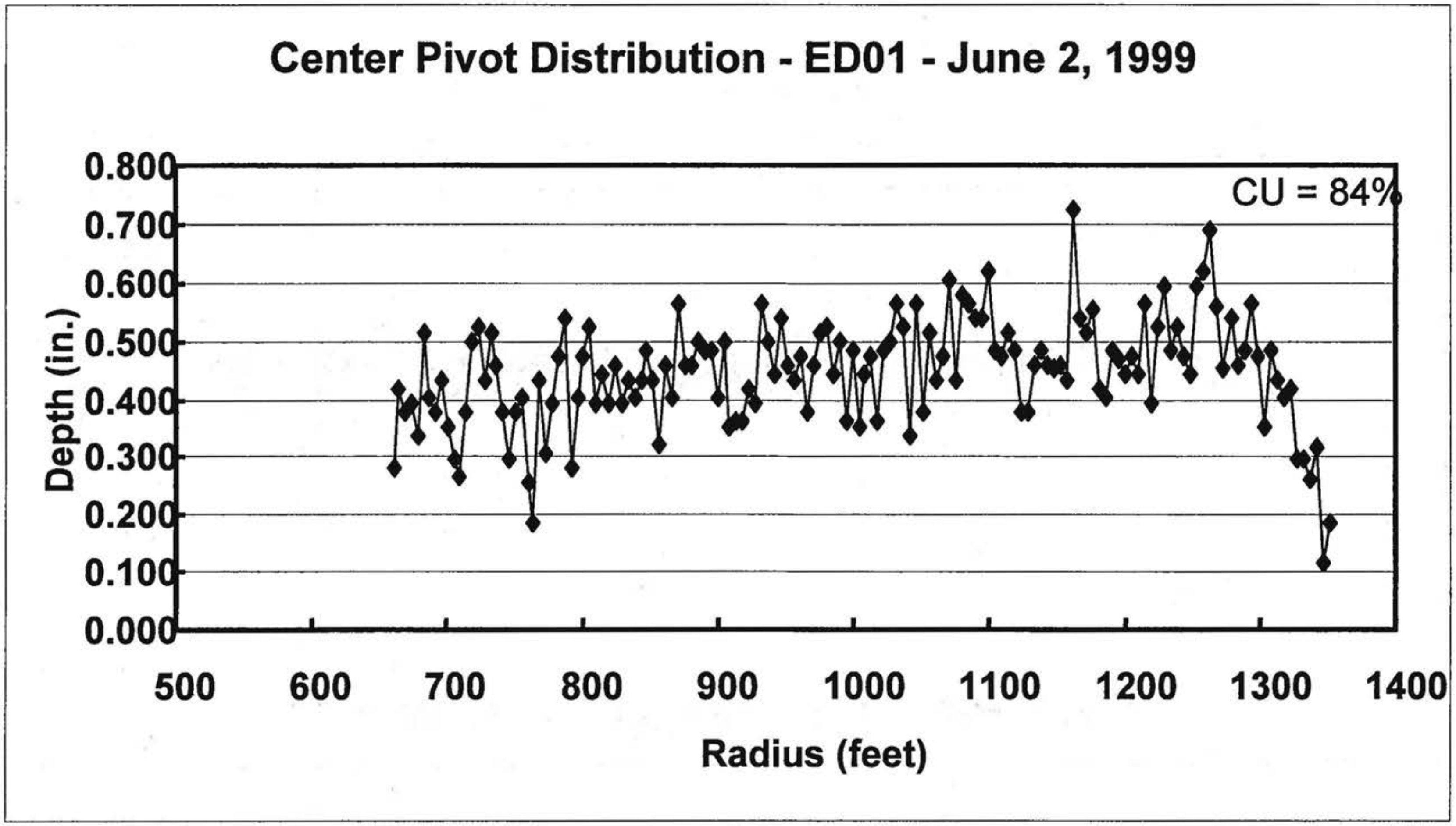


Figure 5c. Center Pivot Distribution Uniformity – System ED01.

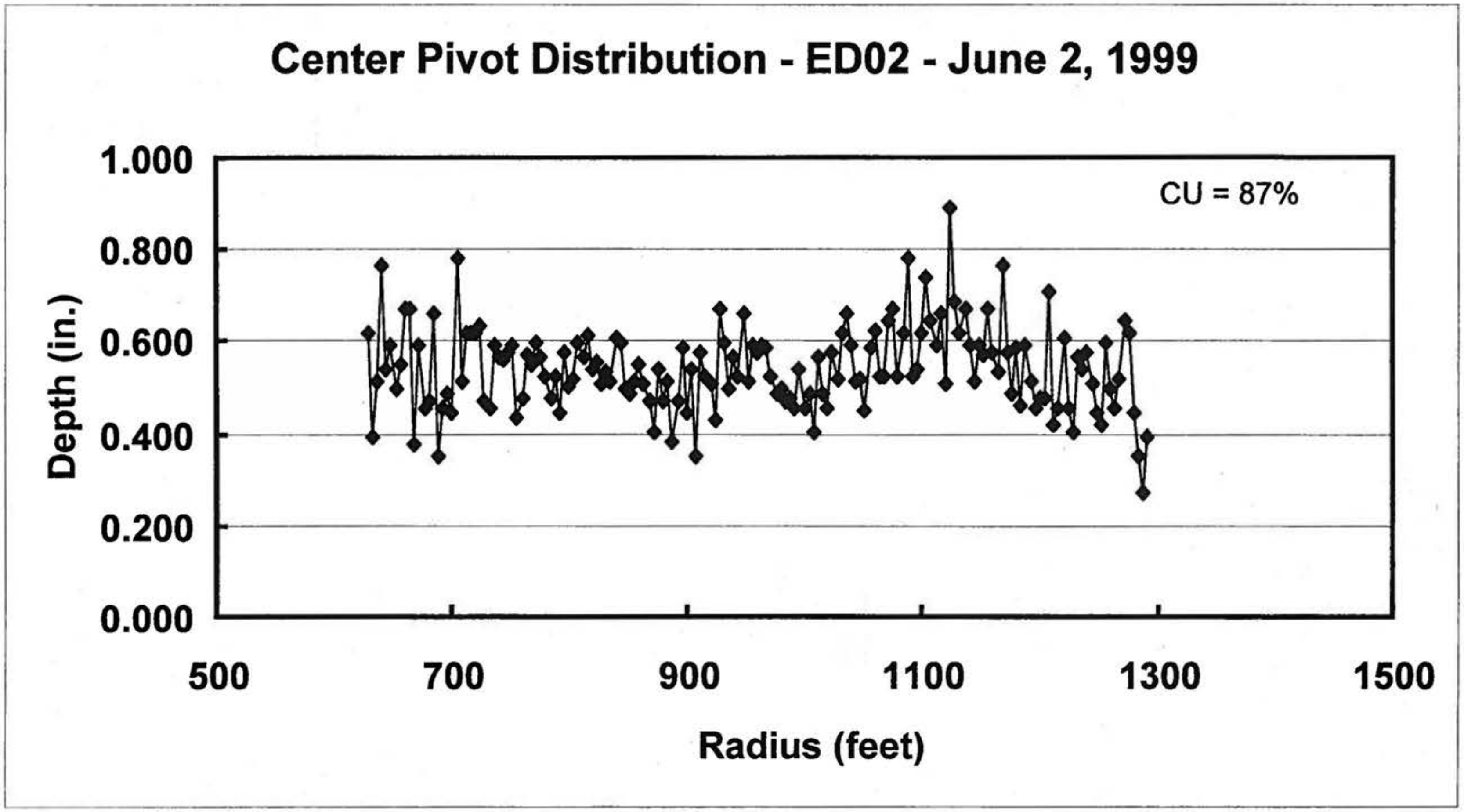


Figure 6.

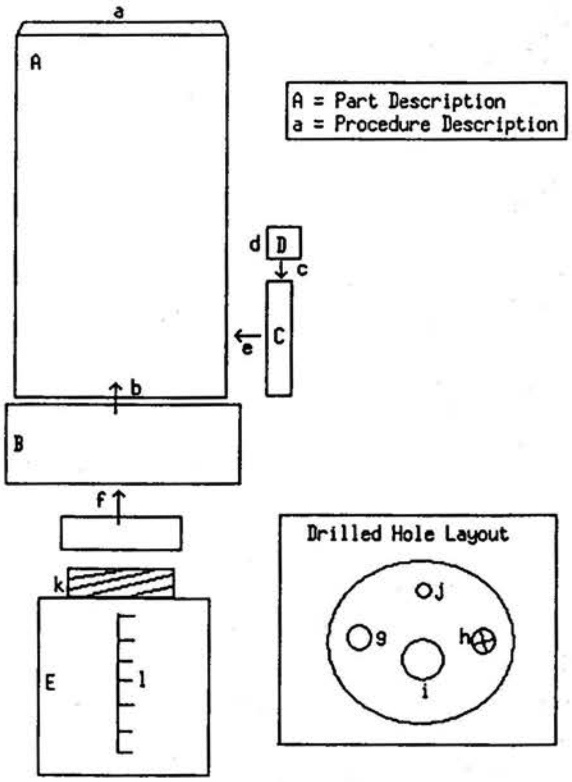
♦IRRIGAGE♦

Bill of Materials - Each

a) 11 inch length of 4" PVC Sewer Pipe (Irrigage Body)
b) One 4" PVC Sewer Cap (Irrigage Body end cap)
c) 4 inch length of 1/2" PVC Schedule 40 Pipe (Irrigage Hanger tube)
d) One 1/2" PVC Cap (Irrigage Hanger end cap)
e) One graduated, plastic bottle with screw cap (Collection Bottle)
f) PVC Cleaner and Cement
g) 2 - #6 X 1/4" Sheet metal screws
h) 1/4", 1/8", and 7/64" drill bits
i) Silicon Sealant

Plan of Procedure

a) Bevel one end of the gauge body on a disc sander
b) Glue the end cap onto the other end of the gauge body
c) Glue the hanger cap onto the hanger tube
d) Flatten one side of hanger assembly on a disc sander
e) Glue the hanger assembly to the side of the gauge body
f) On a belt sander, flatten a spot on the bottom of the gauge body and the top of the collection bottle cap
g) Center the collection bottle cap on the bottom of the gauge body end cap, then mark and drill pilot holes for the screws with the 7/64" drill bit.
h) Silicon seal the collection bottle cap to the gauge body end cap, and secure with the two #6 X 1/4" sheet metal screws.
i) After silicon has cured, drill a 1/4" hole through the bottle cap and the gauge body end cap
j) Drill a 1/8" breather hole through the bottle cap and the gauge body end cap
k) Screw on collection bottle
l) Mark graduated scale in tenths of an inch (see volume conversions)



Inches	Millileters	Ounces
0.1	21	0.7
0.2	41	1.4
0.3	62	2.1
0.4	82	2.8
0.5	103	3.5
0.6	123	4.2
0.7	144	4.9
0.8	165	5.6
0.9	185	6.3
1.0	206	7.0
1.1	226	7.7
1.2	247	8.4
1.3	267	9.1
1.4	288	9.8
1.5	309	10.5
1.6	329	11.2
1.7	350	11.9
1.8	370	12.6
1.9	391	13.3
2.0	411	14.0
2.1	432	14.7
2.2	453	15.4
2.3	473	16.1
2.4	494	16.8
2.5	514	17.5

IMPACT OF WIDE DROP SPACING IN CORN

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Introduction

In many areas of Nebraska, the summer of 2000 was marked with below normal precipitation and above normal temperature and sunshine. As growing degrees climbed, it became more and more difficult for center pivot sprinkler systems to meet the water demands of the growing corn crop. The result of water stress on the crop was not completely evident until late in the season when the crop was nearly mature. A differential in crop height resulted in many fields and could be seen from the perimeter of the field. Aerial observations of the fields revealed concentric rings that corresponded to sprinkler spacing.

Field Evaluations

To evaluate what was being observed in the field, a series of field samples were collected. Many center pivot systems are designed with wider sprinkler spacing for interior spans and closer sprinkler spacing for the outer most spans where additional sprinklers are needed to meet application requirements. When possible, yield samples and soil moisture data were collected in this transition area to insure similar soil type and cultural conditions.

The location of sprinklers were first identified in relation to the wheel tracks. Then the location of sprinklers were superimposed in that area of the field where the center pivot sprinkler devices run nearly parallel with the planted rows of corn. Corn rows were identified within each sprinkler device spacing section of the pivot. In other words, in those areas with wide spacing or those with narrow spacing. Samples were then collected from those rows of corn that were between a series of three sprinkler devices, regardless sprinkler spacing. Corn yield was determined by sampling 10 feet of row. Soil water content was measured to a depth of 4 feet at one location within each sampled row.

Field Results

The results of field measurements at the different sites are shown in the following figures. As can be seen, the yield at a number of the sites declined between the sprinkler devices when sprinkler spacing was approximately 19 feet while yield tended to be more uniform for the narrow sprinkler spacing of 9 feet.

Because soil water data was collected at the end of the season when the crop was mature, some of the differences in soil moisture content may have been eliminated with late season precipitation or added irrigation. However, a number of the sites still show soil water levels at the 4 foot level to be much less in the rows that are located directly between two sprinkler devices.

Site description and yield and soil moisture results are discussed below:

McCook site 1 had sprinkler devices spaced 6 ft apart and located in the corn canopy at alternating heights of 3.0 and 4.5 ft. Soil moisture was nearly constant across the rows while yield was nearly 25 bu. less in the row directly between the sprinklers.

McCook site 2 had sprinkler devices spaced 10 ft apart at an 8 ft height. At this height, the sprinkler devices were out of the canopy for the bulk of the season. Soil moisture content was constant among the rows and yield varied by approximately 15 bu.

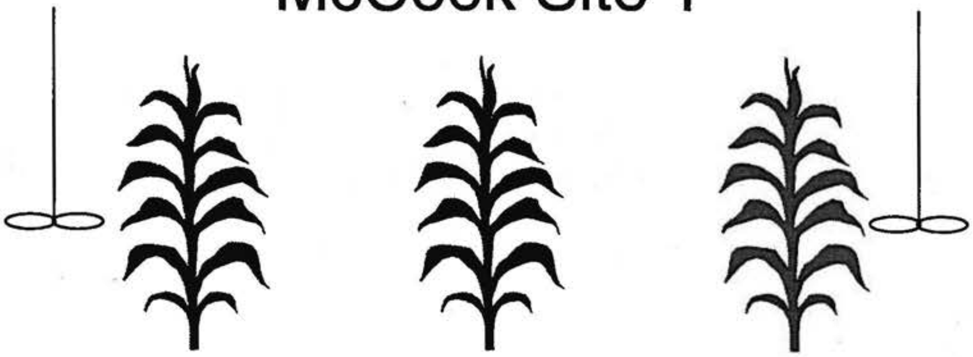
Sprinkler devices were spaced 19 ft apart at a height of 2 ft at McCook site 3. Although yield was similar, soil moisture content declined by nearly 10 % when comparing the row next to the sprinkler device to the row furthest from the sprinkler device.

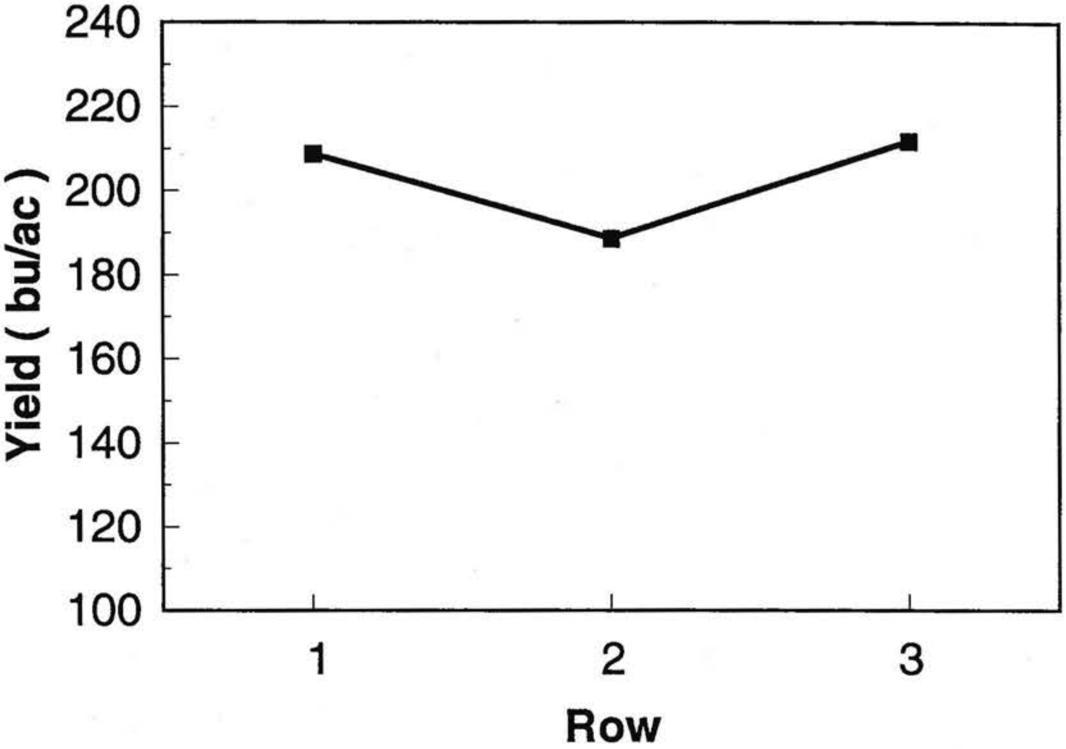
At the Hay Springs sites, data was collected for both wide and narrow sprinkler spacing within the same field. Hay Springs sites1 and 2 were from one field and Hay Springs sites 3 and 4 from another field. Hay Springs site 1 had sprinkler devices located at a 7 ft height and spaced 9 ft apart. There was no reasonable pattern for either yield or soil moisture content at this location. At Hay Springs site 2, sprinkler devices were also at a 7 feet height but spaced 18 feet apart. Soil moisture differences were not detectable at the end of the growing season but corn yield did decline by approximately 25 bu as the distance increased from the sprinkler devices.

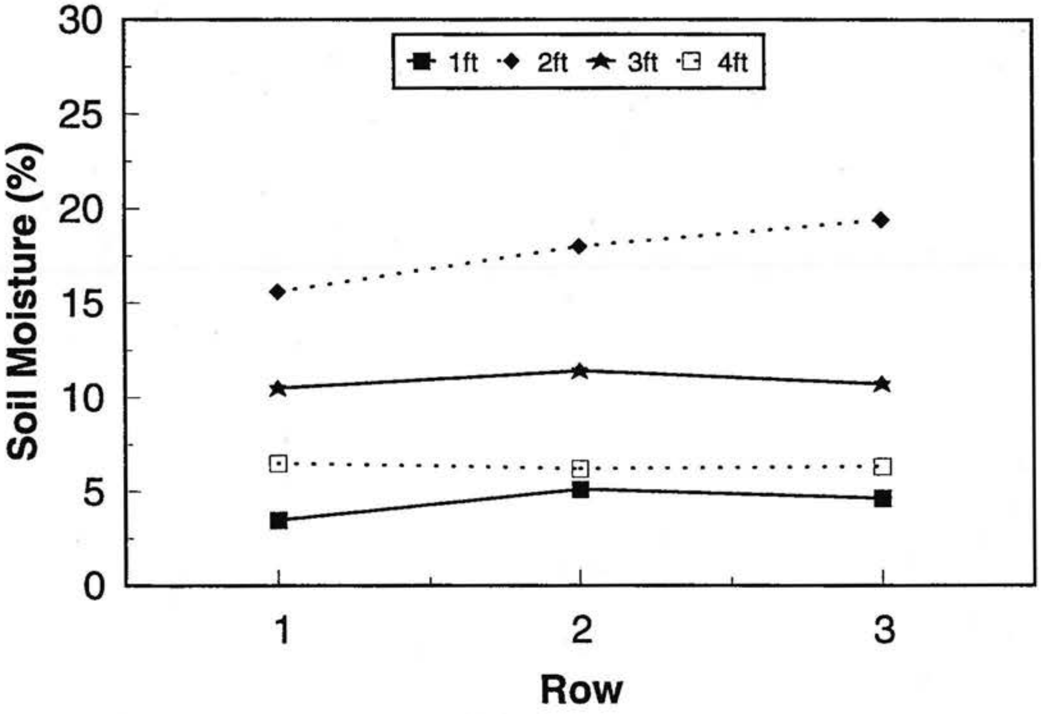
Hay Springs site 3 had sprinkler devices spaced 9 ft apart at a height of 7 ft. No differences can be seen in soil moisture content and corn yield averaged approximately 215 bu. At Hay Springs site 4 sprinkler devices were spaced 18 ft apart at a height of 6.5 ft. Both soil moisture content and corn yield declined for the rows furthest from the sprinkler device. Corn yield dropped from over 220 bu to less than 180 bu.

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

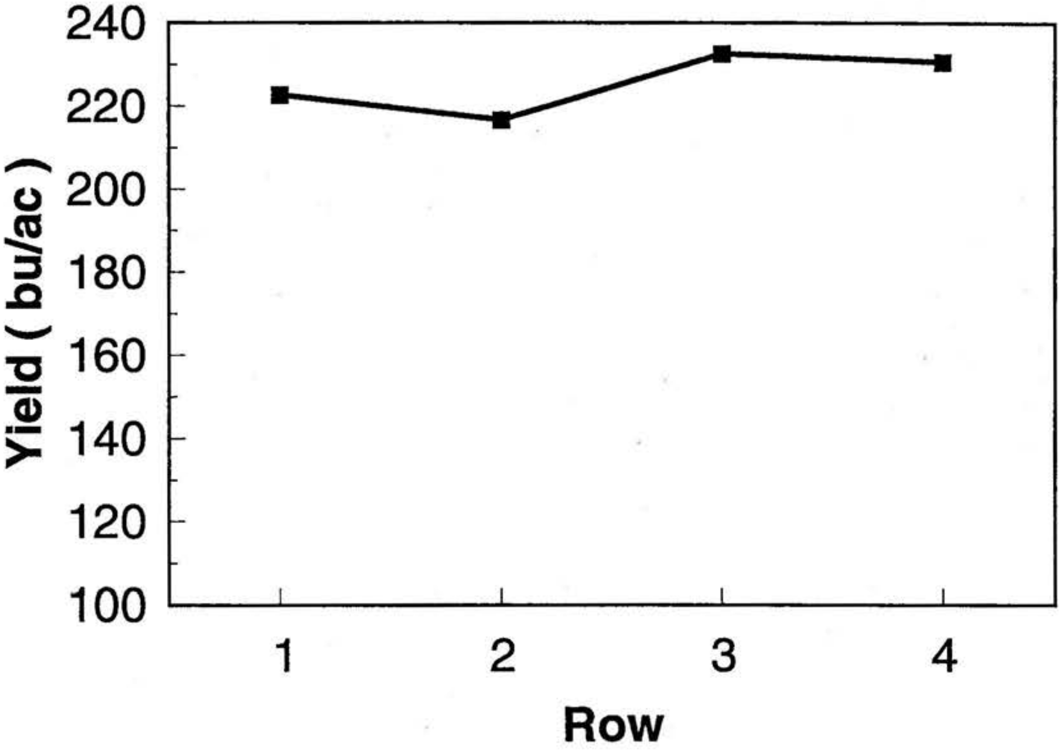
McCook Site 1

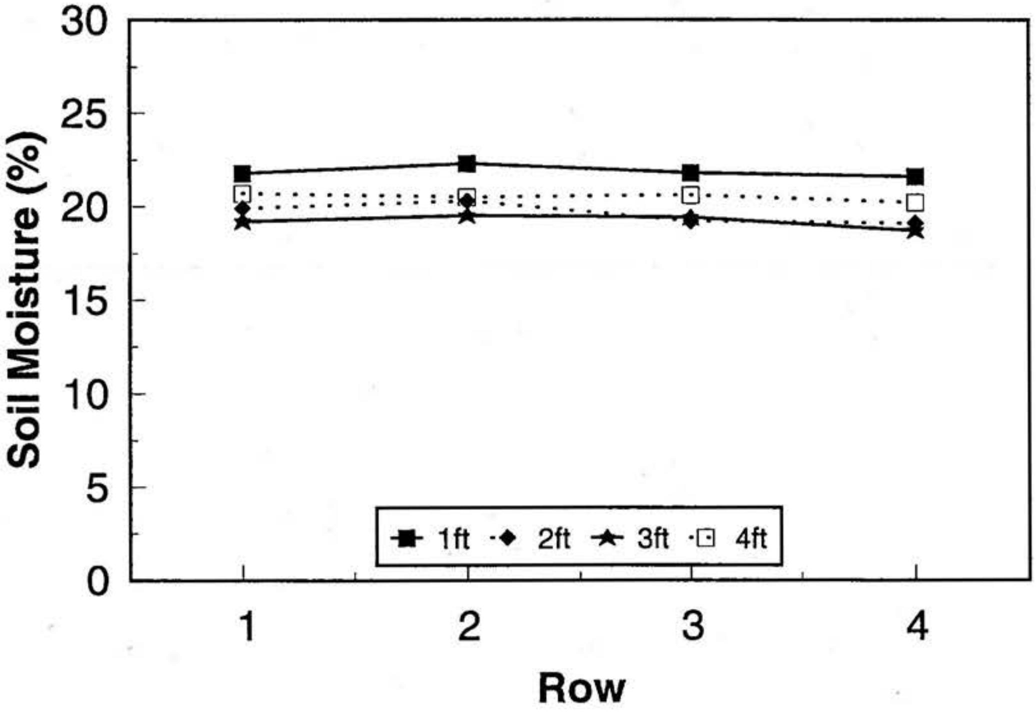




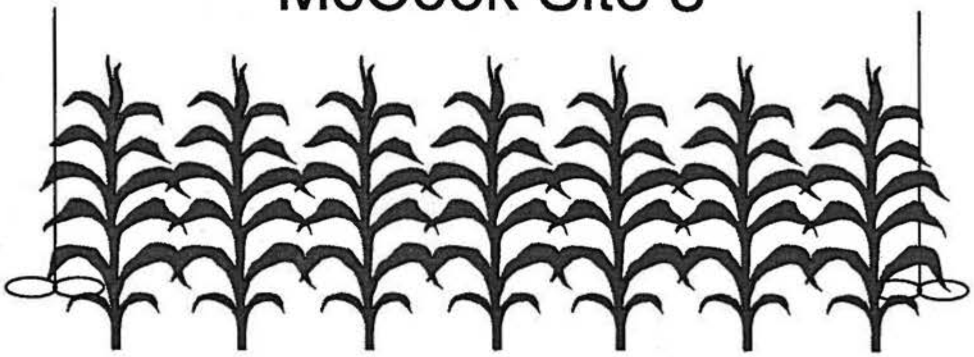


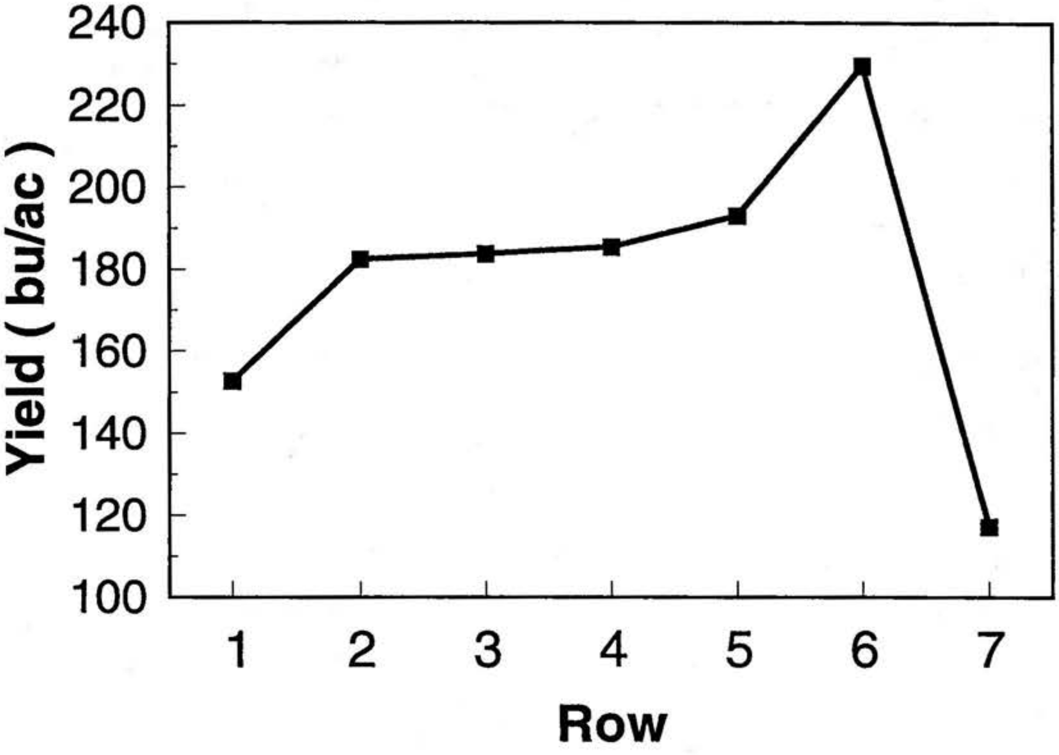
McCook Site 2

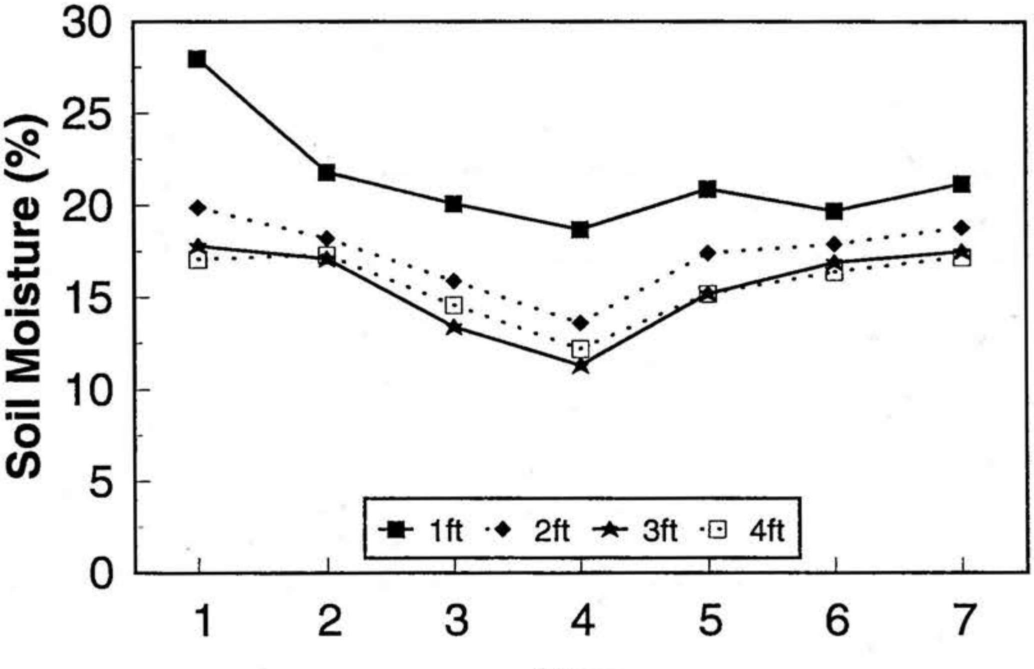




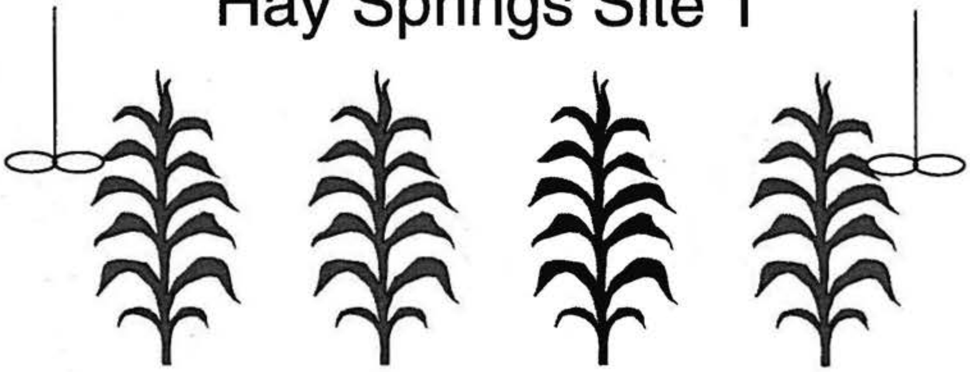
McCook Site 3

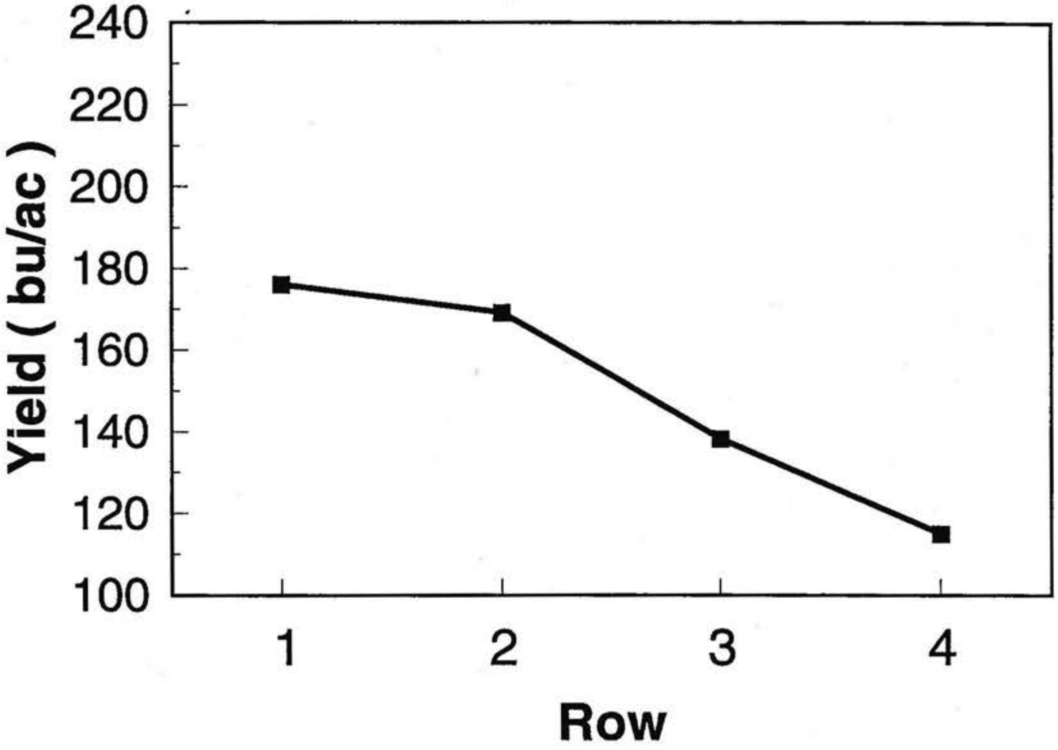


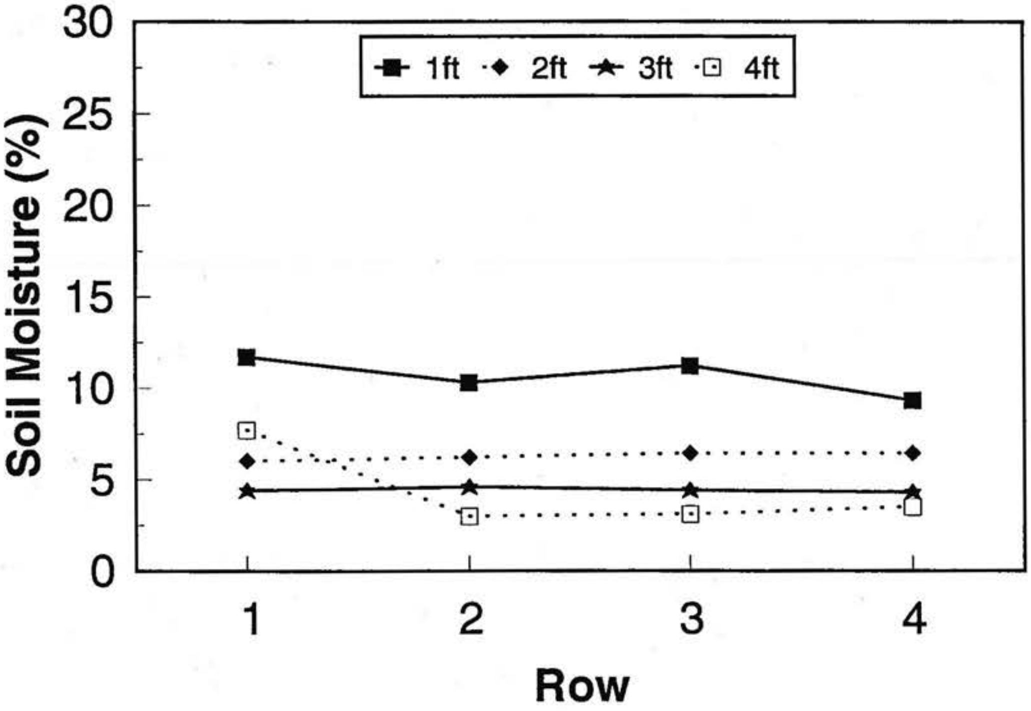




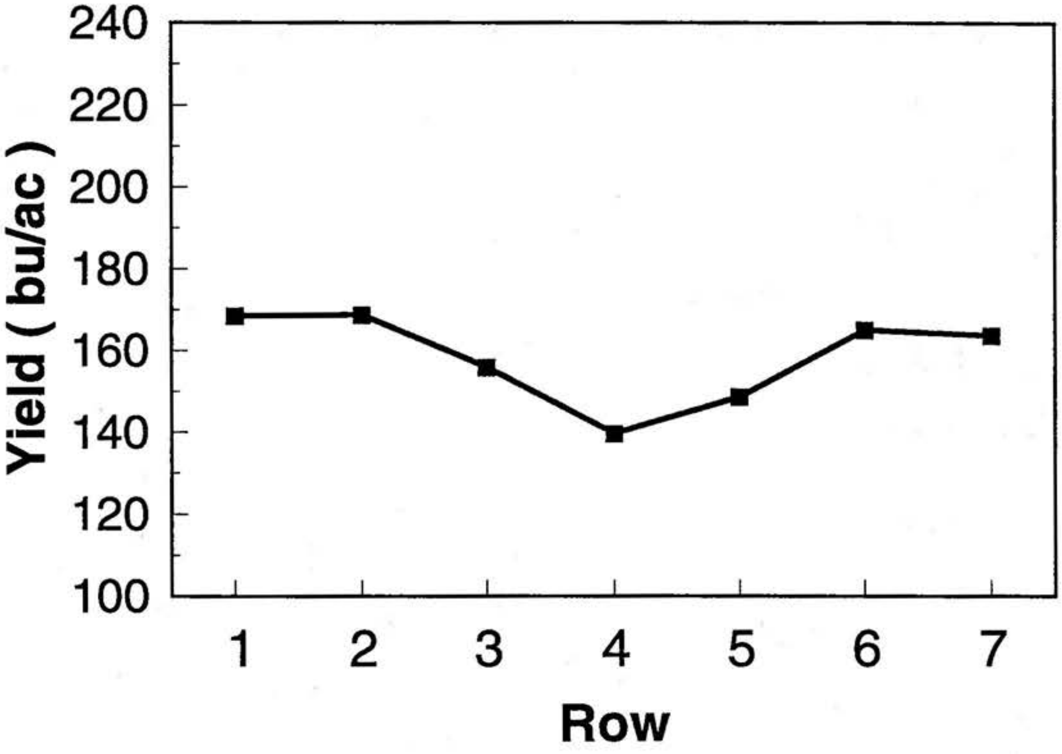
Hay Springs Site 1

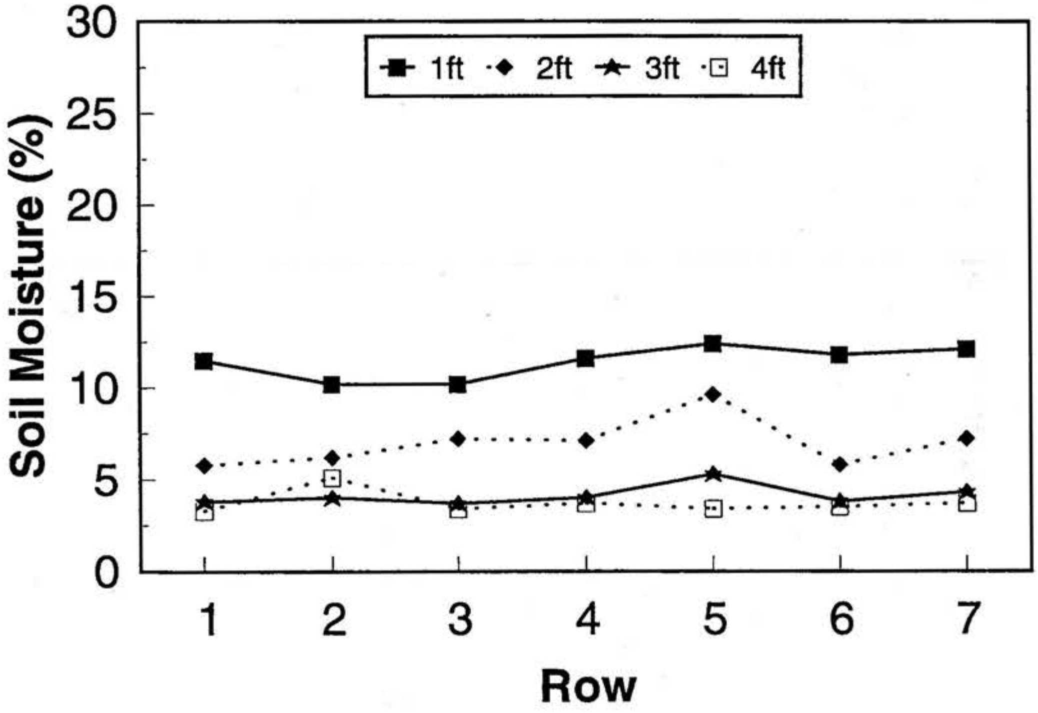




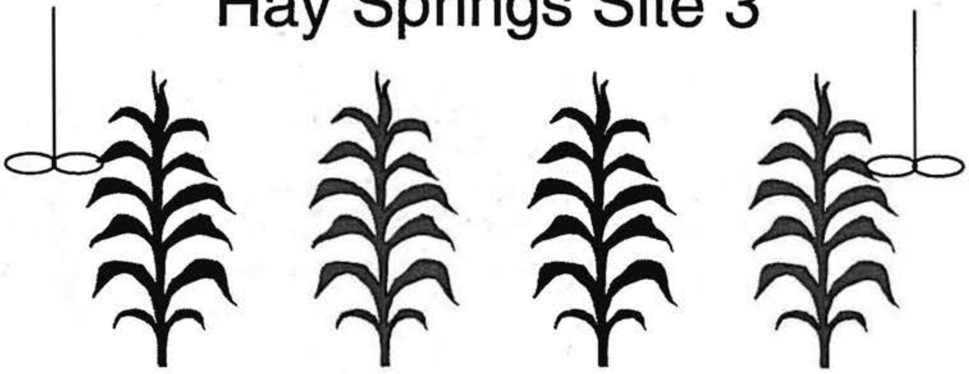


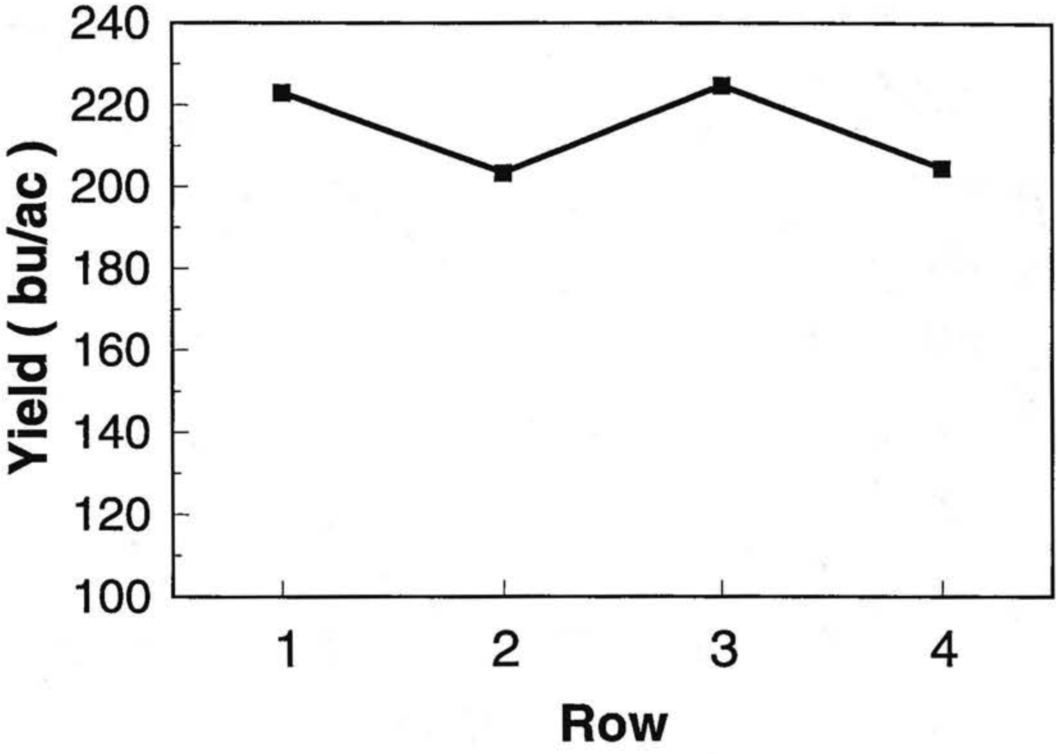
Hay Springs Site 2

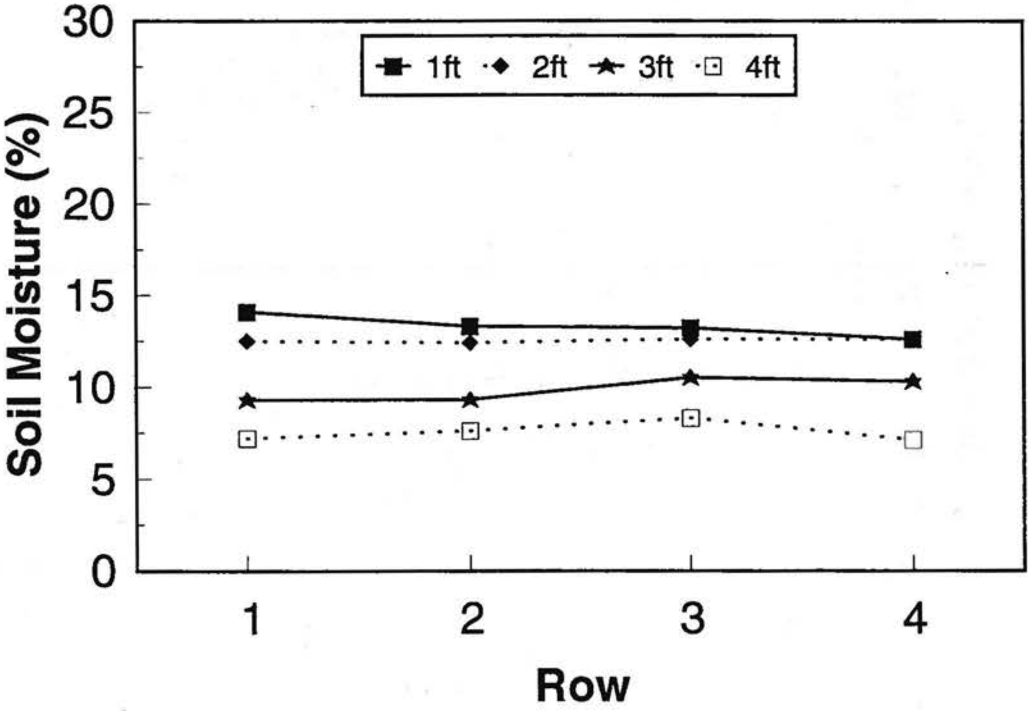




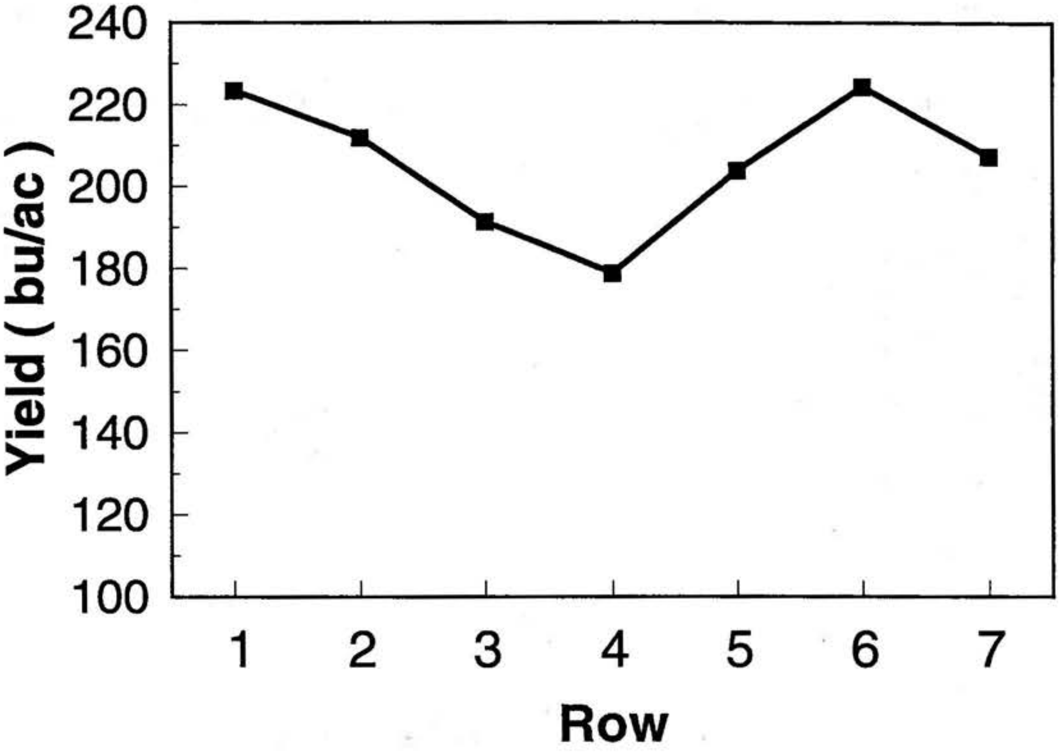
Hay Springs Site 3

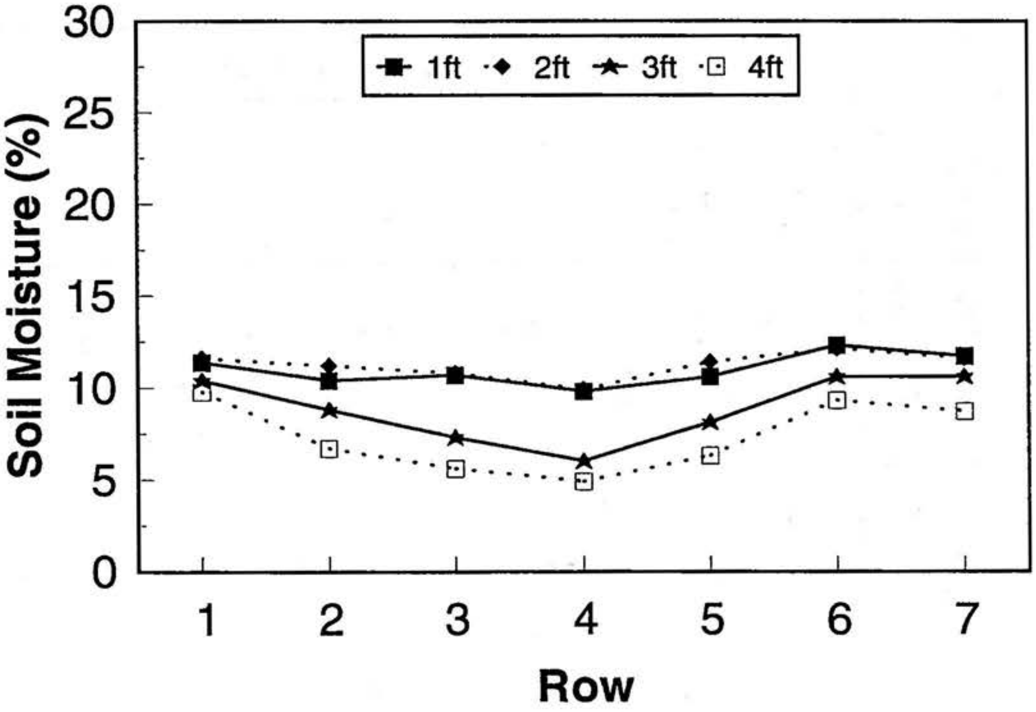






Hay Springs Site 4





Polyacrylamide (PAM) Effects on Irrigation and Sediment Yield

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Introduction

Irrigated crop production is critical to global agricultural output. Surface irrigation, predominantly furrow irrigation, accounts for more than 60% of the earth's 600 million acres and about one-half of Nebraska's 8 million acres. Irrigation associated erosion seriously impacts irrigation's ability to sustain its 2- to 3-fold yield advantage over dryland agriculture. In Nebraska, soil erosion due to surface irrigation is estimated to average between 7-8 ton/ac/yr. Erosion is also a significant contributor to non-point source pollution including: sediment; biochemical oxygen demand (BOD); phosphorus; nitrates; and various pesticides.

Top soil, which is necessary for crop production, is difficult, if not impossible, to replace when removed from a field. To limit erosion, erosion-related non-point source contamination, and to sustain production levels on furrow irrigated fields, cost-effective top soil maintenance is necessary.

Polyacrylamide, an environmentally safe industrial flocculent, widely used in the municipal water treatment and food processing industries, has the potential to significantly reduce furrow-irrigation-induced erosion. PAM is a long-chain, high molecular weight polymer that when mixed with irrigation water stabilizes near-surface soil particles by forming polymer "nets" around existing soil aggregates. Polymer-stabilized aggregates are less likely to disintegrate during irrigation. PAM reduces erosion by maintaining the integrity of the top few millimeters of the soil's structure and essentially keeps sediments in place.

Maintaining the surface structure during an irrigation can also alter the infiltration or water intake rate. Increased infiltration will mean an increase in furrow advance time. Recent improvements in irrigation technology and furrow irrigation management practices have increased water application uniformity and improved irrigation efficiency. To maintain these gains, best PAM-specific furrow irrigation management practices must be defined.

PROCEDURES

The study was conducted on cooperator fields in the Panhandle and South Central areas of Nebraska. There were a total of seven study sites in 1999 and 2000. Fields were selected to represent the range of soil textures found in Nebraska. Site descriptions are given below.

Site 1	Tripp Very Fine Sandy Loam, 0.8% slope, 1.8 in/ft water holding capacity, 1999.
Site 2	Kenesaw Silt Loam, 0.5% slope, 2.6 in/ft water holding capacity, 1999.
Site 3	Ortello fine Sandy Loam, 0.5% slope, 1.8 in/ft water holding capacity, 1999.
Site 4	Mitchell Silt Loam, 1.9% slope, 1.8 in/ft water holding capacity, 2000.
Site 5	Tripp Very Fine Sandy Loam, 0.8% slope, 1.8 in/ft water holding capacity, 2000.
Site 6	Kenesaw Silt Loam, 0.5% slope, 2.6 in/ft water holding capacity, 2000.
Site 7	Ortello fine Sandy Loam, 0.5% slope, 1.8 in/ft water holding capacity, 2000.

Furrow irrigation treatments included: 1) conventional irrigation; 2) conventional irrigation with PAM; 3) surge irrigation; and 4) surge irrigation with PAM. Treatments were replicated four times at each site. Alternate-furrow irrigation was the standard practice at each site. Fields were cultivated and ditched prior to the first irrigation. No additional tillage was done after the first irrigation. PAM was injected into the water at 10 ppm and mixed prior to distribution on the field. PAM was injected in the water only during the first irrigation.

Measured irrigation parameters were furrow inflow and outflow and irrigation advance times to the end of the field. Runoff samples were collected from each treatment on an expanding time scale – more samples earlier and fewer samples as runoff continues. Samples were analyzed for sediment content for each event using Imhoff cones. A calibration curve was developed for each site to determine sediment content based on the Imhoff cone reading.

PAM TRIAL RESULTS

Furrow advance time and sediment discharge from the individual field trials are given in Figures 1-3 for the first three irrigations, respectively. Using surge during the first irrigation resulted in furrow advance times that were nearly equal to or less than the corresponding conventional irrigation treatment, with the exception of Site 7. Overall, the PAM treated furrows had furrow advance times that were equal to or greater than the corresponding no PAM treated furrow.

Sediment loss was reduced when PAM was added to the irrigation water for both surge and conventional irrigation treatments. Neither surge or conventional irrigation was consistently better for reducing sediment loss. At site four, field slope was 1.9% compared to 0.8 and 0.5% for the other sites. At this location, PAM significantly reduced sediment loss from nearly 1 ton/ac to nearly zero.

At those sites having field slope of 0.8% or less, total sediment loss with or without PAM, was less than 0.1 ton/ac. For fields with relatively mild slopes, the use of PAM may not be practical.

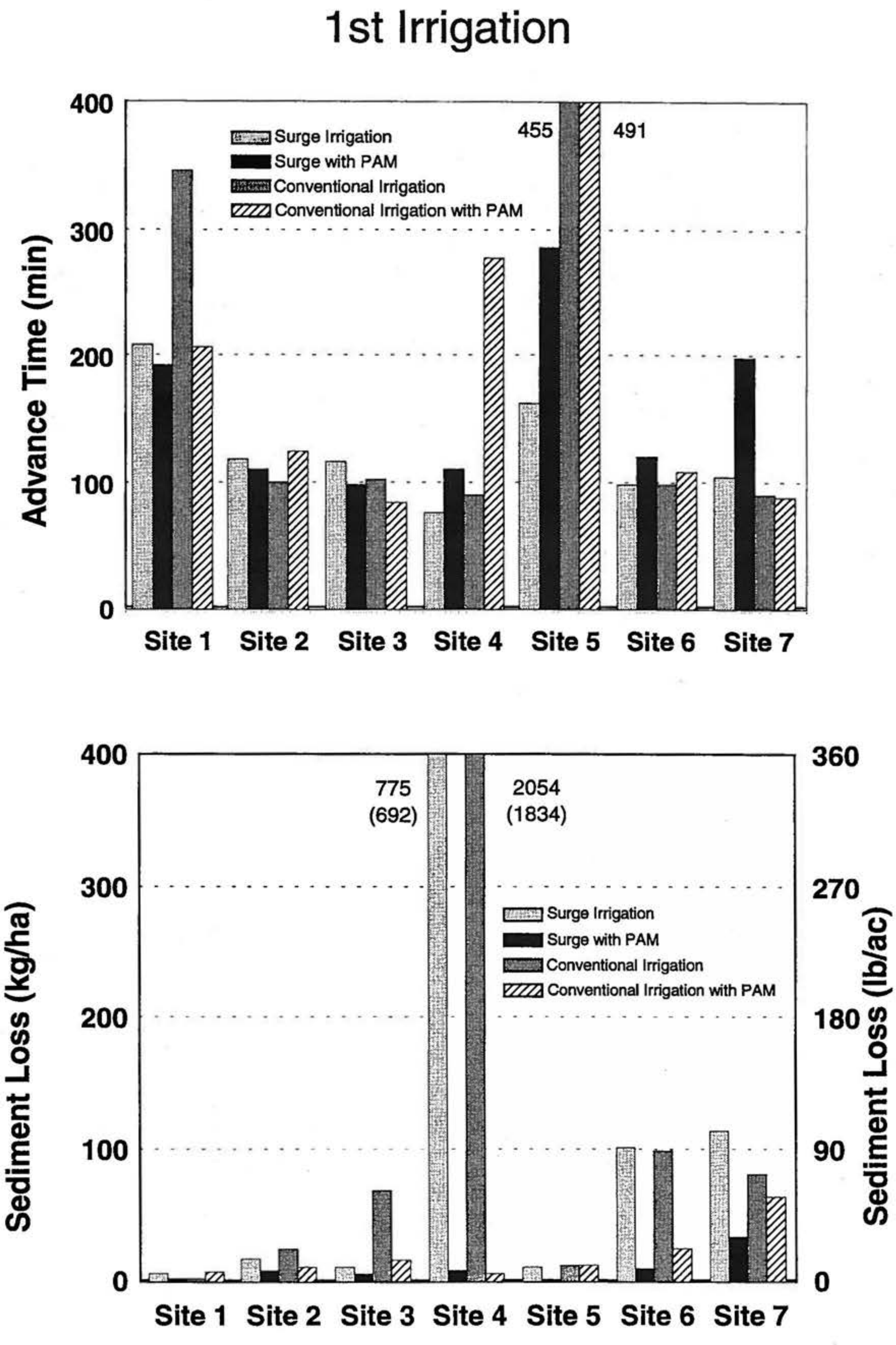

Figure 1. Advance time and sediment loss during the 1st irrigation for 7 sites.

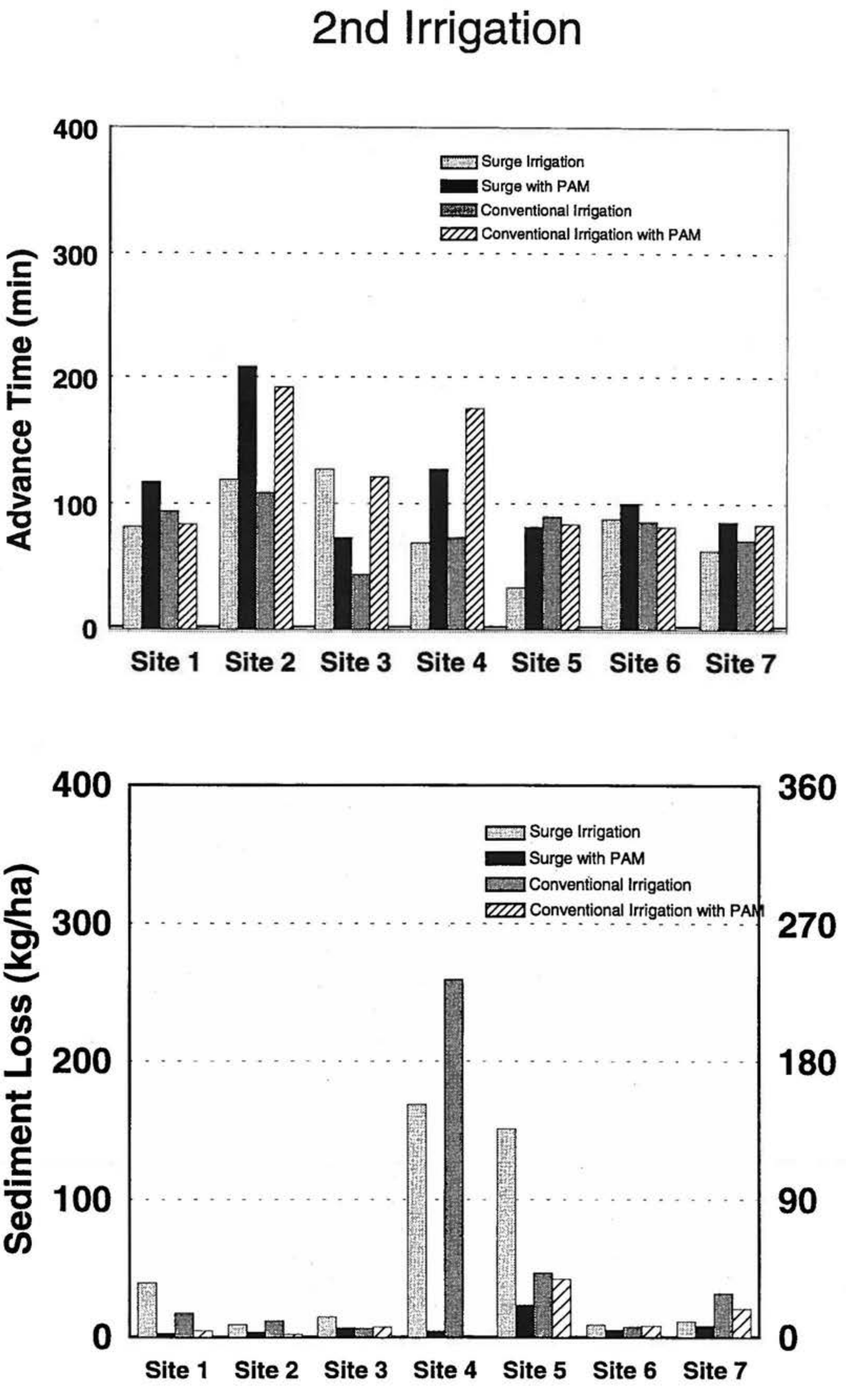

Figure 2. Advance time and sediment loss during the 2nd irrigation for 7 sites.

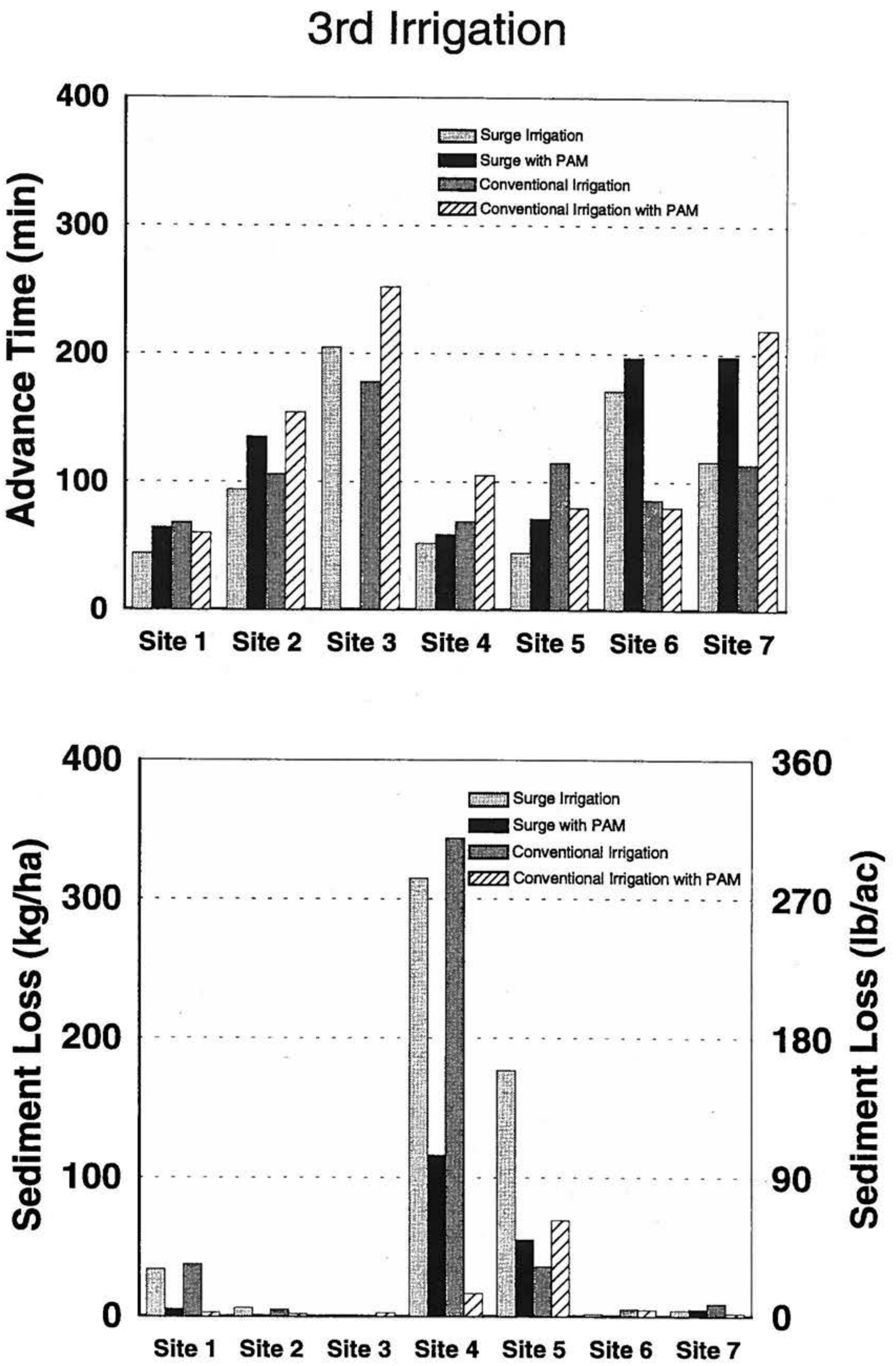
3rd Irrigation

Figure 3. Advance time and sediment loss during the 3rd irrigation for 7 sites.

USING SURGE IRRIGATION FOR AUTOMATION

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Introduction

Furrow irrigation continues to be a primary method of water application in the central high plains of the U.S. In Nebraska alone, over 3.5 million acres of land is irrigated using some form of surface irrigation. The number of furrow irrigated acres have declined due to the conversion from furrow to center pivot irrigated systems. The primary reason for conversion is irrigators looking for methods to reduce labor costs. Yet not all situations allow for conversion to a center pivot, installation costs are high and land area to be irrigated sometimes does not allow for circular fields.

In those situations where furrow irrigation needs to be used, systems that provide automaton can still be implemented. Automation comes in the form of surge irrigation. Surge irrigation gives furrow irrigators some labor savings without a significant investment in equipment. Surge irrigation or surge flow is the process of intermittently applying water in an irrigation furrow. This is compared to continuous flow which is the conventional process of applying water for the entire irrigation set time. Surge irrigation was first studied as a method of reducing the amount of runoff that occurred during irrigation. It was discovered that in addition to reducing runoff, the time required for water to move to the end of the field could also be reduced.

The intermittent application of water is accomplished by cycling irrigation water between two irrigation sets. In years past, the idea of cycling irrigation water was used when water was not getting to the end of a field. The irrigator would move on to subsequent sets and return in one or two days to finish irrigating the partially watered sets. When irrigated a second time, the irrigation water would be moved all the way to the end of the field because the soil surface had sealed and more water was available in the furrow at that point where flow had previously stopped. This same thing occurs when using surge irrigation, except three to six cycles are used and the cycling is done automatically at short durations, 20 minutes to 2 hours.

How Surge Irrigation Works

When water first makes contact with the soil in an irrigation furrow, the rate of infiltration is high. As the water continues to run, the infiltration rate at that point in the furrow is reduced to a near constant rate. When water is shut off to the furrow all water remaining in the furrow will, within a few minutes, infiltrate the soil. During this process, the surface soil particles are consolidated near the surface and the result is the formation of a seal in the furrow. When water is reintroduced to the furrow the intake rate in the previously wetted section is further reduced due to the sealing action. The result is more water being carried down the furrow rather than infiltrating the soil.

High infiltration of water at the head end of a furrow irrigated field is common with continuous flow irrigation and can lead to poor irrigation system performance due to deep percolation and poor water distribution across the field. Surge irrigation, by reducing the rate of infiltration in the top of the field, not only reduces the loss of water due to deep percolation, but also improves the distribution of water between the top and bottom portions of the field. In other words, the amount of water applied at the top of the field is more closely the same as the amount of water applied at the end of the field. In figure 1, the infiltration pattern of surge and continuous flow are shown to demonstrate the difference in uniformity of water application between the two systems.

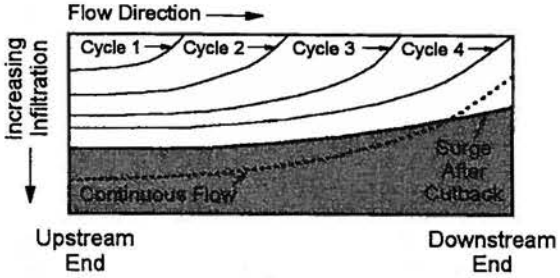

Figure 1. Infiltration patterns for continuous flow and surge irrigation.

Rather than manually moving irrigation sets to achieve an on-off cycle, a irrigation surge valve is used to automatically alternate flow between two irrigation sets. Figure 2 shows one method of using a surge valve. Cycle times used with surge irrigation vary with soil texture and slope. Fine textured soils respond less to using surge irrigation than do coarse textured soils that have higher initial intake rates. If field slope is so steep that it causes a rapid rate of advance, the effects of surge irrigation will also be reduced. Finally, if the intake rate of a soil is low due to soil texture, tight soils or compacted layers, surge irrigation is likely to be less effective in reducing the irrigation advance times below those for continuous flow.

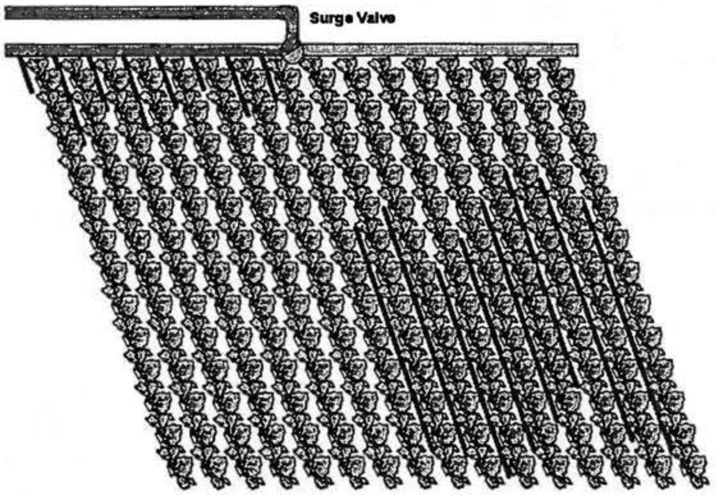

Figure 2. One method of using surge valve for irrigation.

The most significant improvement in water advance using surge will likely occur during the first irrigation of the season. This is probably the most important because following winter freezes and thaws, spring tillage and crop cultivations, the soil can be left loose and dry just prior to irrigation. These are the conditions that provide the greatest potential for improvement when using surge. Yet, as the season progresses, the soil in the furrows becomes more firm and water advance may not pose that much of a problem. However, whether it is late in the irrigation season or field conditions are such that water advance is not a problem, the advantages of using surge is not diminished.

Once water is advanced to the end of the field, surge flow can reduce irrigation runoff. This is accomplished, by using short duration cycles that advance water nearly to the end of the field before being cycled to the other irrigation set. This process continues until adequate water has infiltrated at the bottom end of the field. This helps maintain high uniformity of water application and improve overall irrigation performance.

Another advantage to surge irrigation, unrelated to the improvements in irrigation system performance, is that the surge irrigation valve can be used to improve irrigation system management without an increase in labor requirements. When setting water, two irrigation sets are made at one time. Although the time requirement is more than making a single set change, the savings come from not having to return to the field at a second designated time to make the second set change. Rather, the return time is to simply check the progress of the two irrigation sets and make any adjustments. Again, later in the season when furrows are firm and advance is much more predictable, returning to check the water may not be necessary, saving more labor.

In some cases if surge is not needed, the surge valve can simply be used as a set changer. For example, if irrigation is being applied using 12 hour sets, two irrigation sets can be made, one on each side of the surge valve. The surge valve can be set to irrigate the first irrigation set for 12 hours before switching to the other set. In this case, the irrigator only has to return to the field every 24 hours.

There are two primary concerns when using a surge irrigation system. First, surge flow will not always be effective in reducing the advance time of water down the furrow. When this occurs, as discussed above, there are still benefits of labor savings and runoff reduction. A second concern, as a result of lower infiltration rates associated with surge flow, is a reduction in total water application. With lower infiltration rates, less water may be applied to the soil during an irrigation set. If this occurs, the irrigator must compensate by irrigating more frequently or increasing set time to avoid under watering.

Surge Irrigation Field Tests

The University of Nebraska has tested and evaluated surge irrigation since 1983 and as recently as 2000. The tests have compared continuous flow irrigation to surge irrigation in various forms. The tests have been conducted on a variety of soil types throughout Nebraska.

In over 35 tests to compare surge irrigation with continuous flow irrigation, surge has never been less effective in advancing water to the end of the field. The average reduction in advance times across a field using surge irrigation compared to continuous flow is between 15 and 20 percent. The differences have ranged from no difference to over a 50 percent reduction in advance time using surge. The majority of these tests have been conducted during the first irrigation. Yet depending on soil type and climatic conditions, surge also resulted in advance time reductions during second and third irrigations as well. Keep in mind, as with conventional continuous flow irrigation practices any difference in soil preparation, soil compaction and soil moisture during field operations or during irrigation can impact the results of using surge irrigation.

Common Questions About Surge Irrigation

IS THERE RESEARCH TO SUPPORT THE BENEFITS OF SURGE IRRIGATION?

Yes. Research has been conducted in Nebraska since 1983. There has been additional research done by many of the Land Grant Universities in the Western US. Their results are similar to those found in Nebraska; improved water distribution, reduced labor needs and water saving.

DOES THE SURGE VALVE REQUIRE PRESSURE IN ORDER TO OPERATE?

No. The valve can operate under open discharge or gravity flow conditions. The only requirement is the valve and pipe diameter must be large enough to accommodate the flow requirements. See figure 3.

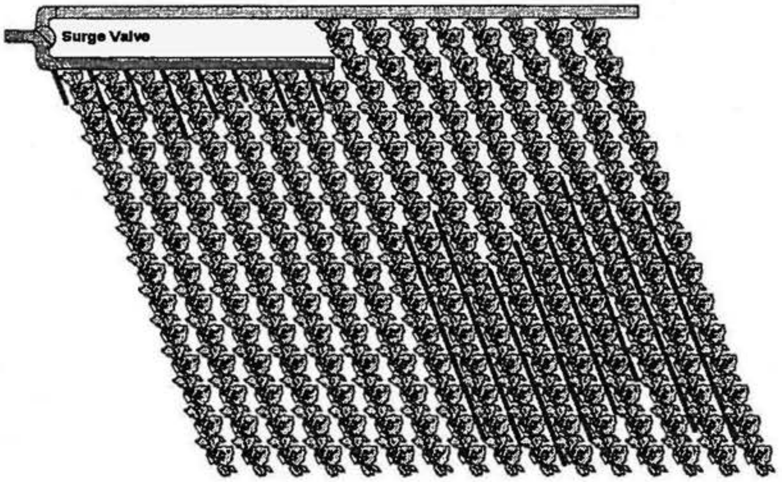

Figure 3. Surge valve under open discharge or gravity flow condidtions.

WHAT IF I DON'T USE GATED PIPE?

The use of plastic or lay flat tubing can work as well as gated pipe. If using plastic tubing, locate the valve so flow is always downhill in the tubing regardless of flow direction in the valve. See figure 3.

I DON'T HAVE ENOUGH GATED PIPE TO GET TO THE MIDDLE OF THE FIELD, WHAT DO I DO?

Using a surge valve often requires that somewhere in the system pipe is used to convey water to the desired location of the valve. Try using some of the lay flat plastic tubing as a low cost alternative.

SHOULD I REDUCE MY FURROW STREAM SIZE AND GO TO LARGER SETS BECAUSE OF IMPROVED IRRIGATION EFFICIENCY?

No. You should start with the same stream size and set size that you use under continuous flow conditions. Adjustments can be made to match stream size and the distance the stream moves down the furrow later.

WHAT SHOULD I DO WHEN THE WATER REACHES THE END OF THE FIELD?

Use the valve to reduce the on-time to 65 percent of the last on-time to keep water on the field. Most controllers do this automatically using a cutback phase. On-times during cutback should move water nearly to the end of the field and then switch to the other set. The water should then flow to the end of the field which will result in some runoff. Remember, runoff alone does not insure adequate irrigation, so check soil moisture.

WHAT KIND OF IMPROVEMENTS CAN I EXPECT?

Field tests have shown reductions in irrigation advance times can range from 0 to 50 percent during the first irrigation. During later irrigations you can expect surge irrigation to be nearly the same as continuous flow.

IF SURGE EFFECTS ARE REDUCED AS THE SEASON PROGRESSES, WHAT ADVANTAGES DO I GET FROM THE VALVE LATER ON?

The valve allows you to make two sets before you need to reset the valve and open and close gates. In short, a form of automation. This may mean that you can operate shorter set times and still apply enough water to fill the profile. Runoff may also be reduced by use of cutback cycle times. The ability to apply less water yet provide adequate water for crop growth means deep percolation and pumping costs can be reduced.

ARE ALL SOILS THE SAME WHEN USING SURGE IRRIGATION?

No. The ability of a soil to seal itself after water has been introduced to the furrow is critical to obtain a reduction in the furrow advance rate. A tight soil with a low infiltration rate may not achieve the reduction in advance times as would a sandy soil that has a high initial infiltration rate.

DO ALL MY ROWS HAVE TO COME THROUGH AT THE SAME TIME TO MAKE SURGE WORK?

No. But like continuous flow systems, management is needed to adjust stream size and number of furrows. Results of field tests indicate that the variability among rows tend to be less when using surge irrigation.

WHAT EQUIPMENT DO I NEED TO GET STARTED?

The equipment needed includes the surge valve and possibly enough mainline pipe to locate the valve at the desired location in the field.

WHAT DO SURGE VALVES COST?

Normally, valves will cost between $1000 and $2,500 depending on the size of the valve and controller options. Getting over the field during the first irrigation in half or three quarters of the time it normally takes may more than pay for a valve in a single year. By realizing a water savings, pumping costs can be reduced. For each inch of water saved, pumping costs savings could be in excess of $200 for a quarter section field. Estimate the savings you could expect and the valve may well pay for itself in just a year or two.

IS THE EQUIPMENT RELIABLE?

Like any technology, equipment has improved with time. Surge valves have been in operation for a number of years and the reliability of the valves has become quite good.

ARE THERE OTHER ADVANTAGES TO USING SURGE IRRIGATION?

Water quality is a major concern in all areas. Irrigation efficiency is often low in furrow irrigated fields and surge can improve irrigation uniformity and efficiency by reducing runoff and deep percolation. The result can be less water applied and less deep percolation which can carry chemicals into the ground water and cause water quality problems.

HOW DO I KNOW AFTER READING ALL THIS IF SURGE IRRIGATION WILL WORK FOR ME?

You don't. Run your own test and compare several rows of continuous flow to rows that you manually surge water between. Make sure the amount of water used in each furrow is the same. Compare the total time that it takes water to get to the end of the furrow.

As an example, let's say water reaches the end of the field for the continuous flow furrows in eight hours. For the surge test furrows water reaches the end of the field in ten hours. But remember, water is being spread between two furrows or twice as many acres. Therefore, for an individual furrow, it takes eight hours to advance to the end of the field using continuous flow while furrow advance is completed in only five hours with surge. This means with the same volume of water you were able to irrigate two rows where normally you only irrigated one.

Summary

Surge irrigation provides furrow irrigators an opportunity to improve their management of irrigation water. By reducing infiltration rates, surge irrigation allows lighter applications which can improve irrigation performance. In addition, reducing deep percolation by using surge means major steps can be taken to reduce the potential for chemical flow to the ground water.

The effects of surge irrigation are most prevalent during the first irrigation when the soils intake rate is high. Although intake rate reduces as the season progresses the advantages of surge continue in the ability to manage water supplies by keeping water on the field and minimizing the amount of runoff leaving the field.

Surge irrigation does not apply to everyone but past success suggests that furrow irrigators should at least consider this water saving technology.

Low Volume Chemical Application System

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INTRODUCTION

Control of pests and diseases are crucial for optimum crop production under irrigated conditions. For many years producers have successfully used chemigation where chemicals such as fertilizers and pesticides are injected in the irrigation water of self-propelled sprinkler systems. However where a foliar-applied spray is desired, even the typical minimum application depth of 6.4 mm (0.25 in) dilutes the chemical too much. In other cases, it may be critical that chemicals are applied in a timely manner even though there is ample soil water to meet crop needs. In some high value crops such as potatoes and onions, it may be necessary to apply chemicals in a timely manner multiple times throughout the growing season to control disease and insect problems. Sometimes crop and weather conditions limit the opportunities for applying the necessary chemicals with ground applicators or airplanes. There is increasing interest among producers to use self-propelled sprinkler systems to apply chemicals through a separate application system mounted on the sprinkler. The current interest in precision farming where areas within a field are managed separately is spurring interest in application systems which can variably apply water and chemicals across a field.

To address the need of the producers and to provide a more robust and flexible chemical application system, Valmont Industries recently introduced the Accu-Pulse system. It is designed to allow application of agricultural chemicals for controlling weeds, pests and crop diseases. The system may be used to apply crop nutrients as well. The Accu-Pulse is a low chemical application system and uses the concept of pulsing the chemical applicators to achieve the desired low rates. It is installed on self-propelled irrigation systems such as center pivots (as shown in Fig. 1) and linear moves. In contrast to chemigation and fertigation systems where chemicals are injected into the irrigation water during the irrigation operation, the Accu-Pulse system runs independent of the irrigation system and uses a separate water supply for chemical dilution. In practice, the irrigation system runs dry when chemicals are applied through the Accu-Pulse system. During the past few years, Valmont Industries has been continuously evaluating and enhancing the design of the Accu-Pulse chemical application system. Of particular importance is their newly designed spray heads or accumulators called "Phillips" which are the subject of few experimental tests reported in this paper.

Uniformity of application is very important in the efficacy of the chemicals especially when applied at very low rates. Usually a coefficient of variation (CV) of 0.15 is considered acceptable (Dr. Paul Ayers, Colorado State University, Fort Collins, personal communication). In the Accu-Pulse chemical application system, two separate tanks and pumps are utilized, where one tank contains the concentrated chemical and the other is filled with water. An injection pump is utilized to inject chemicals directly into the solution supply line that runs the entire irrigation system. This on-the-go mixing of chemical and water, however, could potentially create non-uniformity in chemical concentrations since the rate of chemical injection is kept constant but the rate of water flow may vary considerably depending on the different number of towers moving over time. It is noted that pulsing of a given lateral only occurs when the tower is moving. The effect of this potential source of varying concentration on the uniformity of the applied chemical concentration is not entirely known at this time and is the subject of ongoing research.

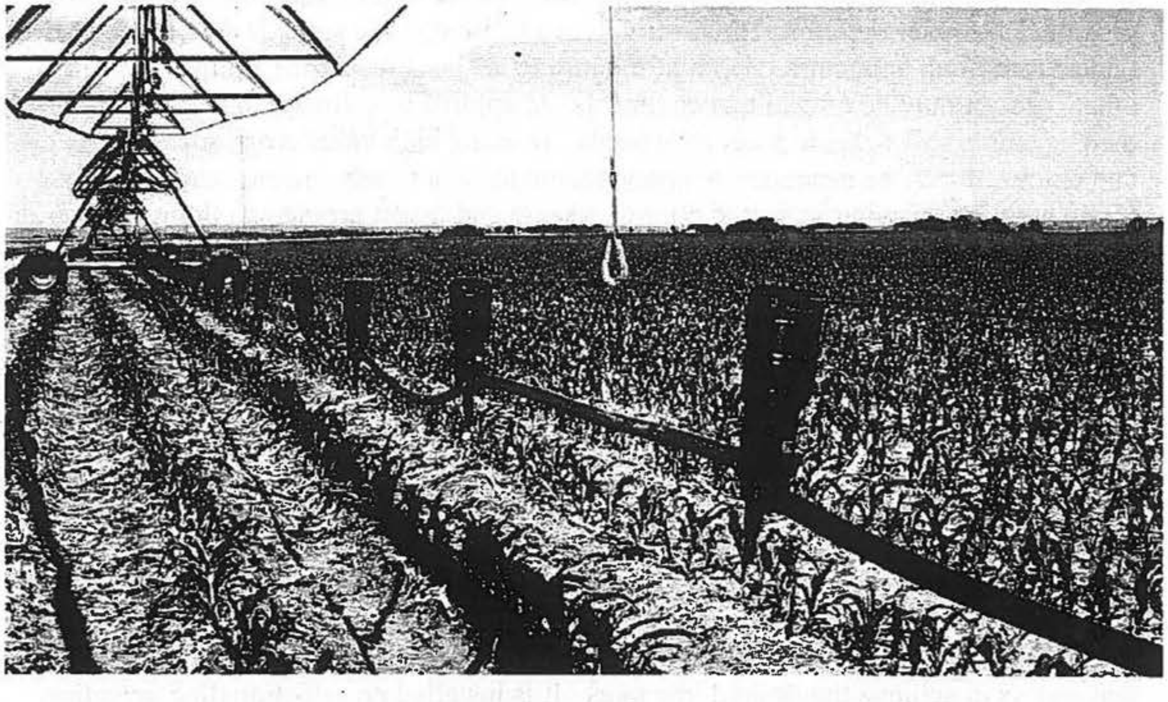

Figure 1: An Accu-Pulse chemical application system mounted on a center pivot.

Figures 2 presents a view of an older version of the Accu-Pulse spray head (or accumulator). The internal accumulator design for the Phillips accumulators (not shown herein) is slightly different than the design shown in Figure 2, but the mechanics of both designs are similar. As shown, the Accu-Pulse spray heads are individual units each molded to consist of a plastic nozzle with a spreader (not shown) at the lower end and an accumulator housing at the upper end. Each unit has an inlet and an outlet port at the sides. The Accu-Pulse spray heads are designed to hang on steel cables and are usually spaced 1.5 m (5ft) apart along the cable, which is strung underneath the irrigation mainline. The entire Accu-Pulse system is made up of individual laterals that feed off a supplyline that runs the length of the irrigation system. In center pivots and linear moves, all Accu-Pulse heads installed on a lateral line between adjacent towers are considered a unit and are pulsed by manipulating the liquid pressure inside that lateral. Each lateral is intended to pulse at pre-specified times (i.e., the last lateral is usually pulsed every 9 seconds). A lateral on a span pulses only when the span is moving. The sequence of discharge and filling of accumulators is unique because it applies the chemical solution in quick pulses.

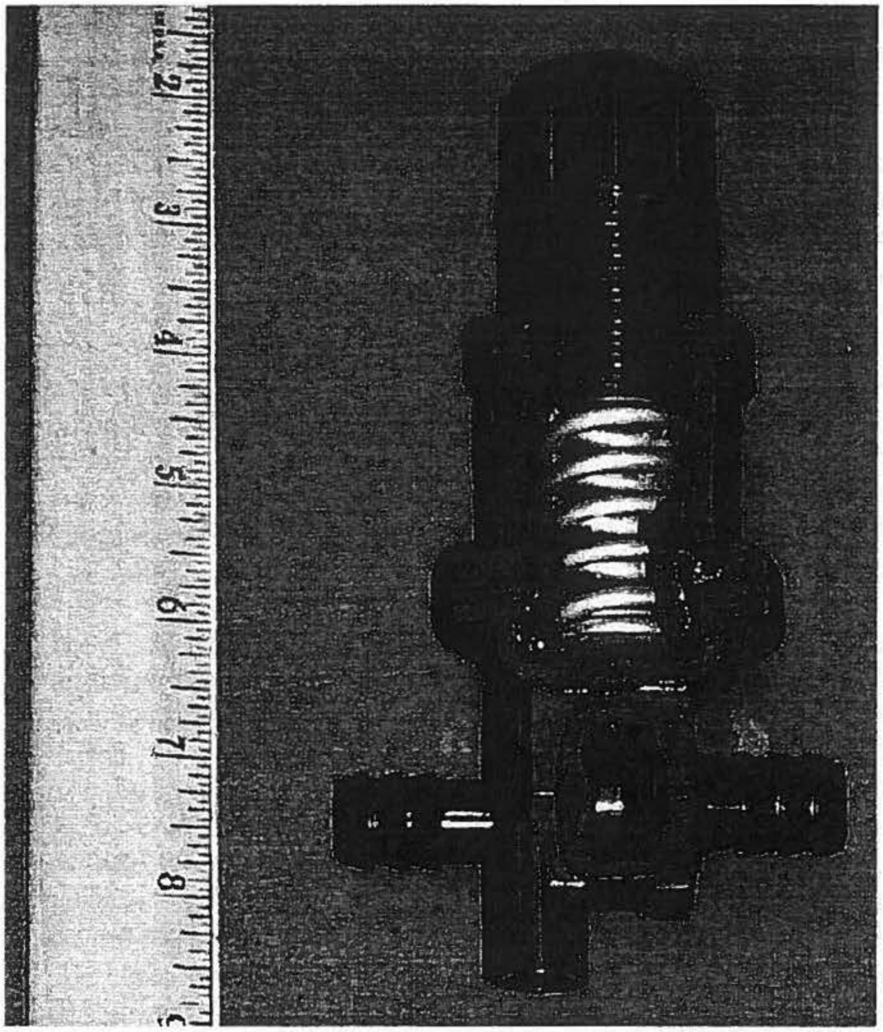

Figure 2. View of the internal components of an older version of the Accu-Pulse spray head (or accumulator).

An integral component of each accumulator is a 2-way valve that directs flow either into an accumulator chamber and the downstream tubing or else the spray nozzle for discharge. Figure 3 illustrates the two valve positions. When the lateral line is pressurized, the outlet to the spray nozzle is closed causing the chemical solution to flow into the accumulator chamber (compressing the spring). As the chamber is filling up, the chemical solution also flows through the lateral tubing to the next downstream spray head. This filling process continues until all of the accumulators on the lateral line are filled with the line pressurized. For safety purposes, a transducer constantly monitors the pressure at the end of each lateral line. In case of a line breakage or leak in any lateral, the entire system shuts off. Two two-way solenoid valves are installed at the upstream end of each lateral. These are called the FILL and FIRE valves and are controlled by relay switches and a programmable logic controller (PLC). Both of these valve are normally closed (when not energized) to guard against the loss of electricity. During operation, the FILL valve is energized (opened) to fill the lateral with the chemical solution to about 55-70 psi. Pulsing occurs by closing of the FILL valve and opening to the atmosphere of the FIRE valve. The FIRE valve is only opened to the atmosphere for a fraction of a second (0.25 sec). Opening of the FIRE valve suddenly reduces the pressure inside the lateral line and the accumulator thus causing the spring to expand forcing the cylinder downward with the solution discharging with a burst. A convex plate (spreader) below the nozzle produces a quick burst of spray about 4 - 4.5 m (13-15 ft) in diameter depending on the height above the soil surface. As the solution forces out, the upstream diaphragm is forced shut. When the FIRE valve is opened, the pulsing of accumulators occurs very rapidly. Our detailed laboratory tests showed that a lateral line with 30 accumulators spaced at 1.5 m intervals will take a fraction of a second to complete pulsing and about 3 to 4 seconds to complete the refilling process following the pulse. The nine-second pulsing interval currently recommended by Valmont Industries thus seems adequate, allowing enough time for the lateral to refill prior to next pulse. The amount of chemical solution applied can be varied by changing the frequency of the pulses, the volume of solution stored in the accumulator chamber, and the travel speed of the machine. The Phillips accumulators have an infinite setting for volume ranging from 0 to 20 setting that corresponds to about 10 to 30 ml per discharge, respectively.

As part of a Cooperative Research and Development Agreement (CRADA) between USDA-ARS Water Management Research Unit (Fort Collins, CO) and the Valmont Industries (Valley, NE), a series of laboratory tests were conducted during 2000 to study the performance of the newly designed Phillips accumulators. The main objective of the tests is to assess the uniformity of discharge volume and chemical concentration using Valmont's Accu-Pulse chemical application system. A combined approach involving both lab and field testing as well as development of a computer simulation model was envisioned to evaluate system performance under various conditions as well as to provide a useful tool for evaluating alternative designs and operating procedures. We felt that it was not physically and economically feasible to try to collect samples that could be analyzed for chemical concentration over an entire section of a field to assess the spatial uniformity of applied chemical. Since it is extremely difficult and costly (if not impossible) to evaluate the many possibilities of variations in mixing ratios due to variations in inflow water rates, simulation modeling will be utilized to evaluate the system. Chemical concentrations measured from laboratory tests will be used to validate and calibrate the model. Results from the simulation model can ultimately be used to produce a map showing the spatial variability of applied chemical.

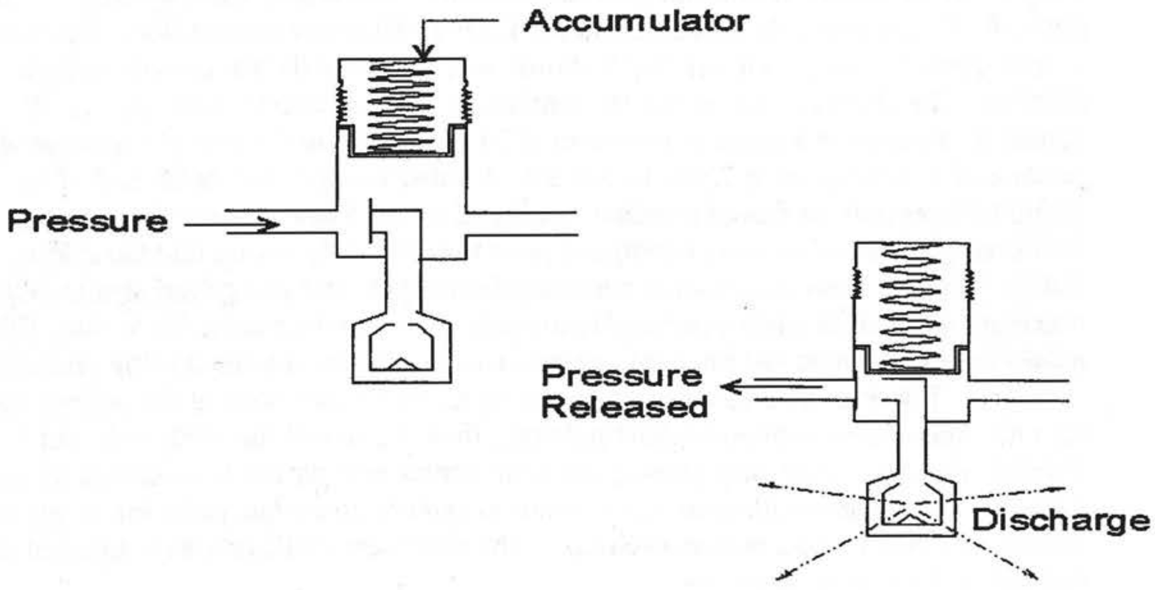

Figure 3. Schematic of the pulsing spray head (or accumulator).

In this report, we are presenting results from two different laboratory tests and briefly discuss key findings. The first test was a static distribution or spray pattern (using catch cans) for the Phillips accumulators. The other test was intended to quantify the discharge distribution for 30 Phillips accumulators installed on a single lateral line, operated using Valmont's recommendations and equipment.

Methods and Materials

Spray Pattern

A total of 167 catch cans (8 cm dia x 15 cm high) were placed in radial lines (covering a maximum of 7 feet in radius) under a Phillips accumulator to measure the depth of water application for 6000 pulses. Can spacing was 0.3 m (1 ft) in the radial direction and either 15 or 30 degree increments in angular direction. The bottom edge of the spreader was set at 5 ft above the top lip of the catch cans. Based on results from preliminary tests, 6000 pulses were found to be sufficient providing adequate volumes in most catch cans for graduated cylinder measurements. Tests were conducted at pressures of 55 and 70 psi with the accumulator at 5 and 15 settings (corresponding to about 14 and 26 ml of discharge per pulse).

Single Span Distribution of Discharge Volume

A single span (lateral) with 30 Phillips accumulators spaced at 1.5 m (5 ft) intervals was setup in the laboratory for discharge measurements. The lateral was suspended from 3 rows of 3/8 inch steel cables approximately 1.2 m (4 ft) above the test floor. The pump system currently being marketed by Valmont was used to make the tests as realistic as possible. The objective was to test the uniformity of discharge for three reps of 50 consecutive pulses at a range of pressures of 35, 45, 55, 70 and 90 psi and a range of accumulators settings of 0, 5, 10, 15 and 20. A valve was installed at the end of the lateral to flush the line free of possible entrapped air for 5 minutes prior to each test. Additionally, 200 pulses were conducted prior to each test to ensure that the system is stable. With the spray heads set at the desired setting, a clear one gallon plastic milk jug was hung underneath each spray nozzle to catch the entire discharge. Each time, fifty pulses were conducted and the total volume in each jug was measured using graduated cylinders. The tests were carried out by setting all 30 accumulators at the desired setting, start the Accu-Pulse system (without pulsing), flush the lateral line with water for 5 minutes, run 200 pulses, stop pulsing but keep system pressurized to minimize air entry, hang milk jugs underneath each accumulator to capture discharge, pulse for 50 times, and measure volume of discharge in each jug. The tests were replicated three times at all settings and operating pressures.

Results and Discussions

Figure 4 presents a 3-D view of the catch can volumes after 6000 pulses of the Phillips accumulator at the 15 setting (operating pressure of 55 psi). This pattern is very typical of all of our measurements, a shape that resembles a donut shape with distinct peaks. The outer peaks were the result of the side-arms in the convex spreader. At the lower setting of 5, the magnitudes of volumes in the catch cans were decreased, but the shape of the pattern remained similar to the one shown in Fig. 4. We intend to study the influence of overlapping on application uniformity and most importantly on ground coverage using simulation modeling.

A summary of results for the single span volumetric discharge measurements is presented in Table 1. The coefficient of variation (CV) is defined as standard deviation divided by mean, a normalized measure of the degree of variability used to aid comparison. Valmont recommends operating the Accu-Pulse system at 55 psi and higher pressures. Figure 5 presents a graph of the mean discharge per pulse at accumulator settings of 0, 10 and 20 all operated at the 55 psi pressure. At this pressure, mean discharge volumes per pulse were 9.8, 14.6, 20.6, 25 and 29.3 ml for the 0, 5, 10, 15 and 20 settings, respectively. That is roughly a ml per setting number plus 10. The settings zero and 20 are the lowest and highest settings for the Phillips accumulators. At 55 psi operating pressure, CV values of 15, 10 and 14% for the 10, 15, and 20 settings indicate very acceptable performance (see Table 1). Irrespective of the operating pressure, the most significant level of non-uniformity in discharge among the 30 accumulators was

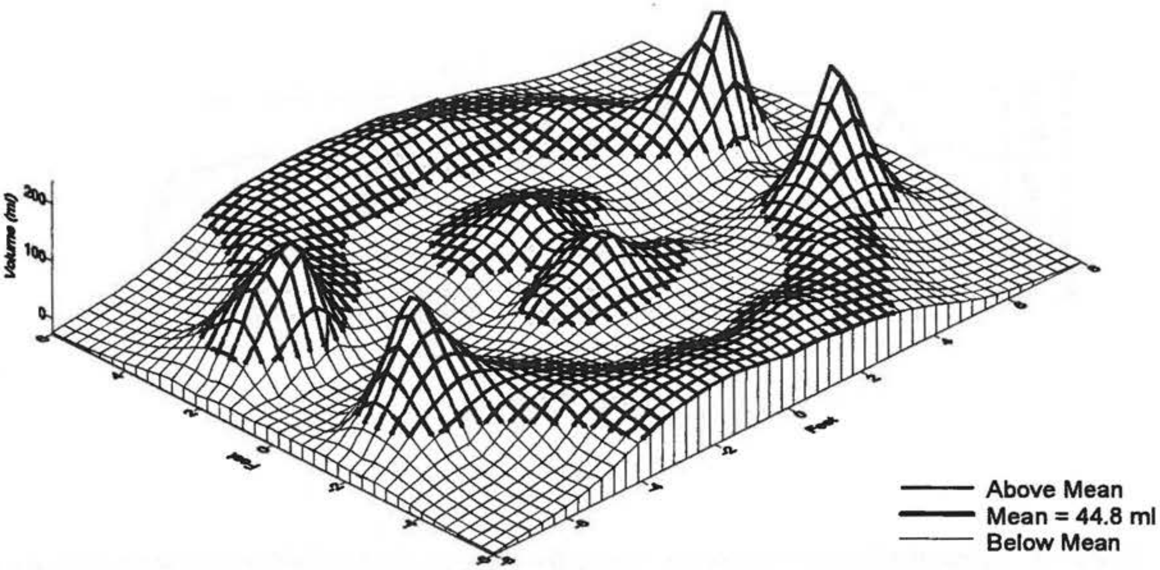

Figure 4. A 3-dimensional graph of the spray pattern for the Phillips accumulator (setting = 15, pressure = 55 psi) after 6000 pulses.

measured at the lower setting of zero with CVs mostly greater than 30%. As the operating pressure and accumulator setting increased, CV of discharge decreased. Our results reconfirms the recommendation by Valmont that best discharge uniformity is obtained at operating pressures of 55 psi and higher.

Conclusions

There is increasing interest, especially by producers of high value crops, in applying agrochemicals with independent systems that are mounted on self-propelled sprinkler systems. The Accu-Pulse chemical application system introduced by Valmont Industries appears to be a promising system that lends itself to precision agriculture and variable rate technology. In a laboratory setting and under a controlled environment, we found acceptable levels of uniformity for discharge volumes from a single lateral with 30 accumulators. We are very encouraged by our initial positive findings and the potential of the Accu-Pulse chemical application system. Additional detailed experiments are currently underway to further evaluate the performance of the Accu-Pulse system. In our opinion, the system requires comprehensive field and laboratory tests to quantify the spatial and temporal distribution of the applied chemical concentration and the effect of overlapping accumulator patterns on uniformity and the wetted coverage.

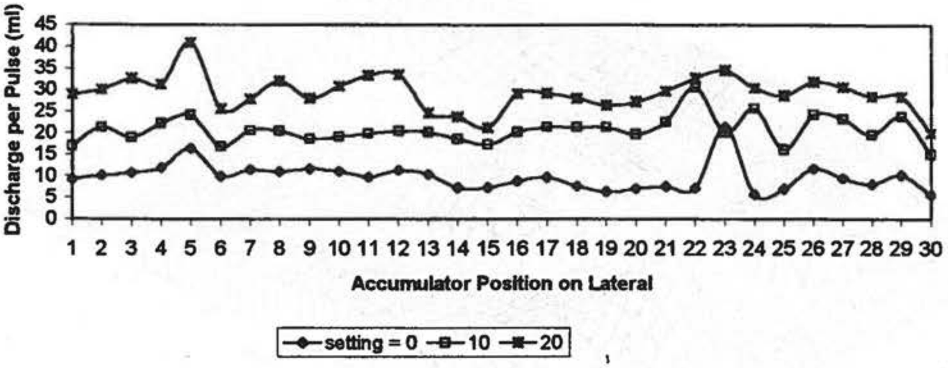

Figure 5. Mean discharge volume per pulse for each of the 30 Phillips accumulators on a single lateral line.

Table 1. Summary of discharge volume per pulse measurements for 30 Phillips accumulators on a single lateral line.

Operating					
Pressure	Accumulator setting				
psi	0	5	10	15	20
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	Mean Discharge per Pulse (ml)				
35	5.9	17.0	19.9	24.7	26.1
45	12.9	16.0	21.0	26.6	25.8
55	9.8	14.6	20.6	25.0	29.3
70	9.2	14.1	19.9	26.1	27.0
90	9.2	14.2	21.3	26.8	29.5
	Standard Deviation (ml)				
35	1.8	4.5	6.4	2.1	3.7
45	8.7	5.0	4.3	3.3	4.1
55	3.1	3.3	3.1	2.6	4.0
70	4.9	2.6	2.4	2.1	2.7
90	2.9	1.9	1.9	1.6	2.4
	Coefficient of Variation (%)				
35	30%	27%	32%	8%	14%
45	68%	31%	20%	13%	16%
55	32%	23%	15%	10%	14%
70	53%	18%	12%	8%	10%
90	31%	13%	9%	6%	8%