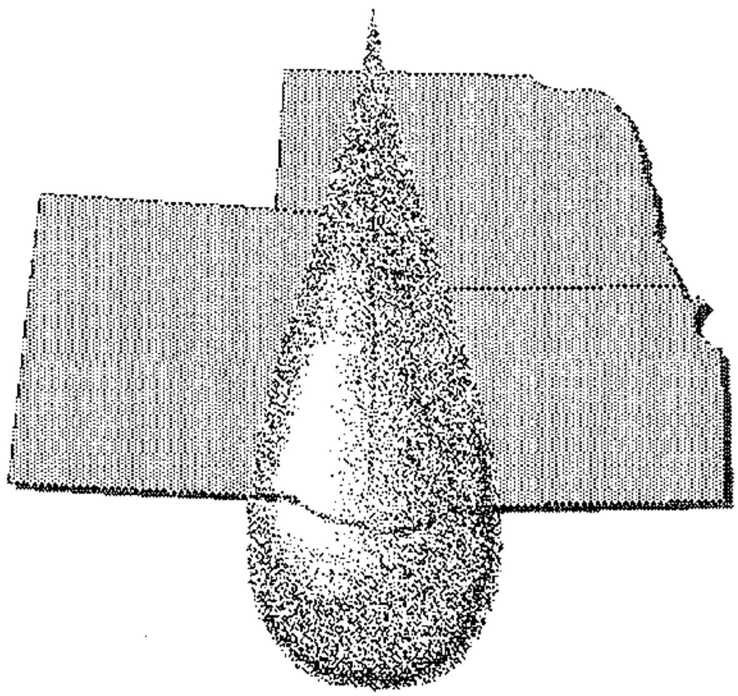
Central Plains Irrigation

Short Course & Exposition

Proceedings



February 4, 1997
8:00 am - 5:15 pm CST
Colby Community Building
285 E. 5th St.
Colby, Kansas

Kansas State University Colorado State University University of Nebraska
Central Plains Irrigation Association

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WEATHER MODIFICATION - WHAT IS IT?

Weather modification is the intentional treatment of one or more cloud systems to produce an effect beneficial for people or to the environment. Programs most often performed in the past have been for one of the following reasons: (1) to increase precipitation, either rain or snow, (2) to reduce crop-damaging hail or (3) to disperse fog.

Shortly after 1946 important scientific discoveries pertaining to weather modification were made. In those early years most of these discoveries were made by a renown group of researchers from the General Electric Research Laboratories in Schenectady, New York. During this time they found they could alter the physical processes within clouds to cause rainfall. Numerous tests were conducted, mostly using dry ice or various complexes of iodine, usually silver iodide, as the material (or "seed") to be placed into the experimental clouds.

All air contains some moisture, often this moisture is described in terms of "relative humidity". If a sample volume of air has a relative humidity of 50% at a given temperature, it contains half the total moisture it can hold at that temperature. If the sample air becomes cooler (as when an air mass rises) it is less able to hold moisture and its relative humidity increases. Eventually, if the sample rises far enough, it can cool to the point where it reaches a relative humidity of 100% despite not having had any moisture added to it.

With sufficient cooling, as in our example, eventually moisture will begin to condense around microscopic particles present in the air (such as dust and smoke). These particles are called *cloud condensation nuclei*. Initially, atmospheric vapor needs these particles to condense upon. With further cooling, droplets will fall below freezing and become "supercooled". Other special, small particles are also found in the air, called *ice nuclei*. These particles cause supercooled droplets or supercooled water vapor to freeze when they become embedded in, or make contact with the droplets or vapor. When both supercooled water (or water vapor) and ice crystals begin existing together in a cloud, their subsequent interaction results in more ice crystals forming and ice crystals growing to a size capable of allowing them to fall to the ground as some form of precipitation. If there is sufficient warming, rain or drizzle occurs; otherwise, snow, hail or sleet may be the case.

The physical make-up of a cloud is, therefore, very important in the process. Cloud volume, moisture characteristics and distribution of nuclei all play significant roles. Cloud condensation nuclei are relatively abundant in the atmosphere, whereas, ice nuclei are comparatively rare. It is in the addition of ice nuclei to a cloud that cloud seeding can stimulate the beneficial effects desired.

Cloud seeding is simply a means of assisting a natural process to evolve. The explanation given above is a simplified representation of the normal circumstance. However, in reality, clouds are much more complex and depending on their individual make-up, they usually require a variety of seeding techniques or seeding materials to be effective in obtaining the desired result.

What about "downwind" and "environmental" effects? According to the Weather Modification Association, positive effects have been recorded for distances of 100 miles downwind of operational areas, while no significant indications of downwind rainfall decreases have been recorded from any long term seeding activity. Moreover, silver and iodine concentrations in rainwater where silver iodide has been used measure less than 1 part per billion - well below acceptable levels set by the US Public Health Service.

Does it work? According to the National Academy of Sciences, it does work. They report that properly designed program operated by competent directors can increase rainfall from 10-25% and decrease damaging hail by 30-70%. These figures are based on nearly 40 years of researching projects in over 40 countries of the world.

Questions concerning cloud seeding can be directed to either of the GMD offices - in Scott City or Colby. The next article will cover the cloud seeding activities on-going in other states as well as Kansas. Please watch your papers. **Finally, the published references below have been provided to the area libraries for your convenience and review.**

The reference materials for this article are: *Weather Modification - Some Facts About Seeding Clouds*, published in 1984 by the Weather Modification Association, Fresno, CA., and personal interview with Curtis Smith, Program Meteorologist of the Western Kansas Groundwater Management District No. 1 Weather Modification Program.

WEATHER MODIFICATION - WHERE IS IT HAPPENING?

A variety of non-experimental weather modification programs have been performed in the U.S.A. and elsewhere around the world for several decades. These programs are each designed to address a particular weather-related problem for a specific area. For instance, snowpack augmentation in the Sierra Nevada mountains of California has been performed since the early 1950's by both hydro-electric utilities and irrigation districts. In Canada the Province of Alberta performed important hail research and seeding operations for many years. Although some of the following western European countries have had operational programs somewhere within their borders, it is not known whether all continue to do so now; they are: Greece, Italy, Turkey and Switzerland. Other eastern and western European countries have performed weather modification programs for one or more decades to reduce hail: France, USSR, Yugoslavia, Bulgaria and Spain. Mid-eastern, North-African and Asian countries have been more interested in winter rainfall stimulation for domestic and agricultural uses and have had periodic programs: Morocco, Libya, Jordan, Iran, United Arab Emirates, India, Thailand and the Philippines. Probably more than any other country, Israel has made the most progress toward scientifically understanding the rainfall process as it pertains to them and have been able to obtain statistically high results from their cloud seeding operations. Most weather modification research and operations in sub-Saharan African countries have been in Kenya, Zimbabwe (formerly Rhodesia) and South Africa. Only Zimbabwe is known to have an operational program at this time, but there is a strong governmental commitment to precipitation research in South Africa. Australia has conducted important research in rainfall. In Central and South America only Chile is known to have active weather modification programs now. Weather modification programs have been performed in Mexico, Panama, Venezuela and Argentina. The Caribbean countries of the Dominican Republic, Jamaica and Antiqua have had rainfall stimulation programs at one time or another.

As the worldwide population has grown larger with time, the worldwide need for a reliable supply of water for domestic use, industry and agriculture has grown. Not surprisingly, worldwide interest in using weather modification as a water resource management tool has increased.

A variety of U.S. governmental organizations and concerned groups have sponsored weather modification-related activities, among them: the Bureau of Reclamation, Air Force, Navy, NOAA and National Science Foundation. Numerous academic Institutions have been active participants in research, but generally they have received their funding from one of the previously mentioned governmental agencies or grants from state agencies. Private funds have been devoted almost entirely to specific operational programs and not research. According to the Weather Modification Association (WMA), 19 universities are currently represented by virtue of faculty membership in that association. The WMA also lists a dozen private groups acting as consultants or operating commercial programs for sponsoring groups.

Kansas is one of 32 states which has enacted weather modification legislation to regulate the quality of activity within the state's borders. The responsibility for holding hearings, issuing licenses and permits and for monitoring weather modification programs rests with the Kansas Water Office. In 1989, the latest year for which statistics were available, NOAA reported 40 separate weather modification activities being performed in 16 states. Kansas and North Dakota were the only two states in the High Plans in which hail suppression and rainfall augmentation were performed last year.

Unrelatedly, we find it interesting that so much severe weather occurs at higher elevations relatively frequently, be it Western Kansas or the earth's equator. When hail occurs in Western Kansas, a high availability of moisture is implied -- usually it occurs seasonally between spring and fall. During periods of high moisture availability, various kinds of clouds form and weather modification can be employed to increase rainfall and reduce hail. The dual objectives of increasing rainfall and reducing hail has been the long-term goal of the successful 17-year program operated by Western Kansas Groundwater Management District #1. The operational headquarters of the program is based in Lakin, Kansas. The next article in this series will cover in depth the Lakin-based program -- Kansas' only active weather modification program.

The reference materials for this article are: *Weather Modification - Some Facts About Seeding Clouds*, published in 1984 by the Weather Modification Association, Fresno, CA., and personal interview with Curtis Smith, Program Meteorologist of the Western Kansas Groundwater Management District No. 1 Weather Modification Program.

WEATHER MODIFICATION - THE LAKIN, KANSAS PROGRAM

Twenty-two years ago, the Western Kansas Groundwater Management District No. 1 endorsed a program to seed clouds to help alleviate the ever-increasing loss of sub-surface water in western Kansas. Per the provisions of the Kansas Weather Modification Act they wrote a detailed operational plan and then secured a license and a permit from the state of Kansas. They also had to secure their funding, which came from local GMD funds and special levies from the County Commissioners. They also had to locate critical equipment and technical expertise (borrowed from the Bureau of Reclamation) and find suitable aircraft (which they leased) before the program ever began in earnest. However, from these modest beginnings the program has gradually evolved each year into the sophisticated program it is today - operating also for hail suppression, authorized for nighttime seeding and owning all its own equipment, including radar, aircraft and building facility.

The 1995 program began in June 1994 when the commissioners were again approached about continued funding. Each year the Commissioners re-consider funding and participating in the program. If they decide to do so, they approve the county funding, which in 1995 was an amount equalling approximately 4.2 cents per acre of cropland plus 1.5 cents per acre of rangeland within the county. The participating counties in any given year comprise the "target area", which in 1995 was made up of Wallace, Greeley, Wichita, Scott, Lane, Hamilton, Kearney, Finney, Gray, Ford, Haskell, Grant and Stanton Counties. Throughout the duration of the program, as many as 16 Counties have been involved.

The 1995 program ran from May 1 through September 15, 1995. Each program day begins with a weather forecast by the project meteorologist and his staff using daily upper air soundings from the National Weather Service in Dodge City, and other weather data. Usually completed by mid morning, the daily operational plan is then telephoned to the pilots at the sites remote from Lakin, and the daily schedule is formulated. A visual and radar watch then commences, with the radar measuring such data as cloud height, location, intensity and other physical characteristics. All readings are electronically stored for review and/or evaluation at a later time. When the weather is right, the appropriate number of the project's five aircraft are sent up to either observe the developing storm or seed it. The program currently has 4 single engine Piper Comanches for seeding at cloud base (with wing-tip liquid fuel generators for silver iodide) and 1 twin-engine Piper Navajo (with a specially built dry ice dispenser) for seeding at or near the cloud tops. The Navajo is hangared at Dodge City while the Comanches are at Lakin, Johnson, Syracuse and Scott City.

The program had 55 operational days in 1995, conducting 411 total flights and seeding for 798 hours. From long term data, these are above average figures for the effort. Like many years before, most program problems resulted in too many storms on the active seeding days, indicating the need for additional aircraft. The 1995 Report recommendations are largely repeats from the 1994 final report. There were at that time needs regarding hanger space, a better rainfall observer network, enlarging the field office and additional planes for better coverage. They also recommended lengthing the program period by at least one week in order to better cover the expected hail incidence period. Program expansion was suggested for the first time for the NW Kansas area. Finally, better radio communications between the pilots and the meteorologist was recommended.

The reference materials for this article are: *Final Report Western Kansas Weather Modification Program, 1990*, published by Western Kansas Groundwater Management District No. 1, and personal interview with Curtis Smith, Program Meteorologist of the Western Kansas Groundwater Management District No. 1 Weather Modification Program.

WEATHER MODIFICATION - A RECENT HISTORY OF NORTHWEST ACTIVITY

For this article the district wanted to take a recent historical look at what efforts our region of the state has dedicated to weather modification, concentrating on efforts beginning with the inception of the Bureau of Reclamation's High Plains Cooperative Program called HIPLEX.

The state actually got formally involved in 1955 when the legislature created the Kansas Water Resources Board (KWRB), charging this body with, among many other duties, the collection of water, soil and climate data in order to develop a state water plan adequately written to best manage the state's groundwater, surface water and atmospheric water. The KWRB began conducting field experiments in Kansas during the summer of 1972. Colby was the first of these three experiments, which became collectively known as the Kansas Cumulus Project, or KANCUP. These efforts introduced the Bureau of Reclamation (Bureau) into the state as it was their radar and computer facilities which were used.

In May, 1974 three sites were chosen by the Bureau to further study the effects of seeding clouds. Colby-Goodland was one of these areas in addition to Miles City, Montana and Big Spring-Snyder, Texas. Shortly thereafter cost-sharing agreements were formalized between these states and the Bureau. In general, the states were to be responsible for defining policy objectives while the Bureau was to handle scientific and field testing objectives. More specifically, the Miles City site was to conduct single-cloud experiments while the Colby-Goodland and Big Spring-Snyder sites were to conduct background data accumulation experiments in preparation for single-cloud seeding in the future.

Also in 1974 the Kansas Legislature passed the Kansas Weather Modification Act which became effective July 1, 1974. This law provided for state regulation of all seeding activities conducted within the state.

The HIPLEX activity continued at the Colby-Goodland site under the state/Bureau agreements until the middle of 1976 when there began a push to transform the project and integrate it with the operational seeding program being conducted out of SW Kansas under direction of the Scott City based Groundwater Management District. This push continued into 1977 with NW Kansas getting ever closer to losing their Colby-Goodland site. This message was beginning to be publicized by the newly formed Northwest Kansas GMD 4 who at their February, 1977 board meeting had already expressed sincere interest in developing an operational program in conjunction with HIPLEX.

GMD 4 began in March, 1977 polling the County Commissioners as to their interest in a local seeding program. In May, 1977 they also placed $5,000 in their 1978 operational budget for a possible program. At that time, Gove, Sheridan and Thomas were the only counties to express an interest. Decatur never discussed the issue and Graham, Logan, Rawlins and Sherman Counties voted "no interest". The GMD Board continued their efforts and in August, 1977 applied for a grant from the state to conduct a 1-month operational program during 1978. This grant was approved for $28,000. The June, 1978 program was conducted and the final report remains in the district office for public review. No further interest could be generated from the counties as the report was forwarded to them for review.

The issue of operational seeding laid dormant for nearly ten years following the 1978 program. In August, 1986 the Lakin, Kansas project contacted this district about adding our ten-county area to the existing program. During an October regional meeting of County Commissioners held in Oakley, Kansas, the issue was discussed and supported by 9 of the 12 counties present. It was then decided to meet again to formally discuss options and alternatives. All commissioners were invited to the working session which was scheduled for November 5, 1986. Seven commissioners representing 4 counties (Thomas, Sheridan, Rawlins and Logan) attended, and a procedure was developed to assess area interest. Each County was to express, by February 15, whether or not they wanted a detailed presentation of the proposal. Wayne Bossert was to then meet with each commission responding "yes", and fully explain the proposal and ask that by March 1, 1987 they decide whether or not they want to poll their voters - with no obligation to that point. By April 15, each county was to meet again with GMD4 staff to design a polling procedure acceptable to the commissioners. Finally, June 1, 1987 was a date each county was to decide to participate or not.

All Counties indicated "yes" to step 1, the presentation, and all counties received a special presentation in their own commissioners' rooms. When March 1 came, Thomas, Sherman, Sheridan, Graham, Gove and Wallace Counties indicated they would be willing to poll their voters, while Rawlins, Cheyenne, Decatur, Logan, and Trego Counties indicated they did not want the issue taken to the public and they were not interested in continuing discussions.

The next step, to meet again and design a method to poll public interest, was already underway with public meetings having been scheduled in Gove, Thomas and Wallace Counties to assess public support. These efforts were in fact unnecessary in that only six counties were going to remain in the program after step 3, which were not enough to operate a program. As a result, there was no need to continue any further, and on June 22, 1987, the proposal was abandoned.

The prospect was revived again in 1993 as the district identified it as an important step in its developing 4-prong program to control water table declines. So once again an effort was mounted to sell the concept of a NW Kansas program to the county commissioners. This effort got further along than any previous attempt, and actually found Sherman, Thomas and Sheridan County commissions agreeing to pass a funding resolution per limits identified in 1994 Final Report prepared by the Weather Modification Advisory Committee made up of county commission appointees. The effort finally failed again when the resolutions in Sherman and Sheridan County were voted down at the ballot following successful petitions in both these counties. Thomas County, as a result, never passed the funding resolution they had intended to.

BY 1995 the State Water Plan process had conducted an evaluation of the WKWMP and consequently included cost share funding to help local counties begin programs in the western 39 counties of the state. The issue again arose in the NW area and at the Northwest Kansas GMD 4 1996 annual meeting in Goodland, a group of irrigators asked the board to consider GMD funding in order to match with the SWP cost share money. Nineteen meetings, two public hearings, a newsletter ballot, and many personal contacts were held and made across the district, which ultimately resulted in 86% of the respondents supporting local funding on the water users to cover the local funding necessary to implement the program proposed back in 1994 by the Weather Modification Advisory Committee. In May, 1996, the board approved a revised 1997 operating budget that included $181,000 for weather modification.

It is important to realize that as of May, 1996, 86% of all participants in the extensive public input process indicated support for the program, even recognizing that the water users would be paying the entire bill. In early 1997 (following tax statements) several petitions were circulated by persons opposing the program for various reasons. The petitions asked the Kansas Legislature to consider the process used by the local GMD and make whatever changes were appropriate to prohibit the board from being able to make similar decisions. The GMD board publicly expressed their disappointment in that the petitions were asking for the elimination of local control, which was considered to be a dangerous approach to this very local problem.

Following the revised 1997 budget hearing which resulted in locally funding 1/2 of the proposed program, the WKWMP went right to work and by January, 1997 put together most of the equipment needed to operate a NW facility. Three Piper Comanche aircraft were bought, an office was leased, a radar and tower were located and put in place, the necessary computer equipment was obtained and most of the pilots and program personnel were hired.

Today we are preparing for the 1997 annual meeting to be held in Colby, which will include a board-approved 1998 proposed budget with $181,000 included for the continuation of the program. It should be a very interesting annual meeting for both those in favor of and those opposed to the program.

The reference materials for this article are: *Weather Modification Activities in Kansas 1972-1977, Bulletin 22*, Kansas Water Resources Board; KSA 74-2608 and KSA 82a-907; Memorandum of Tri-State HIPLEX Conference, Colby, KS, dtd August 30, 1976; Kansas Water Resources Board letter to Rep. Tom Bevill, dtd February 22, 1977; and various GMD working files on weather modification.

WEATHER MODIFICATION - EVALUATING THE EFFECTS

When most people are first introduced to the concept of seeding clouds to increase rainfall and reduce hail, the first question asked is, "Does it really work?" The answer is, "Yes, it really works -- when performed at the proper time and under the proper conditions". History has taught us, sooner or later, all groups sponsoring long-term weather modification programs want to know how well their program is working, and eventually they conduct a program evaluation. In the evaluation game, however, we must all realize that different programs are designed for different purposes and are all operated differently. In addition, the standard statistical methods normally used have changed over time, and even on occasion more "creative" evaluation methods have been used. As a result of both these facts, program evaluations are very difficult to compare between each other if you're trying to generally quantify how well all modification programs work.

Normally things which can be counted and measured lend themselves well to standard statistics in which inferences are made about a group from a random sampling of it. Unfortunately, when it comes to something like clouds, no one knows exactly how much rain would have fallen from a given cloud had it not been seeded, or what size or number of raindrops or hailstones would likewise have fallen. Also, no one can know ahead of time exactly what amount of rain will fall over a growing season or how much hail damage to crops and property will occur with or without cloud seeding.

For these reasons, and others, weather modification programs generally have to be operated many years before "suggestions" of effect occurs or before any statistical results are accepted by the scientific community. Total agreement within the scientific community on such results are rare. In attempting evaluations, researchers usually develop a "target and control" approach in which an area of seeding effect is called the "target" and the "control" is, presumably, a nearby area unaffected by cloud seeding. Comparisons between the two areas are made, over time, in hopes of finding important differences between them that can be attributed to cloud seeding. Evidences of success are sometimes claimed through routinely collected data such as crop insurance (loss and liability), crop yields, and hail storm information including the sizes and numbers of hailstones, the frequency of hail events, etc.

It is again important to point out that different operational cloud seeding programs are conducted differently. In addition, over the period of time for which a program is being evaluated the program itself may not remain fixed: methods of delivering seeding agent into clouds can change; the type of seeding agent may change; aircraft numbers might change (increase or decrease); and even the target area size and shape may change from year-to-year. Furthermore, similar to many businesses, there can be important differences between the way commercial operators run their weather modification programs. Over extended time periods, rarely do two programs with similar objectives operate in exactly the same way as the other. Evaluational results, therefore, may vary widely for many reasons as well as from natural causes such as climatic shifts. Identical evaluational results are not to be expected from any two programs being compared.

Some evaluations of current and previous programs to reduce hail and to stimulate rain are of interest:

(1) North Dakota - This hail reduction program, which has been operated in western North Dakota since the late 1950's, has shown a 43.5% reduction in crop-hail damage. Rainfall increases slightly less than 10% were also found.

(2) Western Texas - An 8-year hail reduction program in the southern end of the Panhandle was found to reduce crop-hail damage by 48% and increase rainfall around 5%.

(3) Kenya - An 8-year hail reduction program, where the number of yearly hail days averaged nearly 200, found a 28% reduction in hail damage and a 12% rainfall increase.

(4) Southwest Texas - A rain stimulation program operating in and around Big Spring since 1971, was found to have a 10.3% increase in rainfall through 1986.

(5) Northern Greece - A randomized hail reduction program operating in 1984 and 1985 found an averaged 75% reduction range for several hail parameters including: (a) number of hailstones; (b) maximum hailstone size; and (c) area over which hail fell.

(6) Western Kansas - A combined hail reduction and rainfall stimulation program operating over 10-15 counties in Western and Southwestern Kansas since 1975. The most current evaluation for its first 11-years was done differently than other evaluations and found that ..."the suggested (hail) suppression effect is a reduction in crop-hail damage of some 25 to 50 percent". That reduction was found to be significant in the eastern part of the target area. Although naturally drier weather occurred during the 11-year period, rainfall changes were found not to be statistically significant. It was noted that only if rainfall changes were on the order of 10% - 15%, or more, could statistical significance be found using their methods. If rainfall changes of this magnitude would have occurred in Kansas, it would rank among the best results of all worldwide programs. However, it was acknowledged the program had many fewer aircraft than it needed to properly service the size of their target area in order to obtain the best results for both hail reduction and increased rainfall.

There is no doubt that evaluations are going to continue for all such programs. Furthermore, the indications of all this work and evaluation clearly show that the scientific foundations of today's seeding are at least fundamentally correct. Therefore, most people in the field hold an optimistic future for the science of weather modification - one which can only improve its performance as more knowledge and experience are gained.

WEATHER MODIFICATION - DEVELOPING A NORTHWEST KANSAS PROGRAM

This is the last article of the district's weather modification series of press releases. In article one the scientific principals of seeding were explored. Next we looked at where such activities were currently occurring. Articles 3-5 dealt with the Lakin, Kansas project in detail, the recent history of weather modification in Kansas and the scientific evaluations of the existing operational programs, respectively.

This entire process was supposed to give the residents and decision-makers of NW Kansas the answers to virtually any question they could ask regarding the subject, except for those questions regarding the specifics of a proposed program for NW Kansas. This last article will deal with this information.

Being proposed is a three aircraft, NW Kansas program covering the Counties of Cheyenne, Rawlins, Decatur, Sherman, Thomas, Sheridan, Graham, Wallace, Logan and Gove, which will be operated in complete cooperation with the existing program on-going in Lakin, Kansas. With a radar site and base in Colby, seeding aircraft would expect to be stationed in Goodland, Colby and St. Francis. The project meteorologist will coordinate all activities from the base, and do so in cooperation with the Lakin project base where practicable. This means that additional aircraft may be available for either program depending on the absence of seedable weather in the other's target area - a significant advantage for both programs.

Funding for such a program is expected to be approximately $362,000.00 per year for the first five years as equipment are being bought, then reduce to approximately $250,000.00 per year for continued operation. For the first year of the program, the local GMD will assess district water users an additional 20.5 cents per acre-foot of water rights to obtain 1/2 of the projected 362,000.00. The remaining $181,000.00 will be requested from the state water plan fund. Since the state water plan fund cost share support is reconsidered every year, and limited to no more than 10 years maximum, other funding sources will eventually need to be obtained in order to continue beyond the period of state water plan support.

The program will simply be an expansion of the on-going WKWMP having been operated in Western and Southwestern Kansas for the past 22 years. Our relationship will be a contractual one with all funding paying for services to provide seeding support for the GMD 4 target area. All equipment will be owned by the WKWMP. Having but one program will allow it to operate as efficiently as possible, and will prevent the need to share or borrow equipment, services, or whatever. In this sense, we will be included in the WKWMP which will as a result have 9 aircraft to cover all or parts of 22 counties in western Kansas.

The program will operate under the Kansas Weather Modification Act, and a state-approved operational plan which considers the technical integrity of the program. This plan is revised every year and can only be approved if the program meets all insurance, personnel and technical requirements.

Program personnel have been working very closely with Colorado local officials to start a demonstration program in the very eastern areas of Colorado. If successful, this will allow our program to obtain a Colorado permit to seed clouds well into that state. This is an important issue for the western edges of our program in that seeding storms coming out of Colorado early enough will improve the program benefits to residents along the state border. To date, Yuma County, Colorado has agreed to request such a demonstration program for 1997 and is expected to support a Kansas request for a Colorado permit. More Colorado support will be sought in the future.

This concludes the series of informational articles designed to answer many questions people might have as they ponder the decision to support the program or not. If questions still linger, contact the GMD office at 1175 S. Range in Colby. The phone number is (913) 462-3915. The district also maintains a home page on the internet which has periodic update information regarding this program in addition to much other information. The URL is "http://colby.ixks.com/~wbossert".

SUMMARY OF THE KANSAS WEATHER MODIFICATION ACT

KSA 82a-1401 and sequence

82a-1401: Title

82a-1402: Definitions:

Board means Kansas Water Office;
Person means natural person, partnership, organization, corporation, municipality or any department or agency of the state
Research & Development Operation means an operation conducted solely for scientific & technical knowledge
Weather Modification Activity means any operation or experimental process trying to induce change in the composition, behavior or dynamics of the atmosphere.

82a-1403: The board is responsible for administering the act, and can make rules and regulations, issue licenses and permits, conduct hearings, and enter into contracts.

82a-1404: Repealed

82a-1405: The board may issue licenses per the act. Each project needs its own license, and can be comprised of one or more specific activities. Each permit shall describe: Geographic area of activity and affected area, and project duration. A license is issued only after the project is determined to provide substantial benefits or that it will advance scientific knowledge.

The board can also make investigations or studies to help it administer the act, and can hold hearings at their discretion.

The board can also expand its knowledge, pending funds, by research efforts in: Weather Mod Theory; use of weather mod for beneficial purposes; protection of life, health, property and the environment. It can also accept grants, gifts and donations for these purposes or the administration of the act.

The board can also contract for weather mod activities to seek relief from droughts, hail, storms, fires, fog or other weather conditions.

82a-1406: No person shall engage in weather mod activities without a permit and a license, or shall violate any term of their permit and license. The board may also exempt research and emergency activities from the required fees.

82a-1407: A license shall be issued to all who: apply in writing; pay the license fee; demonstrate they possess the skill and experience needed and demonstrate that they have either: 8 years of experience (3 years as a project director); have a related college degree and 3 years of experience; or have a related college degree, 25 hours of meteorology and 2 years experience.

82a-1408: $100.00 license fee set for each year.

82a-1409: License can be suspended if permit conditions violated, fraud was used to obtain the license, negligent activity occurred or the act was violated. Complaints against any licensee must be filed in writing, specifying the charges. The board then may set hearings concerning the revocation of the license allowing the permit holder 30 days to respond.

82a-1410: Appeals for aggrieved persons.

82a-1411: Permit also conditioned upon: 1) proof of ability to respond to damages or accidents arising out of conducted activities. Must have a minimum of $50,000 coverage against bodily injury or death; $100,000 against bodily injury or death of two or more persons; and $100,000 against property damage to others. State agencies and municipalities are exempt; 2) submission of a complete operational plan containing information as to how the program will be run, its objectives, target area, environmental statement of effects, the method(s) to be used to evaluate the program, and any other information required by the board; 3) publishing notice of intent to engage in seeding activities and conduct of a public hearing to hear all comments; 4) if a project for profit, demonstration of the economic benefit to the area; 5) if a project for research, demonstration as to how the project will expand knowledge; 6) an approved statement of the safeguards to protect public property, health, and welfare; and 7) an approved statement of how the project is designed to minimize risk and maximize economic and/or scientific gains.

82a-1412: Operations can take place only under the direction of the licensee.

82a-1413: $100 fee shall be remitted to state treasurer and deposited to the state general fund.

82a-1414: A separate permit required for each calendar year activity. An emergency permit can be issued by the board without prior publication under certain instances.

82a-1415: The permit may be revised, suspended or modified by the board if the licensee is first notified and given a chance to respond, or an emergency exists which warrant such amendments. A licensee's refusal to comply with any such order shall be grounds for immediate revocation. It is the responsibility of the licensee to notify the board of any expected or anticipated emergency situations.

82a-1416: Licensee must confine operations to the conditions of the permit.

82a-1417: Must file reports required by the board. The board shall establish reporting guidelines and provide forms, etc.

82a-1418: Board may suspend or revoke a permit if the licensee no longer meets the operating qualifications. The board may also refuse to renew any license or issue any permit to any person failing to comply with the provisions of the act.

82a-1419: Board cannot suspend or revoke a license or permit without reasonable notice and opportunity to be heard.

82a-1420: State agencies and county and municipal employees shall be immune from liability resulting from activities.

82a-1421: Board may issue a cease and desist to anyone illegally operating.

82a-1422: The fact that a permit and license is issued does not absolve anyone from damages they may cause.

82a-1423: Makes it a class B misdemeanor to illegally conduct activities, make false statements to obtain a license, fail to file required reports, or otherwise operate outside the permit and license.

82a-1424: If any portion of the act is found invalid, it shall not affect the remainder of the act.

82a-1425: County commissioners may participate and may levy a tax not to exceed 2 mills upon assessed property to fund such activities, after sufficient public notice which must include information about the amount and duration of the levy. The act does exclude counties with population more than 180,000 but less than 220,000 and an assessed valuation more than 350,000,000 but less than 365,000,000 from this assessment authority. A petition of more than 5% of the qualified electors of a county filed within 60 days of the last publication will bring the issue to a county vote where a majority must approve it. Finally, commissioners may spend other funds on weather mod as well.

Water Runoff from Sprinkler Irrigation --- A Case Study

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When water is applied through a sprinkler irrigation system, it should soak into the soil where it lands rather than flow to a low spot in the field or runoff the field. Runoff causes nonuniform water application, poor irrigation efficiency, and possible leaching of chemicals to the groundwater. Some systems like LEPA (low energy precision application) are designed so that water does not immediately soak into the soil. However, proper LEPA designs also call for tillage practices that hold the water on the soil surface where it lands until it has time to infiltrate into the soil. All sprinkler systems should be designed for no water leaving the point of application or zero runoff.

This NebGuide will illustrate, through an example center pivot, the influence of soil texture, topography, and irrigation system characteristics on potential runoff. The example covers conventional tillage with no allowance for surface storage of water due to tillage. Additional background information for this case study can be found in: *Water Runoff Control Practices for Sprinkler Irrigation Systems, NebGuide G91-1043; and Selecting Sprinkler Packages for Center Pivots, NebGuide G88-870.*

Case Study

The base system characteristics of this example center pivot are given in Table 1a. Each characteristic in the table can influence the potential for runoff. Soil texture and intake family, defined by the Natural Resource Conservation Service (NRCS), determine how fast water will infiltrate into the soil. In this example we are dealing with a silt loam soil that has an intake family of 0.3. Field slope influences how much water might naturally puddle or infiltrate later, and how easily the water might flow to a lower part of the field. In this example we have a moderate slope of 3-5%.

The characteristics of the center pivot system influence how intensely water is applied to the soil. In this example, system capacity is 800 gallons per minute, system length is 1340 feet, application depth is 1 inch of water per revolution, and wetted diameter of the sprinkler heads is 40 feet. The overall runoff resulting from this field system is 26%, which means that 26% of the water pumped through the system did not infiltrate where it landed. The runoff moved to a lower part of the field or it left the field reducing the water application efficiency by 26%.

Each of the land surface factors and center pivot characteristics are varied individually in Table 1b – 1g. These examples show how each factor influences the overall runoff from the field.

Soil texture cannot be changed in a given field; it has a tremendous impact on runoff as shown in Table 1b. A soil in intake family 0.1 (clay, silty clay, or silty clay loam) has very slow infiltration and produces 44% runoff from our base system. However, silt loam, very fine sandy loam, fine sandy loam, or loamy fine sands in the 1.0 intake family can infiltrate all of the applied water with zero runoff.

Slope (or changes in field elevation) is another factor that cannot be changed. Table 1c shows a field with a slope of 1-3% has limited runoff to 8%, while a slope greater than 5% can produce runoff equal to 35% of the water applied. The influence of land surface factors on runoff shows that sprinkler packages must be designed for each field. As soils and slopes vary from field to field, sprinkler packages must be closely matched to the conditions of that field.

Irrigation system capacity influences the application rate or intensity if other system characteristics are the same. Table 1d gives the influence of changing system capacity on runoff. When system capacity drops to 700 gallons per minute, runoff is 22%. When system capacity increases to 900 gpm, runoff is 29%. Although not given in Table 1, runoff is greater near the outer end of the system than near the center. Outer spans have more area to water in the same amount of time which gives less time for the water to infiltrate into the soil. Thus, the greatest potential for runoff exists at the outer spans of the system.

Application depth of each irrigation event also influences runoff. Table 1e shows that if the operator speeds up the pivot and puts on 0.75 inch instead of 1.0 inch, runoff is reduced to 16%. If the pivot is slowed to put on 1.25 inches, runoff increases to 33%. The practical limits for irrigation applications are normally 0.75-1.25 inches. Smaller applications are less efficient in delivering water to the crop. Larger applications have the potential for more runoff.

Wetted diameter of the sprinkler pattern has a large influence on runoff, as presented in Table 1f. The wetted diameter is determined by the type of sprinkler device and operating pressure of the irrigation system. A minimum wetted diameter should be selected to produce little or no runoff. Eliminating runoff through sprinkler selection is more important than moving the sprinkler heads nearer or into the canopy to reduce water loss. As shown in Table 1g, more than one system characteristic may need to be changed to reduce runoff to acceptable levels. Here the application depth was reduced to 0.75 inch and the wetted diameter was increased to 60 feet for an overall runoff of 7%. A further increase in wetted diameter to 80% reduced overall runoff to 2% of the applied water.

A computerized program, *Estimating Potential Runoff and Energy Savings from Sprinkler Package Conversions,* is available from Nebraska Cooperative Extension. It calculates potential runoff from all combinations of soil types, field slope, system capacity, system length, application depth, and wetted diameter. Choosing the right sprinkler package is important for least cost irrigation of a particular field. The best sprinkler device may or may not operate at the lowest pressure. The system selected needs to eliminate or minimize runoff to deliver water efficiently and uniformly to the field.

Table 1. Example of runoff potential from a center pivot irrigation system.

Soil Intake Family	Slope (%)	System Capacity (gpm)	System Length (ft)	App. Depth (inches)	Wetted Diameter (feet)	Potential Runoff (%)
Table 1a. Base system characteristics.						
0.3	3-5	800	1340	1.0	40	26
Table 1b. Influence of soil intake family (soil texture) on runoff.						
0.1	3-5	800	1340	1.0	40	**44**
0.5	3-5	800	1340	1.0	40	**11**
1.0	3-5	800	1340	1.0	40	**0**
Table 1c. Influence of slope on runoff.						
0.3	**0-1**	800	1340	1.0	40	**0**
0.3	**1-3**	800	1340	1.0	40	**8**
0.3	**>5**	800	1340	1.0	40	**35**
Table 1d. Influence of system capacity on runoff.						
0.3	3-5	**500**	1340	1.0	40	**14**
0.3	3-5	**700**	1340	1.0	40	**22**
0.3	3-5	**900**	1340	1.0	40	**29**
Table 1e. Influence of application depth on runoff.						
0.3	3-5	800	1340	**0.50**	40	**3**
0.3	3-5	800	1340	**0.75**	40	**16**
0.3	3-5	800	1340	**1.25**	40	**33**
Table 1f. Influence of wetted diameter on runoff.						
0.3	3-5	800	1340	1.0	**30**	**48**
0.3	3-5	800	1340	1.0	**60**	**15**
0.3	3-5	800	1340	1.0	**80**	**8**
Table 1g. Influence of application depth and wetted diameter on runoff.						
0.3	3-5	800	1340	**0.75**	**60**	**7**
0.3	3-5	800	1340	**0.75**	**80**	**2**

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

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SUMMARY

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

INTRODUCTION

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

PROCEDURES

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

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

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

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

RESULTS

Water application pattern as affected by row orientation and nozzle spacing

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

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

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

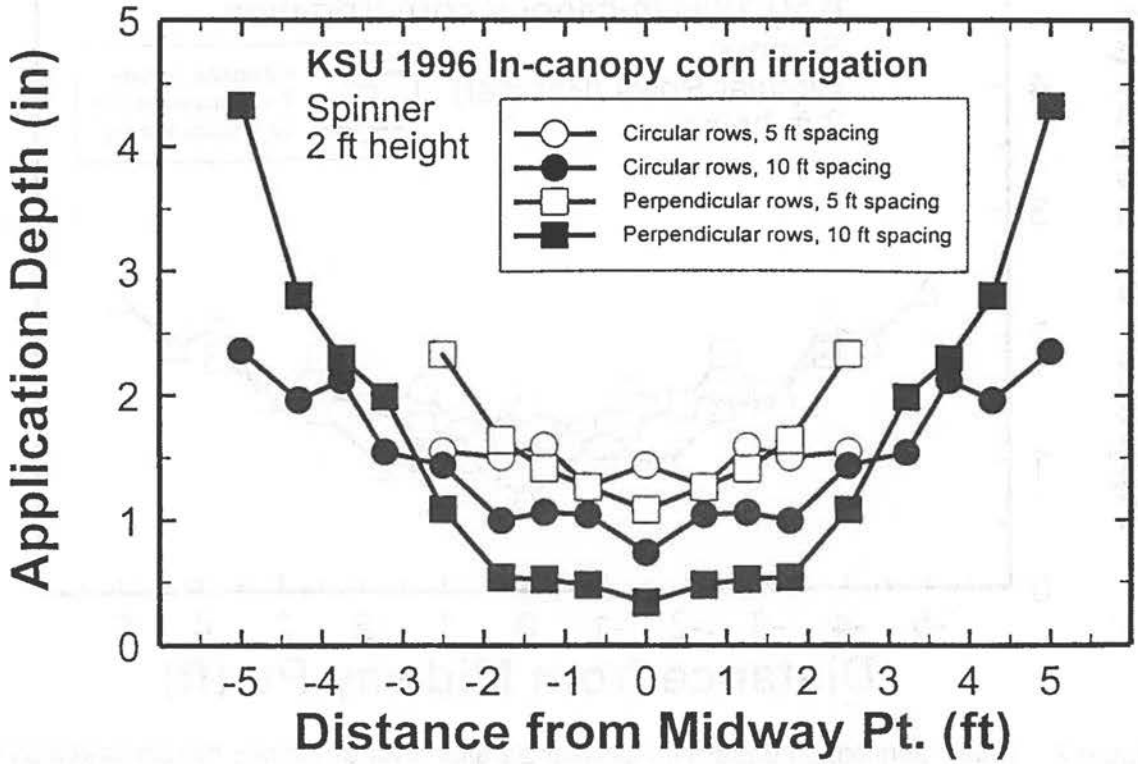

Figure 1. Water application pattern as affected by row orientation and nozzle spacing for spinner nozzles at the 2 ft height in a fully developed corn canopy after tasseling.

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

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

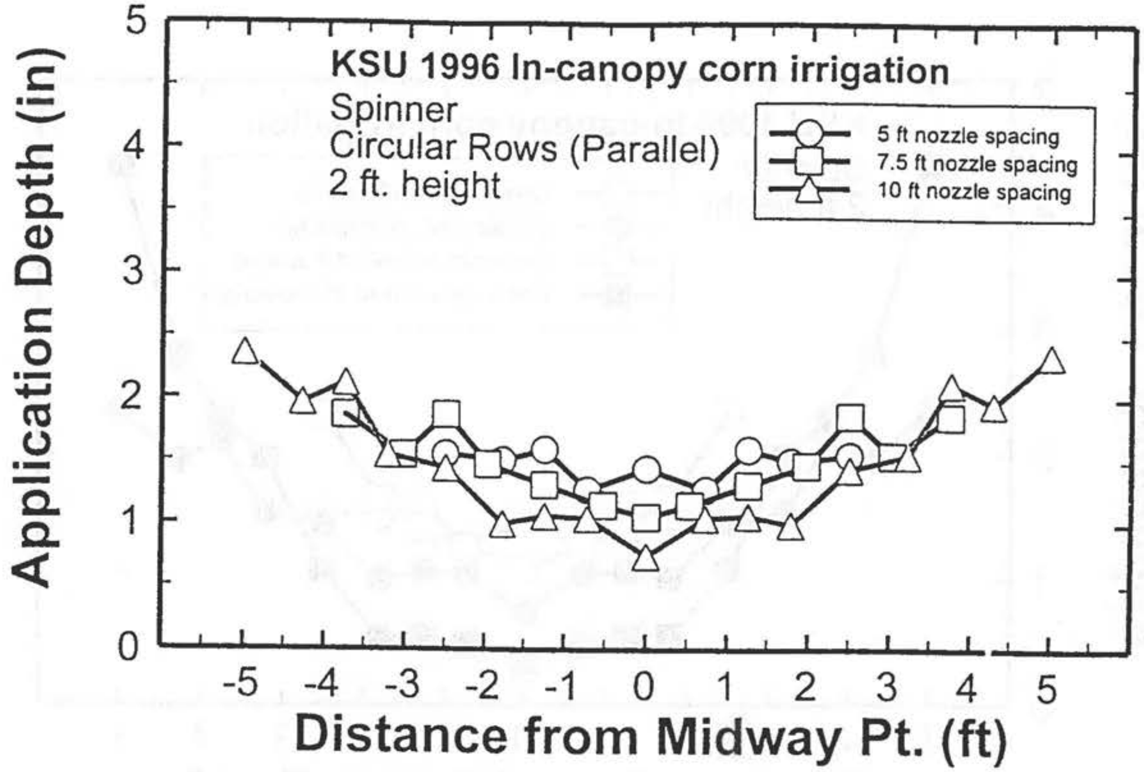

Figure 2. Water application pattern for circular parallel rows at various nozzle spacings for spinner nozzles at the 2 ft height in a fully developed corn canopy after tasseling.

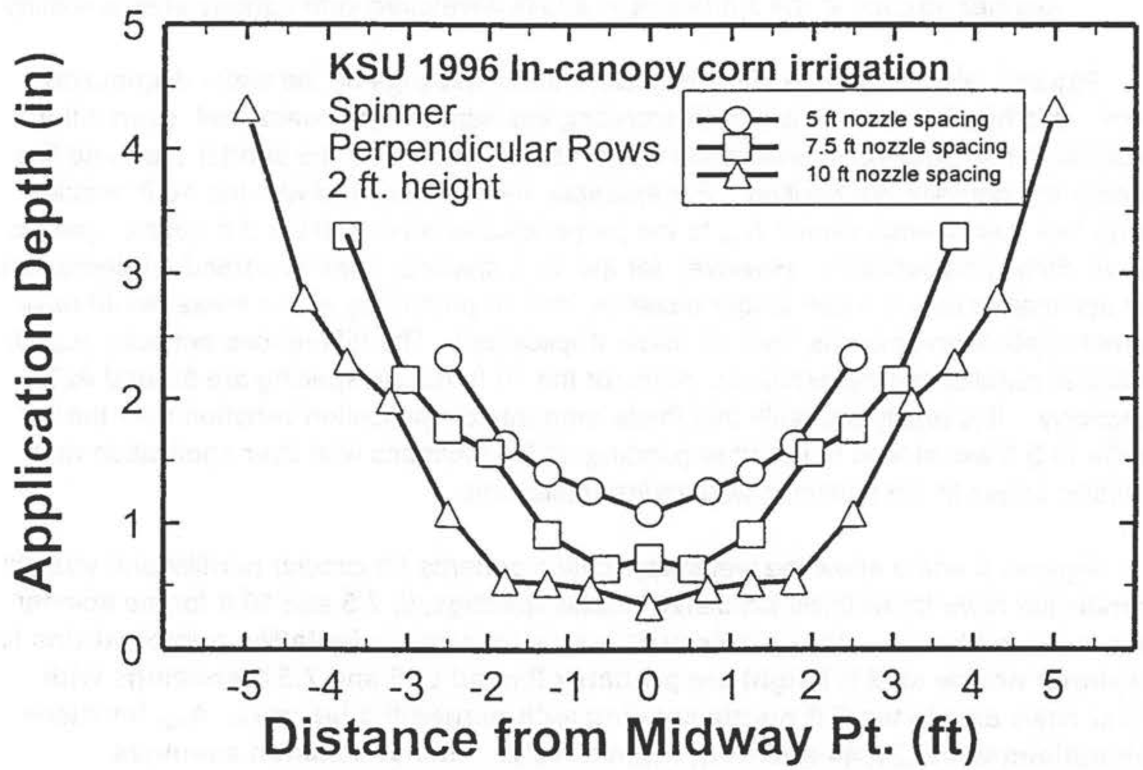

Figure 3. Water application pattern for straight perpendicular rows at various nozzle spacings for spinner nozzles at the 2 ft height in a fully developed corn canopy after tasseling.

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

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

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

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

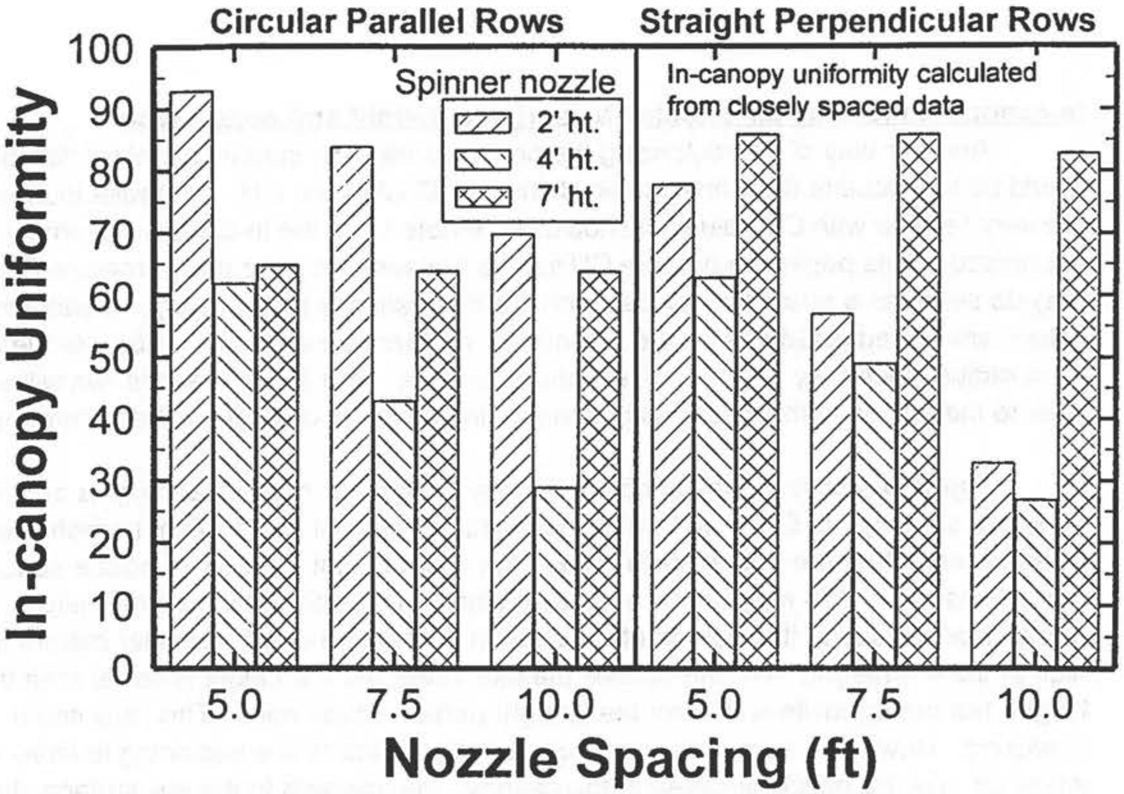

Figure 4. In-canopy uniformity as affected by nozzle spacing and row orientation for spinner nozzles at various heights in a fully developed corn canopy after tasseling. The uniformity between corn rows was calculated from closely spaced containers.

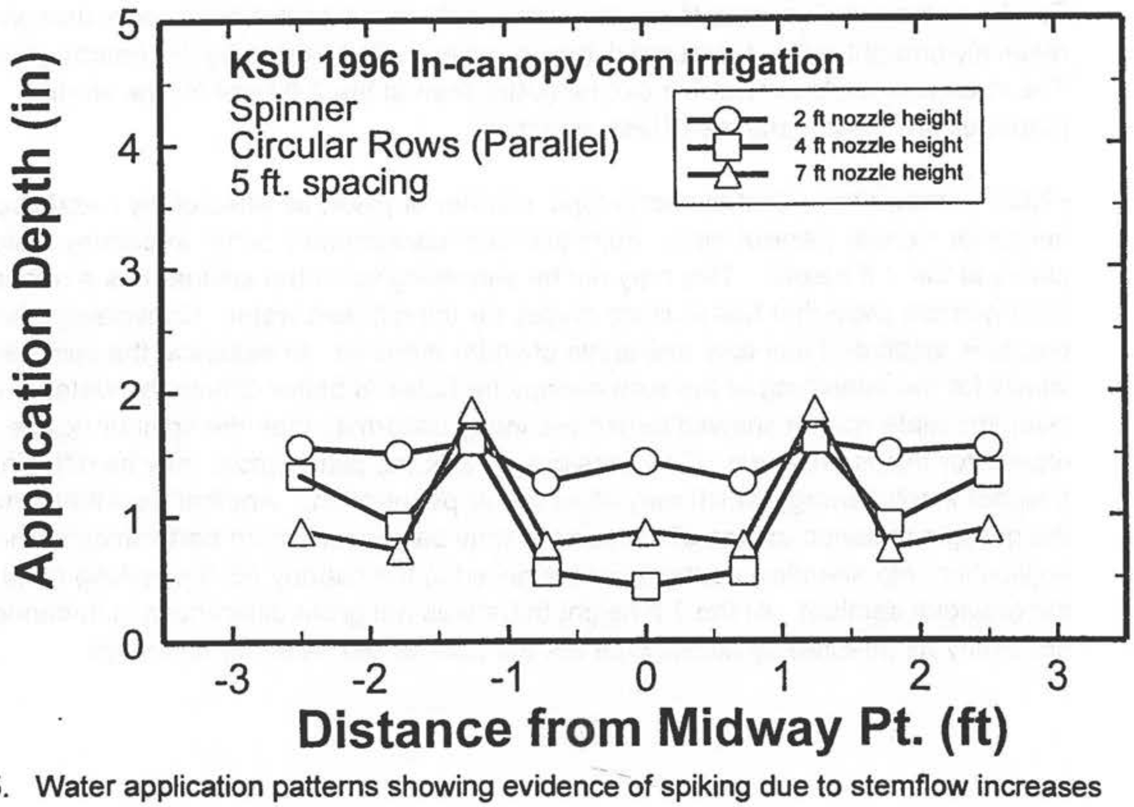

Figure 5. Water application patterns showing evidence of spiking due to stemflow increases as nozzle height increased from 2 to 4 to 7 ft in a fully developed corn canopy.

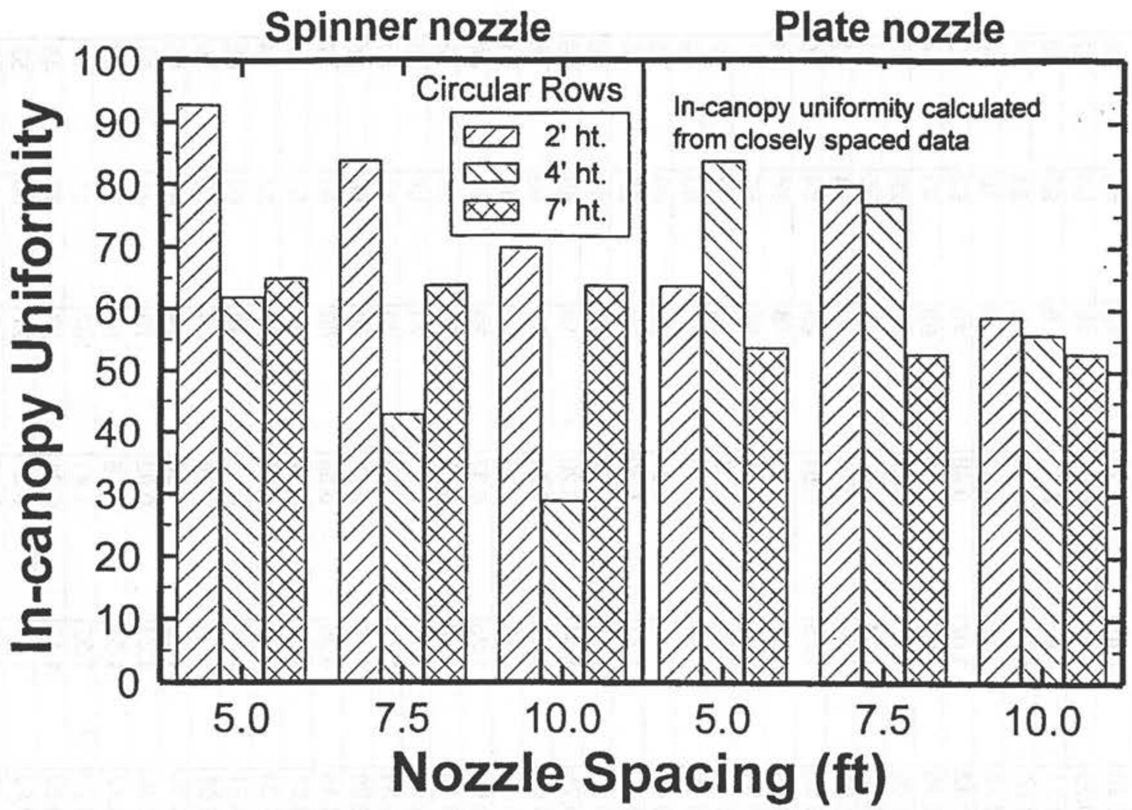

Figure 6. In-canopy uniformity as affected by nozzle spacing and nozzle type for circular parallel rows at various heights in a fully developed corn canopy after tasseling. The in-canopy uniformity between corn rows was calculated from closely spaced (6-9 inches apart) containers.

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

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

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

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

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

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

An Economic Analysis of Flood and Center Pivot Irrigation System Modifications

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ABSTRACT

An after-tax net present value (NPV) analysis of investing in three irrigation system modifications for the production of corn, grain sorghum, wheat, and alfalfa is conducted. Modifying a high pressure center pivot with low-drift nozzles and adding surge valves to a gated pipe system is economically feasible for each crop.

Introduction

A major source of irrigation water in the western High Plains is the Ogallala aquifer. Available water from this source is declining because withdrawal rates are higher than recharge rates. Pumping costs are increasing because of greater pumping lift requirements and increasing energy costs. Lower well capacities, which usually result from declining water levels, also limit managers' irrigation scheduling options and increase the risk of crop water stress. As a result, irrigators in western Kansas are faced with the decision to invest in more efficient water distribution systems with greater application and fuel efficiencies or to remain with their existing system. Investment in new distribution-system technology has three potential net effects: the variable pumping costs per acre-foot can be reduced by lower fuel consumption per hour; the total variable cost per acre can be reduced by a higher application efficiency, which allows for less water to be pumped to obtain equivalent net application levels with fewer pumping hours; and yields and gross revenues can be increased by employing optimal irrigation scheduling which may have been previously constrained by low application efficiencies of an older system. Williams et al. (1996b) presents an analysis of investment in a new irrigation system when a current system is not in place. This report examines modifications of an existing system or changing to a new system from an existing system.

The economic analysis presented in this paper evaluates investment decisions for three irrigation system modifications: the modification of a high-pressure center-pivot system (HPCP) to a low-drift-nozzle center-pivot system (LDN); the addition of surge valves (SF) to a conventional furrow flood gated pipe system (FF); and the conversion from a conventional furrow flood gated pipe system (FF) to a low-drift-nozzle center-pivot system (LDN). These modifications are evaluated for production of corn, grain sorghum, wheat, and alfalfa.

Procedures

An after-tax net present value analysis is used to assess the economic feasibility of the aforementioned modifications. The NPV analysis is conducted with the Irrigation Economics Evaluation System (IEES) microcomputer model (Williams et al. 1996a). The IEES program calculates operating and ownership costs for irrigation systems and can be used to analyze distribution system changes on an after-tax NPV basis. IEES estimates costs and returns over a ten year period and produces after-tax net present values for owning and operating a current and a proposed system. When the IEES program is used to evaluate switching or modifying distribution systems, field operation production costs, and yield and crop price estimates are included to estimate the net present value of the modification or system switch. The NPV of net returns represents the amount of money made or saved from switching or modifying the distribution system.

Irrigation Costs

Data required for IEES to calculate costs for each scenario are listed in Table 1. The flow rates and pumping water levels are 1994 averages from the Kansas State Board of Agriculture. The marginal tax rate is based on a four year average of net farm income from irrigated cash crop farms in the Kansas Farm Management Association. This average places these farms in the 15% federal tax bracket and the 6.25% state tax bracket. The resulting marginal tax rate is 35.38% (including a self employment tax rate of 14.13%). Irrigation fuel costs are based on a natural gas price of $2.50/mcf and are a function of the required horsepower and the number of hours that the pumping plant operates. Additional details concerning how operating costs are calculated can be found in Williams et al. (1996b).

Crop Production Costs

Production costs other than those estimated using IEES for operating the irrigation systems are from KSU Farm Management Guides (Langemeier). These costs include seed, herbicide, fertilizer, fuel and oil, crop machinery repair, and crop consulting. Total labor hours for the crop excluding irrigation labor are from Langemeier et al.

Crop machinery fixed costs, including depreciation, interest, and insurance are included as nonirrigation production costs. Depreciation and insurance costs are from the KSU Farm Management Guides. Machinery interest is equal to one-half of the original machinery cost multiplied by 8.2%. Machinery depreciation and interest costs for row crops are also adjusted to reflect the addition of the reservoir tillage tool when the LDN system is evaluated. Land costs, including real estate taxes and interest, are also included in the analysis and are from the KSU Farm Management Guides.

Yield and Price Estimation

Yields are estimated by entering an irrigation schedule, inches applied per application, and application efficiency in a yield simulator developed by Stone et al. The simulator assumes 16.4

inches of annual rainfall in addition to that applied by irrigation. Crop yield is determined in the model by evapotranspiration (ET) and available soil water.

Simulated yields are obtained by applying the available water in an economically optimal schedule, given depth per application feasible for each system and the time required for each irrigation event. Irrigation events are scheduled in an attempt to fully satisfy crop water requirements during the critical crop-development stages. Priority is given to meeting the crop water needs during head emergence for grain sorghum and wheat, and silking for corn. Numerous schedules are evaluated until the economic return from irrigation of the crop is maximized or the available irrigation water is exhausted by a maximum property right of 24 acre inches per year or the limiting well capacity and time interval during the season in which additional irrigation events potentially could enhance crop yields are exceeded.

Crop prices used are 5-year, average, national average price projections for 1995/1996 to 1999/2000 from the Food and Agriculture Research Institute. These prices are adjusted to western Kansas prices by comparing a ten year average price in western Kansas to a corresponding ten year average national price. The prices used to estimate gross revenue with the estimated yields are $2.62/bushel for corn, $2.35/bushel for grain sorghum, $3.36/bushel for wheat, and $71.96/ton for alfalfa.

System Modification Scenarios

Each system is assumed to be installed on a square quarter section with a well in the upper corner of the field. Flood systems are assumed to irrigate 158 acres while center pivot systems are assumed to irrigate 126 acres. When a flood system is replaced with a center pivot system, the production of wheat in a wheat-fallow rotation on the dryland corners is assumed. It is assumed that the existing power unit can be used to power the modified system and the terrain and soil type do not preclude the feasibility of any system. This analysis assumes the pumping plant is operating efficiently. Modifications to the pumping plant in the following scenario descriptions are only considered to be necessary to enable the proposed system to operate efficiently but are not necessary for an existing system.

High-Pressure Center Pivot (HPCP) to Low-Drift-Nozzle Center Pivot (LDN) Scenario

The existing high-pressure center pivot utilizes 60 impact sprinklers mounted on top of the lateral. The application efficiency is assumed to be 80%. Conversion to the low-drift-nozzle system requires installation of drop tubes and low drift nozzles. The nozzles are placed 30 inches above the ground 60 inches apart. The LDN system application efficiency improves to 90% because of decreases in evaporation and wind drift.

Two alternatives are available to the irrigator for conversion of the existing pump. The first alternative involves adjustment to the bowl(s) of the pump to allow for the drop in pressure from 75 psi to 18 psi which is required for this modification while maintaining power unit efficiency. This adjustment is a quick fix method which creates inefficiency in the pump. Efficiency of the pump, after adjustment, is estimated to be 51.7%. The second alternative is to pull the pump from the well and modify it to maintain or increase pump efficiency. The cost of modifying the pump requires an investment of $3,825. This investment will allow the pumping plant to operate at 80% efficiency (5% more on average than a currently existing pump). The LDN system also requires the purchase of a specialized implement for a reservoir tillage operation for the row crops in the analysis. This additional implement mounts behind a cultivator shank and is designed to implant small basins in the furrow to retain runoff. This operation is needed to maintain the irrigation application efficiency. A nine-row reservoir tillage tool is generally pulled behind an eight-row cultivator. This requires an investment of $2,296 per circle given the average number of circles per irrigated farm in western Kansas. The total investment for the addition of the low-drift-nozzle system package along with the reservoir tillage tool is $6,832. If the pumping plant is modified to maintain efficiency, it is $10,657.

Furrow Flood Gated Pipe (FF) to Surge Flood Gated Pipe (SF) Scenario

Furrow flood gated pipe systems operate typically with an application efficiency of 65%. The low application efficiency is due to nonuniform water distribution, resulting in deep percolation at the top of the field. Surge valves create an intermittent flow of water through the furrows and application efficiency is increased by reducing tailwater volume and reducing deep percolation. The installation of surge valves is expected to improve application efficiency to 75%. Two solar powered surge valves are assumed to be installed by the irrigator resulting in an investment of $3,246. Adjustments to the existing pump and power unit are unnecessary.

Furrow Flood (FF) to Low-Drift-Nozzle Center Pivot (LDN) Scenario

For this scenario, the existing underground line from the well to the furrow flood system is assumed to be in the wrong location for use with a new LDN center pivot. The existing gated pipe is assumed to have a salvage value of $4,488 (42.5% of the original investment). An investment in a reservoir tillage tool is included in the initial investment for the LDN system. Therefore, the initial investment costs for a new LDN center pivot include the pipe from well to center pivot, a center pivot, LDN nozzles, and a reservoir tillage tool minus the salvage value of the existing gated pipe. Adjustments to the pumping plant are also necessary due to higher operating pressure requirements. The net investment for the installation of the LDN system and pump modification is $46,103. Installation of the low-drift-nozzle system increases water application efficiency by 25% (from 65% to 90%). Under this scenario, 32 acres of a wheat-fallow rotation are produced on the dryland corners.

Results

Operating Costs

Operating cost savings from switching systems are observed for all scenarios and crops (Table 2). For the HPCP to LDN modified pump scenario, fuel cost savings accounted for a majority of the operating cost savings. Fuel cost savings had a much smaller impact in the FF system modifications. Under these scenarios (FF to SF and FF to LDN), fuel cost savings are observed only when fewer inches of water are applied by the new or modified system, and fuel costs actually increased for corn production under the LDN compared to the FF system even though fewer inches of water are applied. These results are due to the low operating pressure of the FF system in comparison to the LDN system and the relatively low application efficiencies of both flood systems. Relatively large labor cost savings are observed for the FF to SF and the FF to LDN. However, savings in labor costs under scenarios which included the LDN system are negated by high distribution system maintenance and repair costs. All other operating costs compared from system to system are within $1 per irrigated acre of each other.

After-tax NPV Analysis

Results of the after-tax NPV analysis for each crop and each system change are presented in Table 2. The after-tax NPV analysis is separated into three components including: operating costs savings, the difference in crop return, and the added ownership costs of the new system. After-tax NPV of net returns from switching systems is calculated by adding the present value of operating costs savings to the difference in the present value of crop return and then subtracting the added present value of ownership costs of the new system. The after-tax NPV of net returns from switching systems indicates whether changing distribution systems is economically feasible.

HPCP TO LDN

The analysis indicates that the addition of drop tubes and low drift nozzles to the high-pressure center-pivot system is economically feasible for the production of all four crops using both a modified and an unmodified pumping plant. However, when the existing pump receives only minor adjustments, net returns are considerably lower than those when the pump is modified. For example, net returns from switching to the LDN system for corn are $1,285 and $6,452 for the unmodified pump and the modified pump respectively. Similar results are obtained for grain sorghum, wheat, and alfalfa. The results of the analysis suggest that the benefits of increasing application efficiency are offset to some degree by increased operating costs, especially fuel costs, when an inefficient pumping plant is used. The analysis indicates it is economical to modify the pumping plant when switching to the LDN system. The production of alfalfa under the modified pump scenario has the highest after-tax NPV of net returns from switching systems. Corn is the second most profitable crop under the modified pump scenario. Both irrigated corn and alfalfa acres have been increasing in western Kansas while irrigated wheat and grain sorghum acres have been declining in the 1990s (Kansas Department of Agriculture). Crop returns increased for all crops under both pump scenarios because of the increased application efficiency of the LDN system.

FF to SF

The analysis also indicates that the addition of surge valves to the gated pipe furrow flood system is economically feasible for the production of all four crops. Under this scenario, positive after-tax net returns from modifying the system are largely due to increased net crop returns for corn and grain sorghum. Wheat and alfalfa yields are similar for both flood systems, but 4 inches less of gross water per acre per season is required by the SF system. The resulting operating costs savings under the SF system make the modification feasible for wheat and alfalfa. The relatively low initial investment cost of switching from FF to SF also contributes to the economic feasibility of the modification.

FF to LDN

The replacement of the furrow flood gated pipe system (FF) with a low-drift-nozzle (LDN) center-pivot system is not economically feasible for the production of any of the four crops. Under this scenario, high ownership costs of the new system produced negative after-tax net returns from switching systems. For wheat and alfalfa, reductions in crop returns also contributed to the infeasibility of the switch. Declines in crop returns are due to the reduction in irrigated acres (158 irrigated acres with FF to 126 irrigated acres with LDN).

Summary and Conclusions

The economic analysis presented in this paper evaluates investment decisions for three irrigation system modifications: the modification of a high-pressure center-pivot system (HPCP) to a low-drift-nozzle center-pivot system (LDN); the addition of surge valves (SF) to a conventional furrow flood gated pipe system (FF); and the conversion from a conventional furrow flood gated pipe system (FF) to a low-drift-nozzle center-pivot system (LDN). These modifications are evaluated for production of corn, grain sorghum, wheat, and alfalfa.

Two scenarios are examined for the modification of a high pressure center pivot to a low drift nozzle center pivot. One scenario involves making the modification without pulling and modifying the pump. In this case, savings in initial investment costs (and the resulting ownership costs) and increases in crop returns are partially offset by the higher operating costs of the inefficient pump. A second scenario under the HPCP to LDN modification involves pulling the pump and modifying it so that it would operate efficiently given the reduced pressure requirement of the LDN system. This scenario, is economically feasible for all four crops.

Two system modifications are examined for a furrow flood gated pipe system. The first modification involves the addition of surge valves to the system. The relatively low initial investment cost of the surge valves along with operating costs savings made this modification economically feasible for the production of all four crops. The second modification considered is replacement of the system with a LDN center pivot. This modification required an initial investment of $46,103 for corn and grain sorghum and $43,076 for wheat and alfalfa, which produced prohibitive ownership costs that were not recovered by operating cost savings. Additionally, loss of irrigated production on the pivot corners significantly lowered crop returns. As a result, it is not economically feasible to produce any of the crops under this scenario.

Table 1. Selected Inputs for Irrigation System Ownership and Operating Cost Estimates Using IEES

A.) Number of acres:

	Sprinkler Systems	126 acres
	Flood Systems	158 acres
	Wheat-Fallow in Rotation	32 acres ➔ (Center Pivot Scenarios)

B.) Operating pressure (PSI):

	HPCP	75 PSI
	LDN	18 PSI
	FF	5 PSI
	SF	5 PSI

Operating pressures are measured at the pump and are used to calculate water horsepower which in turn is used to calculate fuel consumption.

C.) Pumping water level: All systems depth to water 175 feet

D.) Flow rate (GPM):

	Sprinkler systems	520 GPM
	Flood systems	570 GPM

E.) Pump efficiency (%):

	Initial System	75%
	Inefficient LDN system	51.7%
	Efficient pump after modification	80%

F.) Before tax interest rate (weighted average cost of capital): 8.20%

G.) Marginal tax rate: 35.38%

H.) Replacement cost of the distribution system (existing system):

	HPCP	$41,216
	FF	$19,222

Replacement costs are from Williams et al., 1996b. Distribution system replacement costs are used in IEES to calculate distribution system maintenance costs.

I.) Replacement cost of the distribution system (new system):

	Corn and Grain Sorghum	Wheat and Alfalfa
HPCP to LDN	$6,832	$4,536
FF to SF	$3,246	$3,246
FF to LDN	$45,372	$43,076

Replacement cost of the new distribution system is entered as the cost of modification plus any additional investment in machinery. It is used to calculate ownership costs of the new system.

Table 1. Selected Inputs for Irrigation System Ownership and Operating Cost Estimates Using IEES

J.) Application Efficiency

	System		
HPCP	LDN	FF	SF
80%	90%	65%	75%

K.) Inches of water applied:

	System			
Crop	HPCP	LDN	FF	SF
CORN	21	23	24	24
SORGHUM	19.5	18	20	20
WHEAT	18	18	24	20
ALFALFA	18	18	24	20

Inches of water applied are from irrigation schedules which maximize net returns. Procedures presented by Williams et al. 1996b and Llewelyn et al. are used to determine these optimal schedules.

L.) Crop yields (bushels/acre or tons/acre for alfalfa):

	System			
Crop	HPCP	LDN	FF	SF
CORN	196.7	201	185.2	191.6
SORGHUM	121.5	122.7	113.8	117.3
WHEAT	72.5	73.8	72.4	72.3
ALFALFA	6.56	6.68	6.65	6.61

Crop yields are used in the calculation of net crop returns. Wheat fallow yields of 35.0 bu./acre are used for 32 acres of dryland wheat production on the non-irrigated field corners in the switch from flood to LDN center pivot.

Table 2. IEES After-tax Net Present Value Analysis				
	Scenario			
	HPCP to LDN		FF TO SF	FF to LDN
After-tax NPV	Unmodified Pump	Modified Pump		
Corn				
Operating Costs Savings	$134.21	$8,038.91	$1,009.90	$1,169.92
Crop Return Difference	$6,040.97	$6,040.97	$13,157.10	$3,559.64
Ownership Costs of New System	($4,890.17)	($7,628.00)	($2,323.40)	($28,219.99)
Net Returns From Switching Systems	$1,285.01	$6,451.87	$11,843.69	($23,490.43)
Grain Sorghum				
Operating Costs Savings	$4,927.36	$11,113.65	$769.93	$1,253.50
Crop Return Difference	$914.93	$914.93	$6,434.94	$2,268.73
Ownership Costs of New System	($4,890.17)	($7,628.00)	($2,323.40)	($28,219.99)
Net Returns From Switching Systems	$952.12	$4,400.57	$4,881.46	($24,697.75)
Wheat				
Operating Costs Savings	$2,518.87	$8,705.15	$6,055.81	$6,539.38
Crop Return Difference	$3,042.28	$3,042.28	($28.10)	($6,448.15)
Ownership Costs of New System	($3,246.75)	($5,984.58)	($2,323.40)	($26,576.57)
Net Return From Switching Systems	$2,314.39	$5,762.84	$3,704.31	($26,485.34)
Alfalfa				
Operating Costs Savings	$2,518.87	$8,705.15	$6,055.81	$6,539.38
Crop Return Difference	$3,837.20	$3,837.20	($1,216.29)	($26,155.19)
Ownership Costs of New System	($3,246.75)	($5,984.58)	($2,323.40)	($26,576.57)
Net Return From Switching Systems	$3,109.32	$6,557.77	$2,516.11	($46,192.38)

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PERFORMANCE OF IN-CANOPY SPRINKLERS

by

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The goal of a center pivot sprinkler system is to uniformly distribute water on the soil surface. Uniform application and infiltration of irrigation water in the soil gives plants equal access to water. To reduce energy costs, center pivots have been converted from high pressure to medium and low pressure systems, while maintaining application uniformity. Design engineers and manufacturers have developed new sprinkler devices that operate at low pressures. These changes provide agricultural water users the opportunity to reduce pumping costs and insure an even distribution of water to all of their crop.

The new low pressure sprinkler devices have been designed to include tubing, called drops, that place the devices closer to the crop. Bringing the sprinkler device closer to the crop reduces water lost through evaporation and drift. In an attempt to reduce water loss even further, some producers are placing nozzles within the corn canopy. In-canopy sprinklers are viewed as very efficient because no water is seen above the canopy. Based on the assumption of improved water delivery, the trend has been too lower pressure and operate within the crop canopy to improve irrigation efficiency and reduce pumping costs. However, there are several factors that must be considered before adopting this change. Several basic questions remain:

1) How much water is lost to evaporation and drift when low pressure sprinkler devices are operated above the crop canopy as compared to within the canopy?

2) What happens to application uniformity when sprinklers are operated within the crop canopy?

3) What impact does the uniformity of in-canopy sprinklers have on the efficiency of water application?

Sprinkler water losses

Water loss from sprinkler devices can be categorized into to three main areas, air loss, canopy loss and ground loss. Water loss in the air occurs through evaporation or drift from the field. Loss of water in the canopy occurs through evaporation of water from the plant leaves. Some water is also intercepted and stored in the whorls of the plant and is evaporated at a later time. Ground losses occur through runoff and evaporation of water from the soil surface. Water stored on the soil surface and later infiltrated is not considered a loss if it remains near the point of application.

Directly measuring the amount of water loss that occurs with sprinkler irrigation is difficult. Based on current and past research, researchers in Texas(Schneider and Howell, 1993) made comparisons among different sprinkler devices and height of sprinkler device with respect to the crop canopy. Their objective was to determine the amount of water loss that occurs above the canopy, within the canopy and from the soil surface. Table 1 gives the measured water loss and application efficiency for low angle impact sprinklers, spray heads, and Low Energy Precision Application (LEPA) sprinkler packages. Water losses and application efficiency are based on a daytime irrigation of 1-inch in corn with a full canopy.

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

Table 1. Sprinkler water losses and application efficiency for 1-inch water application.

Based on their results and a review of other studies, these researchers concluded that converting from impact sprinklers to spray heads will improve application efficiency by approximately 5%. In converting from spray heads to a LEPA system, the application efficiency can increase by as much as 10%. The improvement in application efficiency occurs primarily as a result of the reduction of evaporation from the crop canopy. The amount of water lost between the sprinkler nozzle and the top of the crop canopy is quite small (only 3% for impact sprinklers). Therefore, less improvement can be made as a result of reducing losses in the air.

To realize the potential improvements in application efficiency using LEPA a complete LEPA system must be adopted. Air losses and canopy losses are eliminated because the LEPA devices are below the crop canopy. Surface storage created by specialized tillage equipment is required to prevent any runoff. LEPA application rates are more than the soil can immediately infiltrate.

Surface storage allows the water to pond temporarily until infiltration is complete. A reduction in soil evaporation is obtained by placing LEPA sprinklers in alternate rows. The crop must be planted in a circular pattern and drops spaced between every other row.

Converting from high pressure to low pressure is a method to reduce energy costs. Energy is not saved by simply moving spray heads into the crop canopy. Nor does lowering spray heads from just above the crop into the crop canopy make a LEPA system. Water losses were determined to be nearly the same for spray heads located just above the canopy and spray heads located within the canopy. This happens because as a pivot moves, drops are caught on the corn plants and the nozzles held at an angle. Water is sprayed on the entire canopy of the crop similar to if the spray head was located above the canopy. This occurs most frequently when corn is planted in straight rows under a center pivot.

An assumption made with the observations in Texas was that runoff was negligible. This can be assumed as long as infiltration is increased to meet the increased application rate or tillage is used to provide surface storage. If runoff does occur, the water lost due to runoff will further reduce the water application efficiency. Runoff can occur for a number of reasons and under different conditions.

Variability of In-Canopy Application

The diameter of coverage can be defined as the circular area that is wetted by a sprinkler. The wetted diameter is determined by the operating pressure of the irrigation system and the sprinkler device selected. Lower operating pressure normally means a smaller wetted diameter. Reducing the wetted diameter can increase the potential for runoff from a center pivot irrigation system by increasing the peak and average water application rate. Sprinkler devices placed on drops within the crop canopy will result in a reduction of the wetted diameter. The reduction in wetted diameter occurs due to the water droplets hitting the leaves of the crop before reaching their designed distance of throw.

Water distribution when using in-canopy sprinkler devices has been a research topic in both Kansas and Nebraska. In a Kansas study, Lamm (1995) determined the coefficient of uniformity for different nozzle spacings and crop row orientation. The coefficient of uniformity is a measure of how evenly water is distributed over the irrigation application area. Figure 1 shows the results of six nozzle spacings for spray heads located 12 in. above the ground. The corn was planted both parallel and perpendicular to the sprinkler line of travel. As shown in the figure, as nozzle spacing increases, the coefficient of uniformity decreases.

The parallel row orientation, simulating a crop planted in a circle, had uniformity coefficients of 70 or more for spacings up to 10 ft. However, based on technology today, the 5 ft spacing with parallel row orientation is only marginally acceptable. When corn was planted in straight rows, the center pivot applied water perpendicular to the rows and the coefficient of uniformity was reduced even further for all nozzle spacings. This row orientation would simulate the majority of a field when the corn was planted in straight rows. For 7.5 and 10 ft spacings, the coefficient of uniformity was between 50 - 60%. The uniformity coefficient usually exceeds 90 for center pivots with devices placed above the crop canopy, and located at design spacing.

In a Nebraska study soil water content was measured as a method to evaluate the uniformity of water distribution. Soil water content was measured in the top 12 in. of soil before and after irrigation. Spinners[1] were spaced 12.5 ft apart and located at a height of 42 inches in a mature corn crop. Sprinklers were moving parallel to the corn rows but not necessarily between the corn rows. Figure 2 shows the location of the sprinklers in the corn rows and the change in soil water content measured before and after irrigation. Soil water content increased approximately 10% in the rows nearest the sprinkler device. Soil water content had no change or increased only at locations directly between the sprinkler devices. The small change in soil water content indicates the rows between the sprinkler devices received little or no water during the irrigation event.

Both of these studies demonstrate the variability in water application as a result of in-canopy irrigation. Poor uniformity results regardless of nozzle spacing or nozzle height. However, poor uniformity may or may not influence crop yield. Soil has the ability to redistribute water applied by a sprinkler to the plants much like furrow irrigation when water is applied in every other furrow. However, the water application pattern shown in Figure 2 could not be redistributed to result in uniform water distribution.

Sprinkler spacings greater than 10 ft are not recommended for in-canopy irrigation of corn because low water application occurs between the sprinkler devices and the soil cannot move the water far enough or fast enough to meet crop demand. Water application nearest the sprinkler device is of more concern because of the high application rates due to crop interference. Without adequate surface storage or improved infiltration, the result of higher application rates will be runoff.

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

Water Application Efficiency

If a system is designed properly, the application rate should be less than the soil infiltration rate otherwise surface storage must be provided. When the sprinkler is located above the crop canopy, uniformity is good and the water application rate is as designed, Figure 3a. As the system travels over a given point, the application rate increases with time for half of the application period then decreases. Also, given in Figure 3a is an infiltration rate curve. If the application rate of the irrigation system exceeds the infiltration rate of the soil, surface ponding or runoff will begin. Adequate storage on the soil surface will allow water to pond until infiltration is completed. If, however, the application rate exceeds both the infiltration rate and surface storage capacity, runoff will result and reduce application efficiency and uniformity.

Figure 3b shows the same irrigation system applying the same amount of water but with the sprinkler located in the crop canopy. The application pattern is distorted and narrowed due to the interference of the crop canopy. When operating within the crop canopy the same amount of water is applied but the application rate is increased because the time of application is shorter. This results in an increase in the amount of potential runoff for a given system. Infiltration rate varies with soil type. The potential for runoff may be reduced if infiltration rate or surface storage is increased.

As wetted diameter is reduced, either by sprinkler design or by crop interference, the application rate increases and the potential for runoff is increased. In a second Nebraska study, runoff was measured from three different sprinkler devices; a LEPA system, Spinners located 42 in. Above the ground and Spinners located above the crop canopy. To evaluate the impact of surface storage, each plot was divided into normal cultivation and furrow diking. Field slope varied between 1 - 3%. The systems were evaluated two different times and the results are shown in figures 4 and 5. The LEPA system resulted in over 15 - 25% runoff from both irrigation events. The spinners located at 42 in. height had runoff of between 10 - 15%. With some surface storage capacity, using furrow diking, runoff from the spinners at truss rod height was lowest at approximately 8%.

The 8% runoff for the Spinners above the canopy in Figure 5. reflects approximately 0.15 in. of runoff during a 0.7 in. irrigation. Locating the Spinners at a 42 in. height increased runoff to a total of approximately 0.35 in. The savings we can expect based on the Texas information is 1-2% moving from above to within the crop canopy. A 2% savings in a 0.7 in. irrigation is 0.01 in. The result of placing the sprinkler devices in the canopy was a savings in water of 0.01 in., but an increase in runoff of 0.2 in.

The same can be said for LEPA where a 10% savings is expected when moving from sprinkler devices above the canopy to a LEPA system. A 12% savings for a 0.7 in. irrigation is 0.08 in. Runoff increased by over 0.25 in. from above the canopy to the LEPA system. The result is 0.17 in. of water to runoff using the LEPA system.

Summary

For the soil and slope in this study, none of the devices in the Nebraska study would be acceptable. Water application rates must be decreased to match infiltration rates of the soil. However, these low applications would not be acceptable. With the Spinners above the canopy, water application could be reduced to approximately 0.5 in. to reduce the potential for any runoff. With the LEPA system water application would have to be decreased by over half, resulting in a 0.3 in. application. The efficiency of irrigation is reduced when applications are in this range due to the increase in the number of irrigations and the subsequent increase in evaporation from the soil and plant canopy.

Other soils having a different slope and intake rate will give different runoff results. The gains made through improved sprinkler devices and reduced operating pressure can be quickly over shadowed by runoff losses. Runoff when not kept at a minimum will result in increased pumping costs and/or crop water stress. As the use of low pressure and drops are evaluated, ask yourself a basic question. Will the change I make result in runoff? If the answer is yes, determine how you can overcome the problem before changes to the system are made. The system you currently have may provide the most efficient application of water.

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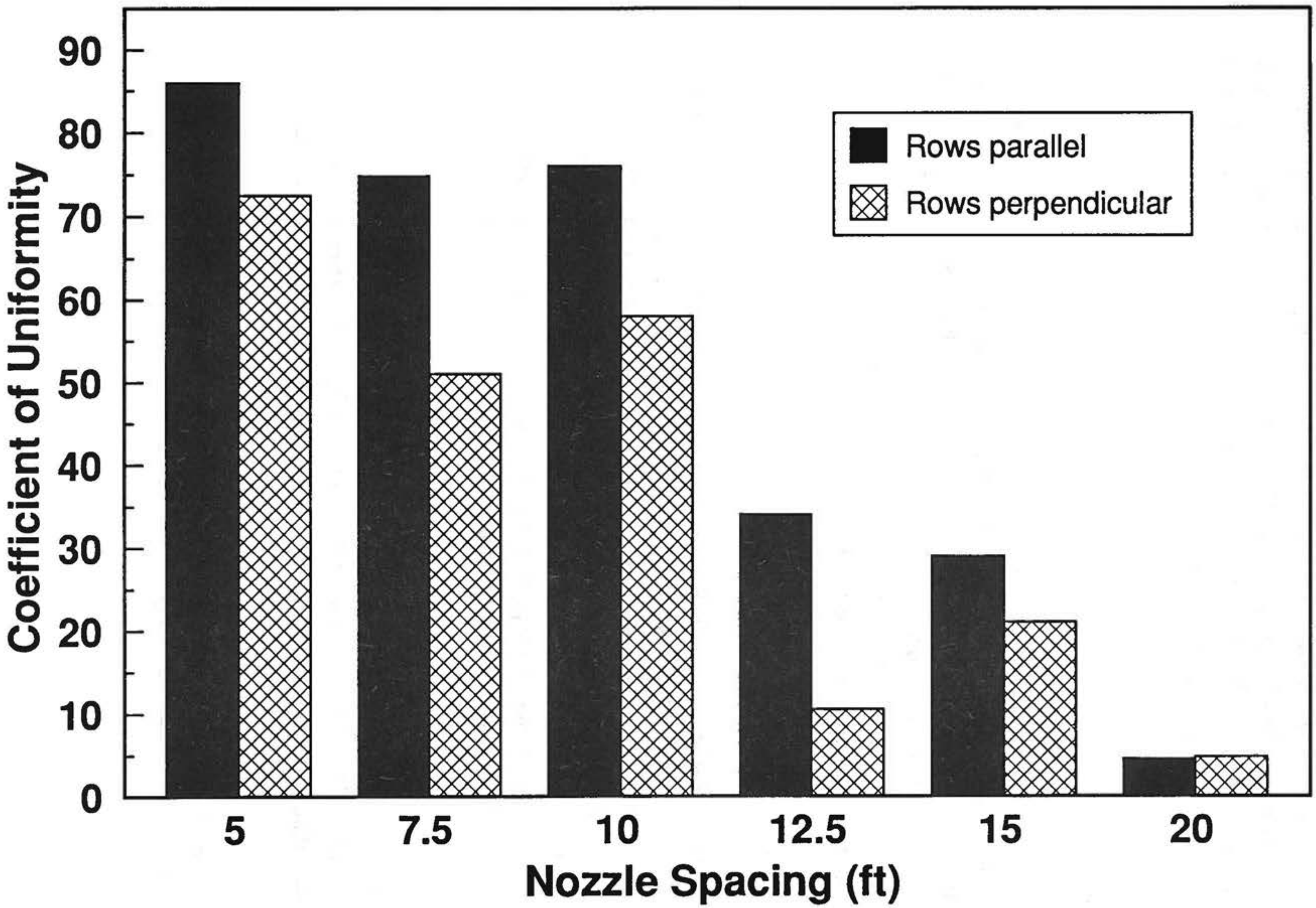

Figure 1. Uniformity coefficient for center pivot sprinkler using spray heads.

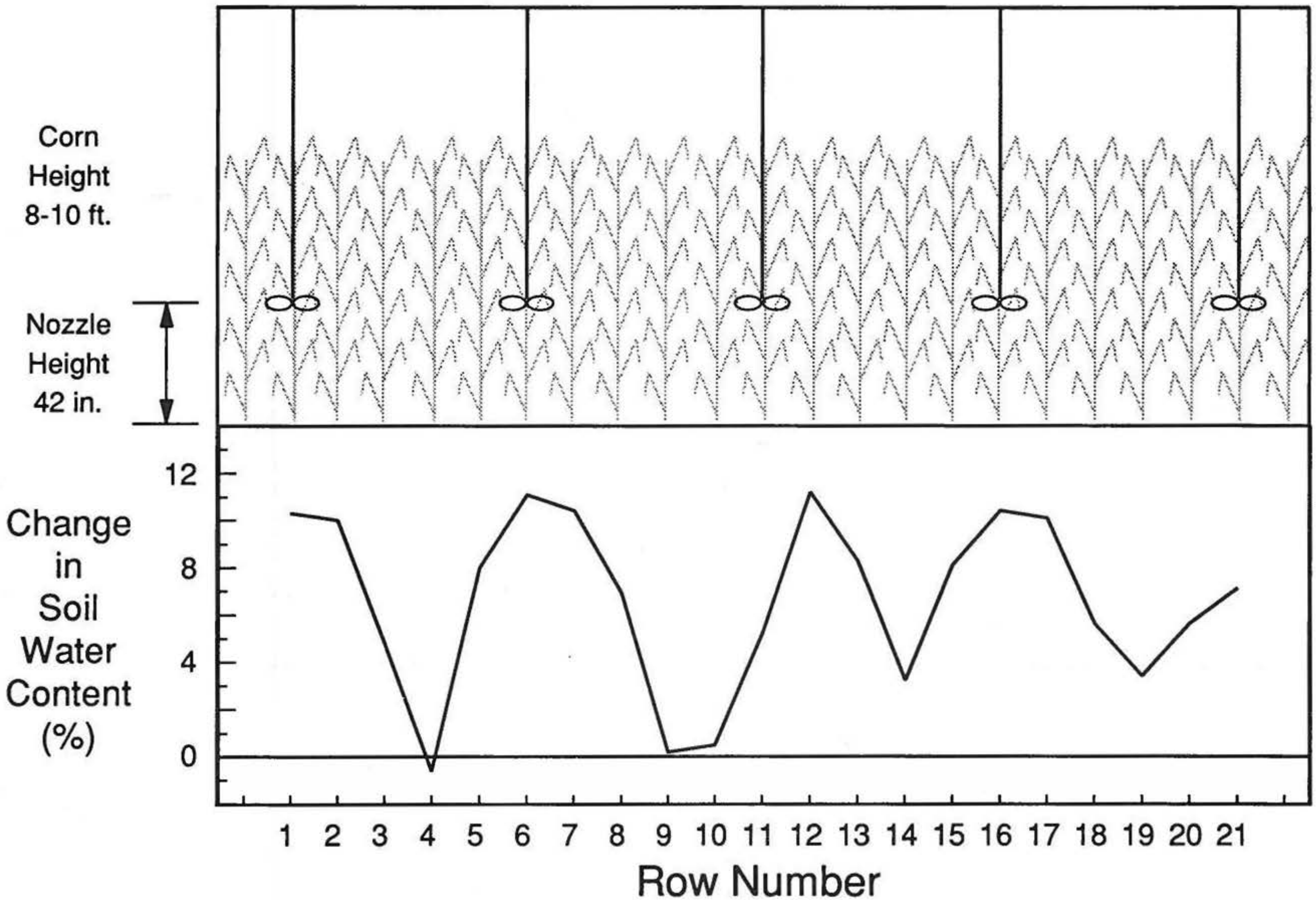

Figure 2. Change in soil moisture content before and after irrigation for spinners at 42 in. height and 12.5 ft. spacing.

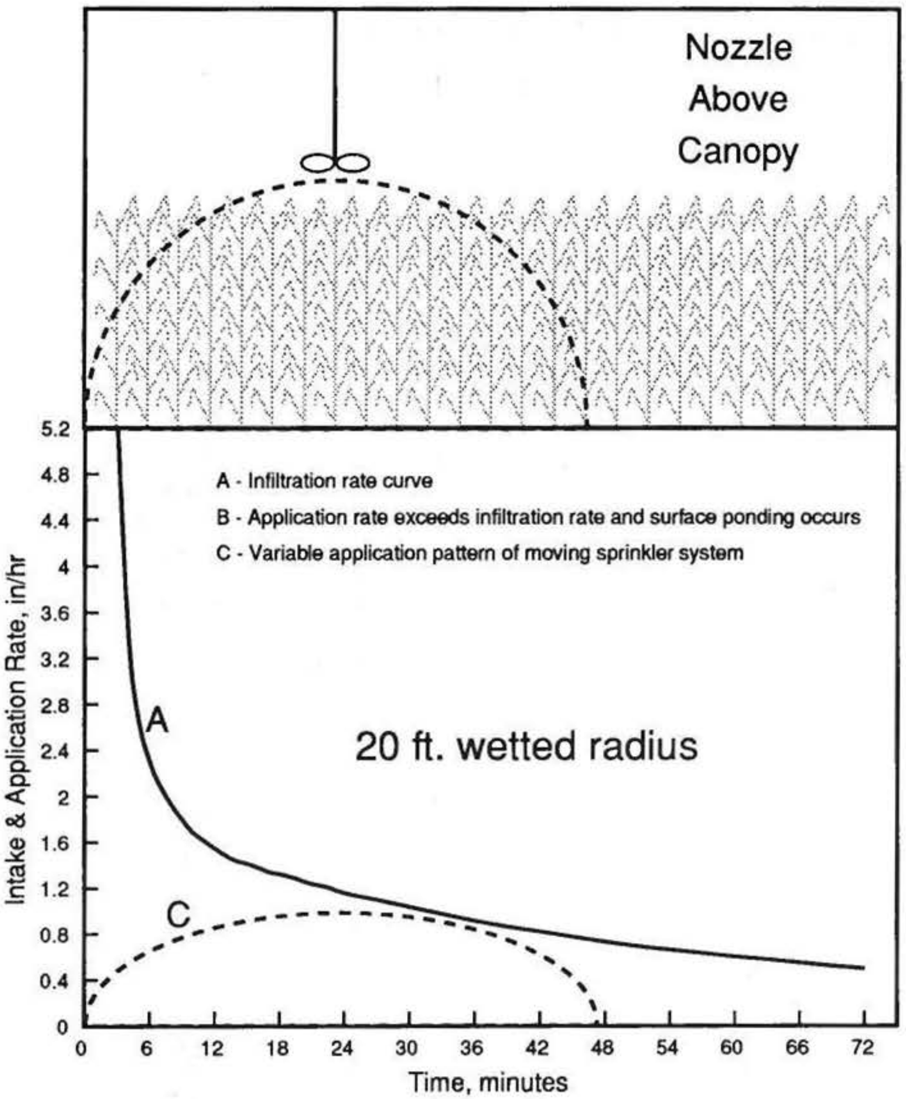

Figure 3a. Potenial runoff for nozzle located above crop canopy.

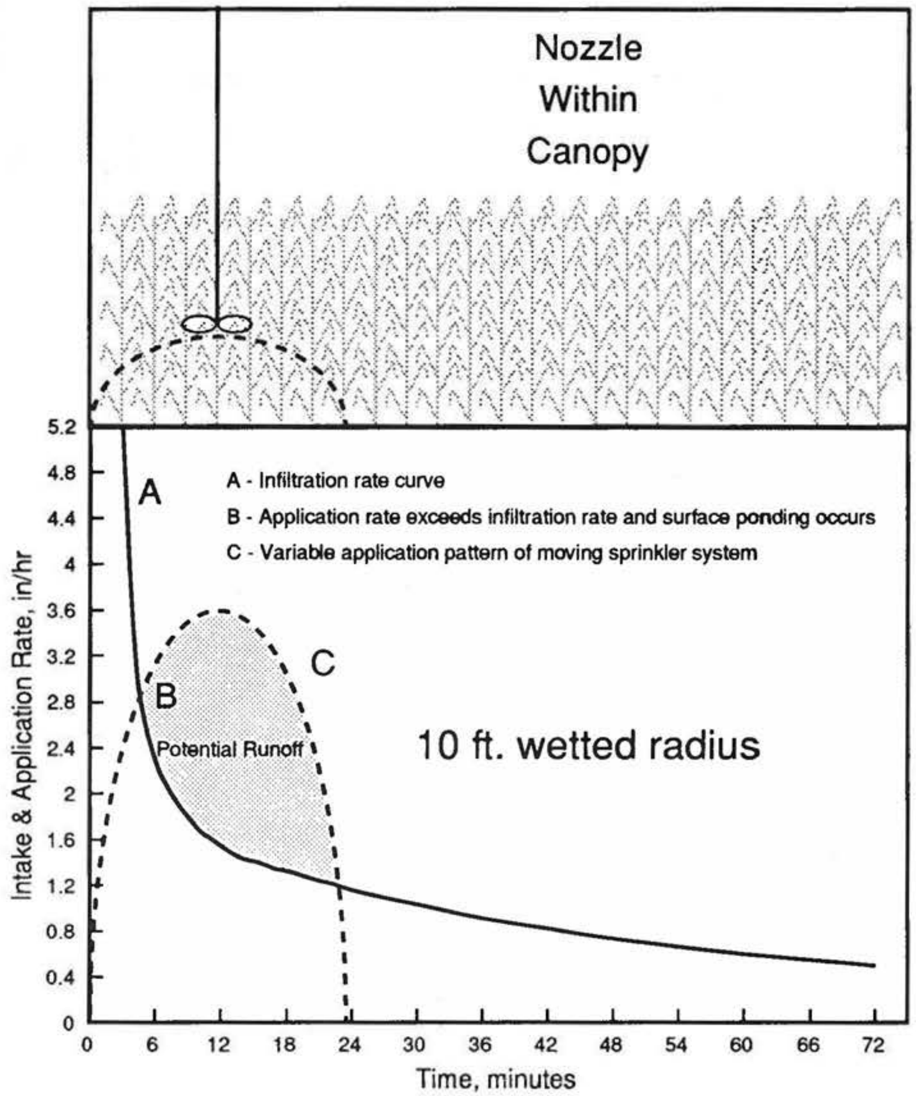

Figure 3b. Potential runoff for nozzle located within crop canopy.

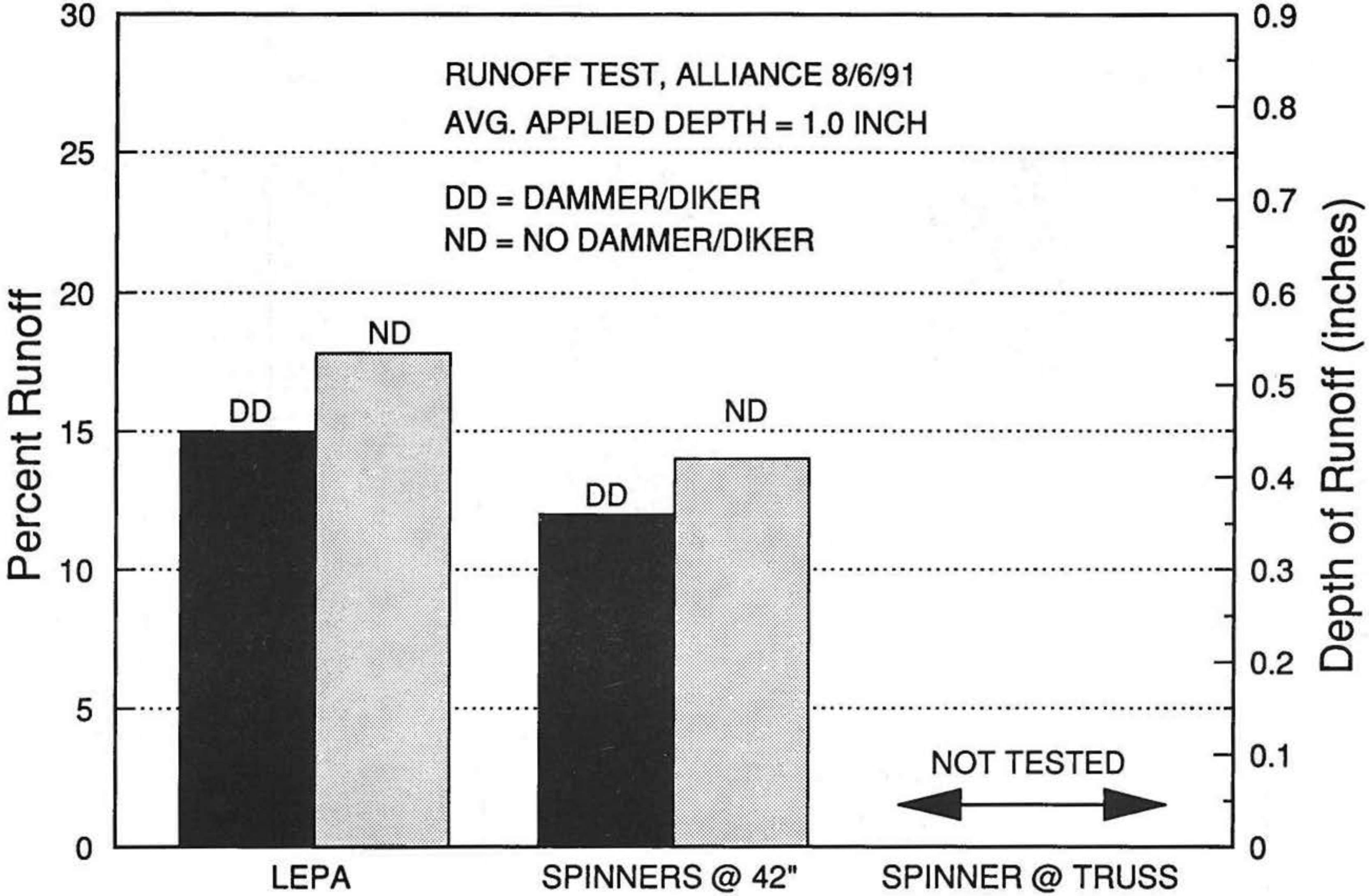

Figure 4. Percent runoff and depth of runoff for LEPA system and spinners at 42" height.

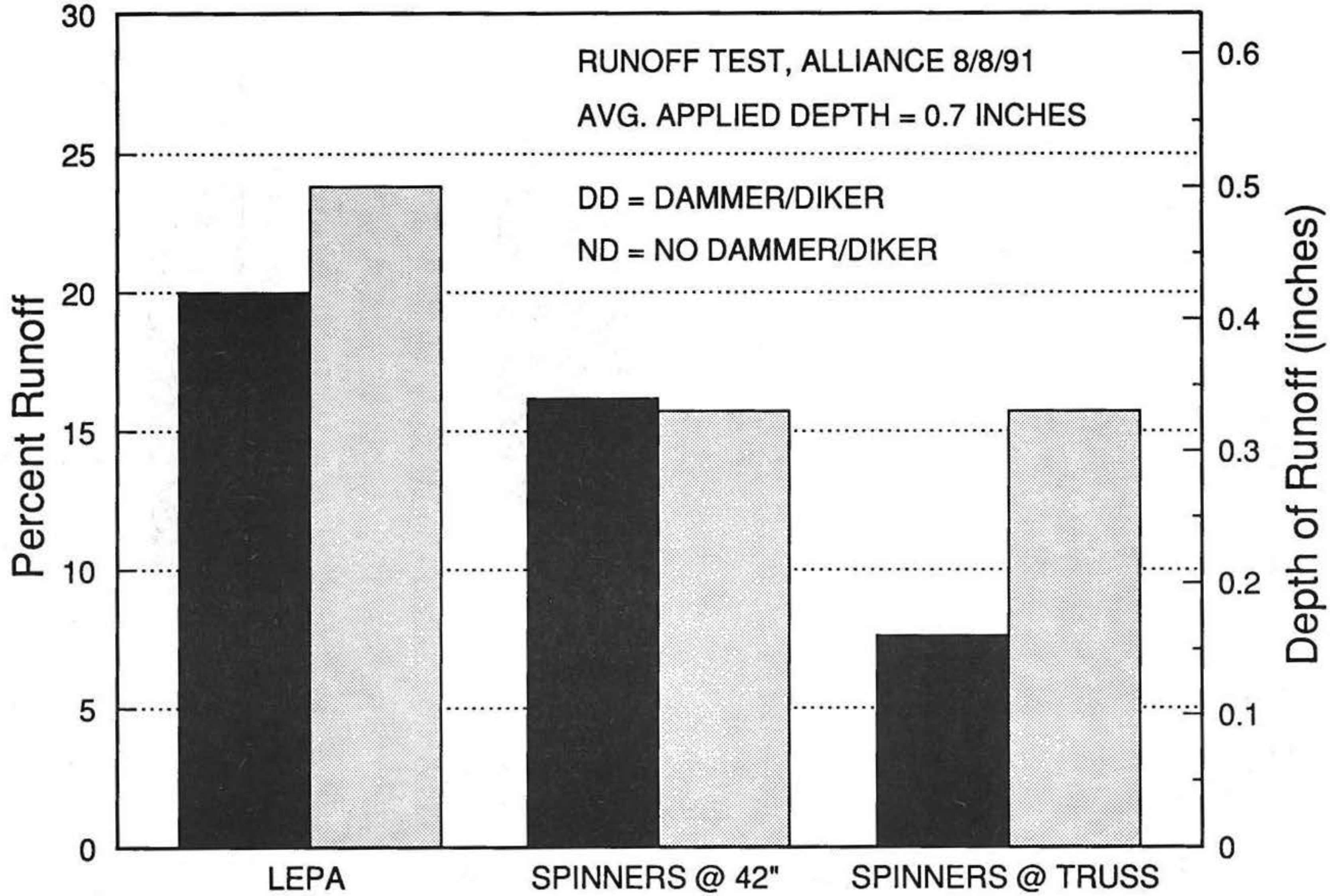

Figure 5. Percent runoff and depth of runoff for LEPA system, spinners at 42" height and spinners at truss rod height.

Irrigation Efficiencies of Surface Systems

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Efficiency rating of any engine, such as, air conditioners, water heaters, furnaces, etc., is of great importance to us. It is an indicator for cost of operation and quality of performance. Similarly, knowledge of irrigation efficiency of a system is important not only to evaluate post construction performance, but also to be able to design and determine the feasibility of a system prior to installation. Each system has its inherent capacity of performance; the lined canal will have greater efficiency due to reduced seepage when compared to an unlined ditch.

Let us consider a field with a crop growing on it. Using irrigation scheduling techniques and soil water monitoring devices we can determine the required depth of irrigation application that is the net amount of water to apply for proper growth and yield. The objective is to refill the root zone to field capacity, the maximum amount that the soil within the root zone will hold for plant use. The required depth for an irrigation event is expressed as an average depth of water to be applied over the entire field.

The required depth as mentioned is the 'net' amount of water to be applied. Diverting or pumping the net amount only will require that the farmer or irrigator must spread the water over the field without any loss, and therefore, achieve 100% efficiency. But in reality the irrigator has to deal with losses and to overcome the loss he has to work with a 'gross' amount. The farmer or the irrigator has the opportunity to influence only the gross amount of water applied. Hence, there is a need for a performance related term which states a relationship between the 'net' requirement and the 'gross' application.

A system that will perform at 100% efficiency may not be feasible economically and attainable operationally. The actual cost of water or return from crop production must be considered to justify changing to an efficient but costly system.

There are many efficiency terms to describe system performances. Although a single definition that describes irrigation efficiency for comparison of all systems is desirable, it is difficult to express the same by one definition to cover physical, economical, and biological evaluations. As a result a multitude of expressions have come about to express different aspects of efficiency. It is necessary for us to familiarize with the expressions. In this write up we will deal only with management and physical efficiency aspects of surface irrigation systems.

Definitions:

Water Conveyance Efficiency (E_c) : The percentage of source water that reaches the field.

$E_c = 100\ (W_f / W_d)$

W_f= water delivered to field

W_d= water diverted from a source

The source of water may be a stream, reservoir, or underground aquifer. The amount diverted or pumped from the source may not reach the field depending on the conveyance and distribution system. Conveyance efficiency is generally a concern for irrigation districts that supply water to a group of farmers through a system of canals and open ditches. Irrigation water in most of Kansas is pumped and carried in closed pipes or conduits, and the conveyance efficiency is expected to be nearly 100%.

Water Application Efficiency (E_a) : The percentage of water available for crop use to the water delivered to field.

$E_a = 100 (W_a / W_f)$
W_a = water available for crop use
W_f = water delivered to field

Water application efficiency gives a general sense of how well an irrigation system is performing its primary task of getting water to meet crop needs. This, however, may mislead as to how well the crop is doing. Water application efficiency can be very high in a situation where the soil profile or root zone has not been filled, although all the water delivered is available for use by the crop. The crop need have not been met and crop failure or a reduced yield may result. It is also possible to have a high E_a , but the irrigation water so poorly distributed that crop stress exists in areas of the field.

Water Storage Efficiency (E_s) : The percentage of water stored in the root zone to the water required to fill the root zone to field capacity (Hansen et al.,1980; Walker and Skogerboe, 1987).

$E_s = 100 (W_s / (W_c - W_a))$
E_s = water storage efficiency
W_s = water stored in a root zone
W_c = available water storage capacity in the root zone (amount between field capacity and wilting point).
W_a = water available in the root zone at the time of irrigation

It is difficult to define the root zone which changes during the season and is different for each crop. This also requires determination of available soil water at the time of irrigation application. When E_a is high the E_s may be low. If a large irrigation is given to raise E_s then E_a may go down. It is recommended that this definition be discontinued from usage (Heermann, et al, 1992). However, for surface irrigation systems the water storage efficiency may be useful if the objective is to minimize the number of irrigation and labor cost.

Irrigation Efficiency (E_i) : The percentage of water delivered to the field that is used beneficially (ASCE, 1978).

$E_i = 100 (W_b / W_f)$
W_b = water used beneficially
W_f = water delivered to field

Irrigation efficiency is more broadly defined than water application efficiency in that the irrigation water may be applied for more uses rather than to satisfy crop water use (ET) only. Other beneficial purpose may include salt leaching, frost protection, crop cooling, and pesticide or fertilizer applications. Most irrigation systems of Kansas are single-purpose (supply water for crop use), which allows water application efficiency and irrigation efficiency to be used interchangeably.

Two other terms may be useful to evaluate a system from the management point of view where water quality degradation may occur due to deep percolation or water loss from run off. These are deep percolation and run off ratios.

Deep Percolation Ratio is defined (Walker and Skogerboe, 1987) as:

$$DP_r = W_{dp} / W_f$$

where, DP_r = the deep percolation ratio

W_{dp} = water percolated below the root zone, and

W_f = water delivered to the field.

This is usually evaluated in conjunction with water application or irrigation efficiency determinations. In many instances this water may not be recovered by a crop. It is significant a term where high water table or leachate may cause water quality deterioration. For a Kansas irrigator this may be important to avoid groundwater contamination and immediate loss of valuable pumped water.

Tailwater Run off Ratio is defined (Walker and Skogerboe, 1987) as:

$$TW_r = W_{ro} / W_f$$

where, TW_r = the tailwater ratio

W_{ro} = water run off from field

W_f = water delivered to the field.

Tailwater is normally reused by pumping from a recovery pit in the same field or adjacent fields. It is of concern if the water is lost, or has the potential to degrade the water quality, or is prohibited by law. Kansas irrigators generally reuse the water by pumping from a tailwater pit and may not be a concern except for additional pumping cost.

Range of Application Efficiencies for Surface Irrigation Systems

System Type	Application Efficiency Range (%)
Basin	60 - 95
Border	60 - 90
Furrow	45 - 80
Surge	60 - 90

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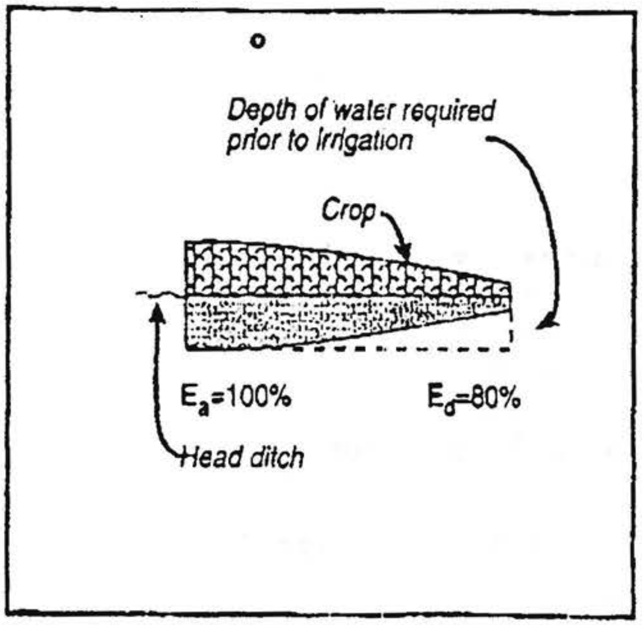
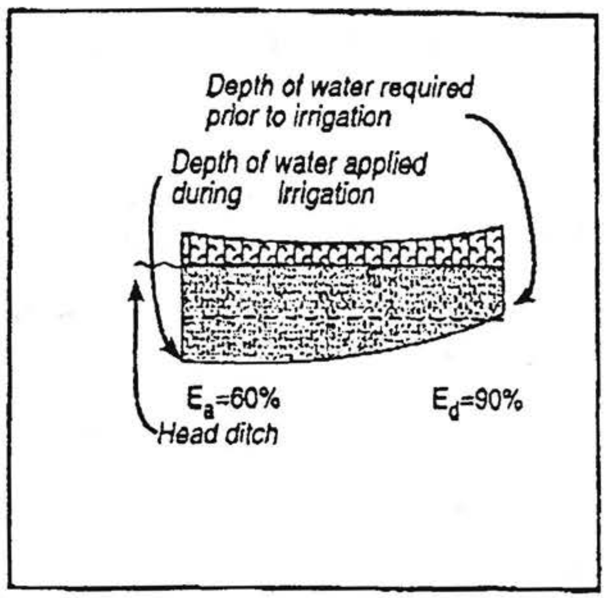
Surface Irrigation

Application Efficiency versus Distribution





IMPROVEMENTS IN IRRIGATION EFFICIENCY

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INTRODUCTION

Efficiency is the name-of-the-game these days. We are constantly reminded that we must be more efficient with our time, our money, our skills, and our resources. Yet, the working definitions of the various efficiencies that each of us use may be quite different. Sometimes the correctness of the appropriate use of an efficiency term is entirely related to one's perspective. The topic of this presentation is irrigation, so let's look at two important efficiency terms in irrigation and look at how the terms interact.

WATER USE EFFICIENCY *(WUE)*

Water use efficiency *(WUE)* is typically defined as the crop yield divided by the amount of water used. Algebraically it can be expressed as

$$WUE = M_{crop} / V_{wuse} \qquad \text{Eq. 1.}$$

where M_{crop} is equal to the mass of the crop and V_{wuse} is equal to the volume of water used. It is easy to see that increases in WUE can be accomplished either by increases in M_{crop} relative to V_{wuse} or by decreases in V_{wuse} relative to M_{crop}. Whereas both techniques increase the beneficial use of water, only the second technique results in water conservation directly. It is important to note that manipulation of either term must be relative to the other term in the equation. Reducing water use is not beneficial if crop yield is reduced to the same extent.

WATER APPLICATION EFFICIENCY *(E_a)*

The water application efficiency (E_a) definition as reported by Heerman et al. (1990) is algebraically expressed as

$$E_a = V_{soil} / V_{field} \qquad \text{Eq. 2.}$$

where V_{soil} is equal to the volume of irrigation water needed for crop evapotranspiration to avoid undesirable water stress and V_{field} is equal to the volume of water delivered to the field. E_a is often incorrectly confused with the water storage efficiency which is the fraction of an irrigation amount stored in the remaining available crop root zone following an irrigation event. The use of water storage efficiency is discouraged by Heerman et al. (1990) because of the difficulty of determining the crop root zone and because the water storage efficiency can still be quite low while sufficient water is provided for crop production. It is easy to manipulate V_{field} so that E_a can be equal to 1 or 100%. It should be noted that any irrigation system from the worst to the best can be operated in a fashion to achieve 100% E_a if V_{field} is low. Increasing E_a in this manner totally ignores the need for irrigation uniformity. For E_a to have practical meaning, V_{soil} needs to be considered to avoid undesirable water stress.

INTERACTION OF WUE AND E_a

Algebraically it has been shown that either efficiency term can be maximized through manipulation of the various terms in the equations. However, some of these manipulations are not beneficial to the irrigator and perhaps, also not beneficial to the economic vitality of the state. Consideration of both terms is necessary to optimize beneficial use of water for crop production.

In a thorough review of crop yield response to water, Howell et al. (1990) enumerated four methods of increasing water use efficiency: 1) increasing the harvest index (ratio of crop economic yield to total dry matter production); 2) reducing the transpiration ratio (ratio of transpiration to dry matter production); 3) reducing the root dry matter amount and/or the dry matter threshold required to initiate the first increment of economic yield; or 4) increasing the transpiration component relative to the other water balance components, for example, through reductions of evaporation, drainage, and runoff.

Clearly, some of these four methods are more difficult than others. Tanner and Sinclair (1983) in a review of studies from the early 1900's to the 1980's conclude that there is very little hope for significantly improving the transpiration ratio (Method 2). Plant breeders and agronomists have made great strides in increasing the harvest index (Method 1) for many of the more important crops. Corn yields have increased an average of 2.5 bu/acre annually for the years 1968-1991 in Thomas County, Kansas due to improvements in corn hybrids and cultural practices. The actual water used by the corn has not changed appreciably although the water use efficiency has increased. The dry matter threshold (Method 3) varies some depending on the annual climatic conditions. However, it does not appear practical that it can be manipulated to a significant extent. Improved irrigation systems and practices can increase both WUE and E_a by Method 4, increasing the transpiration component relative to the other water balance components.

Crop yield is linearly related to transpiration for many field crops from the point of the dry matter threshold through the point of maximum yield (Figure 1). However, the relationship of crop yield and total water use is usually curvilinear. The area between the dotted line and the curve represents the inefficiencies caused by the irrigation system and/or inappropriate irrigation/precipitation timing or amounts. Use of irrigation water beyond the point where the dotted line and the curve join at maximum yield represents wasteful overirrigation and should be eliminated immediately. All of the points on the rising dotted line have equal WUE, so all are equally beneficial in terms of WUE. However, most irrigators are practicing irrigation for the beneficial purpose of increasing crop yields and economically need to produce near the top of the rising leg. Lamm et al. (1993) analyzed 9 different resource allocation schemes for irrigated corn ranging from full irrigation to severely deficit irrigation. Full irrigation was found to be the most economical operating point. They concluded,

Irrigators wishing to continue to grow corn when irrigation is limited by physical (water supply) or institutional constraints should seriously consider reducing irrigated land area to match the severity of the constraint.

Only reductions in the area between the dotted line and the curve (Figure 1) and obviously elimination of overirrigation should be considered as opportunities where improved irrigation systems and practices can increase WUE and E_a. Many irrigators are already upgrading irrigation systems and management of their present systems to *stretch* water. The opportunity for water use reductions is significant but the ultimate reductions can not be economically obtained overnight. The irrigation sector continues to search for economical ways to reduce inefficient water use in a manner that can optimize both WUE and E_a.

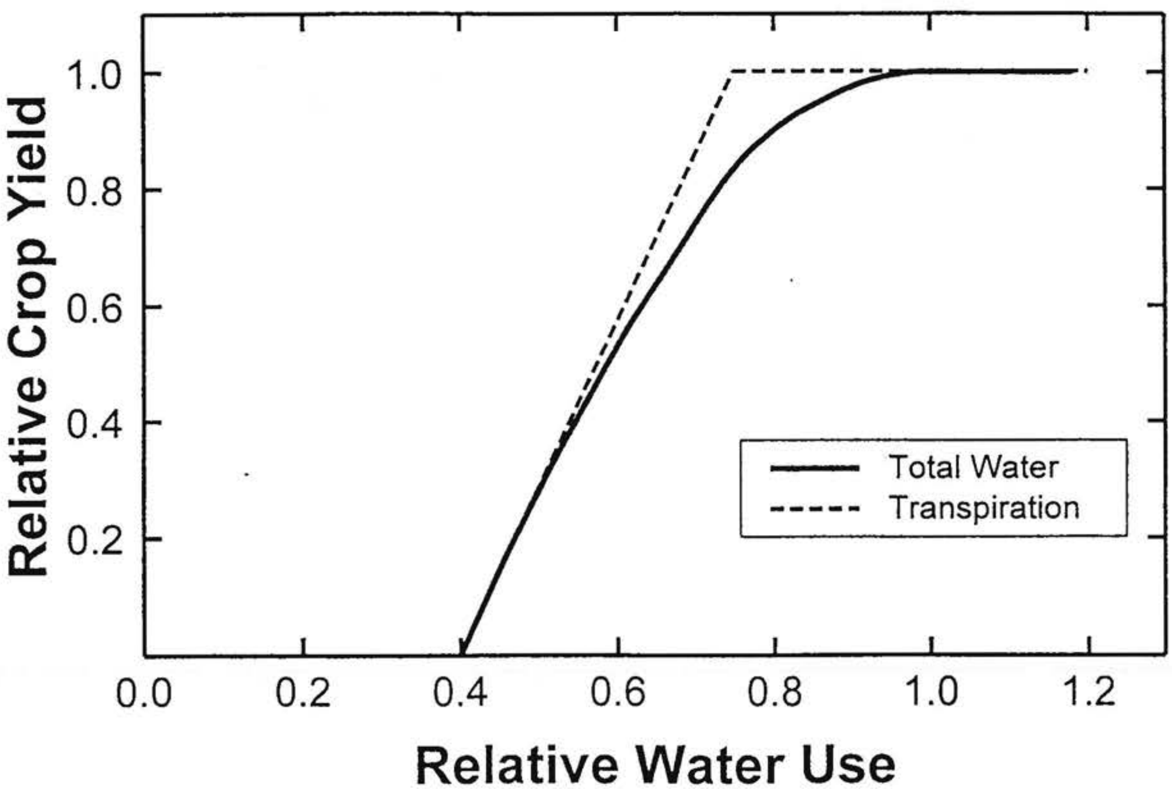

Figure 1. Hypothetical crop yield response to total water use and transpiration. Area between dotted line and curve is inefficiency. Use of irrigation water beyond where dotted line and curve rejoin (maximum crop yield) is wasteful overirrigation. Starting point for both lines is dry matter threshold. *Numbers shown for example only, actual values will vary.*

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Chemigation

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INTRODUCTION

Chemigation is the application of agricultural chemicals (fertilizers, micro nutrients, fungicides, herbicides, insecticides, nematicides, soil conditioners, growth regulators, and biological agents, as well as gray water and animal wastes) into water flowing through an irrigation system. Chemigation is an efficient and economical means of applying inputs necessary for crop, turf, nursery, greenhouse, and landscape management, among others.

In Kansas, chemigation is defined by state law (K.S.A. 2-3301 et seq, Kansas Chemigation Safety Law) as "any process whereby pesticides, fertilizers or other chemicals or animal wastes are added to irrigation water applied to land or crops, or both, through an irrigation distribution system." Chemigation by Kansas definition,
should therefore not be confused with the chemical treatment of water such as chlorination, fluoridation, hard water remedies, pH adjustment, or the addition of antibiotics among others, where irrigation water is not applied to land or crops, or both, through an irrigation distribution system.

Chemigation can be conducted using drip/trickle, flood, furrow, and sprinkler irrigation systems. Drip/trickle and subsurface systems can only be used for chemigation of soil-applied agricultural chemicals. Flood and furrow irrigation systems can, at times, present problems with chemical application uniformity and may limit some chemical applications. Sprinkler irrigation systems (solid set, center pivots, lateral move, etc.) can accommodate both soil and foliar applied chemicals and are the primary method of choice in Kansas.

Just as there are benefits and risks associated with applying agricultural chemicals using conventional (ground and aerial) methods, there are benefits and risks associated with chemigation. In some cases, with proper management, better application efficiencies offer a reduction in the amount of agricultural chemical used, timely application, and less impact on the environment.

The most significant risk when utilizing chemigation is for water source contamination due to backsiphonage, backpressure, or over irrigation. To minimize risks related to chemigation, an irrigation system must be properly designed, equipped and operated. Safety equipment must be added to the system and procedures followed to ensure operator and environmental safety as well as the desired results of the chemical application. Proper management and maintenance of the recommended safety equipment is essential for successful chemigation. Mandatory safety equipment, record keeping, permitting, certification, and management requirements are outlined by the Kansas Chemigation Safety Law.

ADVANTAGES AND DISADVANTAGES TO CHEMIGATION

The application of chemicals through an irrigation system offers many advantages. Advantages obtained depend on the type of irrigation system used and the type of chemical being applied, among others.

Advantages

Properly designed and operated irrigation systems may apply chemicals more uniformly than aircraft or some ground sprayers.

Chemigation allows prescription and timely application of chemicals based on crop requirements even when fields are too wet for tractors or it is too foggy for aircraft or even at night. Proper timing also allows for application under the proper optimum weather conditions so that reduced rates of chemicals might be effective.

Many chemicals require moisture for activation or precise depth of incorporation. The appropriate amount of water applied through irrigation can incorporate chemicals to the desired depth and, at the same time, provide moisture for activation. The amount of irrigation applied depends on soil type, soil moisture content, and depth of chemical incorporation required.

Chemigation allows for the application of chemicals under various tillage situations and is, therefore, compatible with reduced or no-till farming.

In those soils or regions where soil compaction is a problem, applying chemicals through irrigation can reduce compaction caused by tractors and other tillage implements.

Mechanical damage to the crop by sprayers is reduced by chemigation.

Chemigation reduces operator exposure to chemicals. It is essentially a closed transfer system and an operator is not required in the field during the entire application.

Chemigation may reduce environmental hazards associated with spray drift.

Chemigation of post-emergence soil-acting herbicides may reduce crop phytotoxicity and increase activity.

Applying chemicals through an irrigation system can save 40% or more in chemical application costs. Greater savings can be obtained when two or more inputs are applied simultaneously (co-chemigation).

Chemigation can reduce energy consumption for application up to 90% and, in some cases, eliminate the need for soil incorporation.

Chemigation systems may simplify cultural practices and improve crop production and quality if used correctly. Timely fertilizer applications can significantly increase crop yields.

Disadvantages

Chemigation requires considerable management input and personnel training. Certification of the operator for chemigation systems is required in some areas of the United States.

Chemigation requires a change in management techniques.

Some chemicals may react with irrigation system components and solutions may be corrosive to irrigation equipment.

Using an irrigation system to apply chemicals may apply moisture to the crop at a time when it is not required or when the soil is already too wet.

Additional equipment and capital outlay may be required for chemigation.

Chemigation increases application time compared to aerial spraying, so climatic factors may interfere or delay application.

Not all chemicals are labeled for use in chemigation.

Some chemicals, due to their chemical properties may not be suited for chemigation.

Environmental concerns exist in regards to the persistence and movement of chemicals in the soil profile and for the possibility of backsiphon or direct contamination of the water source.

Irrigation Scheduling Using Evapotranspiration (ET):
Example Schedule

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Irrigation scheduling can be accomplished by keeping an account of crop water use relative to the amount of water available for withdrawal from the soil profile. Measurement of crop water use or evapotranspiration (ET) can be indirectly measured by monitoring soil water levels or calculated using weather information and specific crop growth characteristics. Calculating crop water use, although an estimate, is an reliable and accurate method that is finding favor with many irrigators since the information can be gathered and delivered electronically to the office and eliminates much of the labor involved in indirectly measuring water through soil sampling. Some soil monitoring is still necessary to confirm scheduling accuracy and account for rainfall and other variations. KSU bulletins, Scheduling Using Evapotranspiration Reports for Center Pivots, L-915, and Furrow Irrigation, L-914 are available from your county extension office. This example will follow the procedures discussed in those bulletins and will assume use of a center pivot system.

Basic Scheduling

Irrigation Scheduling Steps:
1. Determine the total crop water use (ET) since the last update.
2. Determine the effective rainfall and irrigation since the last update.
3. Update the schedule.
4. Begin irrigation when soil water depletion equals or exceeds the net irrigation application amount.

To initiate the scheduling steps, characteristics of the field (soil) and irrigation system and certain management guidelines must be determined.

Determine the Active Root Zone of the Crop

For the bulk of the season, a managed root of three feet for most field crops is a general recommendation. However, some soils may have restrictions that reduce root penetration. Early season irrigation should account for a shallow root zone, either using information from crop production handbooks or visual inspection through digging. Record a root zone depth of 3 feet on line A of Table 3 for this example.

Determine the Soil Water Storage Capacity

Sandy soils hold less water than silts or clays. Specific information is available from a NRSC county soil Survey. KSU bulletin L-904, Soil, Water, Plant Relationships, will have generalized information. Table 1 (from L-904), is shown below. Assume a sandy loam soil for today's example. From Table 1, the available soil water holding capacity is 1.56 inches per feet. Record this soil water holding capacity on line B of Table 3.

Determine Allowable Soil Water Depletion

Crops have differing levels of soil water depletion tolerance, although most field crops are not extremely yield sensitive to some soil water deficient. However, to maintain good growth conditions, the general management recommendation for field crops is to maintain less than 50 percent depletion in the soil profile. Record 50 percent allowable depletion on line D of Table 3. Multiply line C by line D and record this result on line E of Table 3.

Determine Irrigation Capacity

The irrigation capacity of any irrigation system depends on the well discharge rate relative to the number of acres covered. Irrigation capacity does not change with application depth. Increasing or decreasing application depth has a proportional effect on the length of the irrigation set. Use the following formula to calculate gross irrigation capacity.

$$\text{Gross Irrigation Capacity} = \frac{\text{GPM} \times \text{Hours/Day}}{450^{*} \times \text{Acres}}$$

* 450 gpm = 1 ac-in/hr (conversion factor)

$$\text{Example:} \quad \frac{650 \text{ gpm } (24 \text{ hr/day})}{\frac{450 \text{ gpm}}{\text{ac-in/hr}} \quad 128 \text{ acres}} = .27 \text{ in/day}$$

Irrigation systems are not 100 percent efficient. Table 2 presents some typical estimates for efficiency for various sprinkler packages - assuming good operating conditions and no surface runoff. Multiply gross irrigation capacity by the efficiency estimate to determine the net irrigation capacity.

Net irrigation capacity = gross irrigation capacity x efficiency

Assume a sprinkler package with an efficiency estimate of 80 percent.

Net irrigation capacity (NIR) = 0.27 inches/day x 0.80 = 0.22 inches/day

The net irrigation capacity can be used to calculate the irrigation application depth by multiplying capacity by length of the irrigation. Assume, for example, the irrigator wants to complete one revolution of a center pivot in 3.5 days.

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$$0.22 \text{ in/day} \times 3.5 \frac{\text{days}}{\text{revolution}} = 0.77 \text{ inches/revolution}$$

It can also determine the length of time needed to apply a certain depth by dividing irrigation depth by capacity. How long would it take this irrigation system to apply 1.0 inches net application.

$$\frac{1.0 \text{ inches}}{0.22 \text{ inches/day}} = 4.5 \text{ days or } 109 \text{ hours}$$

Remember, however, the grow amount pumped was 0.27 inches/day or 1.22 inches in the 4.5 days.

Filling in the Schedule

The remainder of Table 3 contains 10 columns to record the daily information needed to schedule. Column 1 is the date. Column 2 is the amount of effective rainfall that enters the soil profile and becomes available for crop use. Column 3 is the net irrigation amount that was determined using the previously described procedure. Record the total application depth in Column 3 when irrigation is initiated and list in column 3 the number of days it takes to complete an irrigation cycle.

Example.

Column 1	Column 3
Date 1	1.00 ↓ 1
Date 2	2
Date 3	3
Date 4	4
Date 5	4.5

Column 4,5,6, and 7 is used to record the information used to determine evapotranspiration (ET). ET may be reported as either Etr or actual ET. If actual ET information is obtained, record it directly into Column 7, marked Crop ET on Table 3, and ignore the columns marked Etr, Stage of Growth, and Crop Coefficient.

Etr refers to reference ET. Etr is the expected ET from a uniform, green,actively growing reference crop due to atmospheric demand. Actual ET is usually less than Etr since plant characteristics of other crops and stage of growth reduce the amount. If Etr is used, it must be modified to reflect the crop type and maturity.

Example: Etr = 0.35 From Figure 1

State of Growth = 7 leaf corn Kco = 0.45

ET = Etr x Kco
= 0.35 x 0.45
= 0.16 inches

The soil water depletion is calculated and recorded in column 8 and 9 to represent two locations in the field. Location 1 is the start of the irrigation cycle and Location 2 is the end of the irrigation cycle for this example. Other locations, or additional locations, in the field could be used if desired, but the starting and stopping points are important. The new soil water depletion is calculated as follows:

Soil water depletion = previous day's soil water depletion + ET
- net irrigation - effective rainfall

Soil water depletion cannot be negative. If this occurs, record zero for the depletion level.

Soil water status when recorded as depletion means bigger numbers are less desirable. Zero depletion means the soil profile is at field capacity. Crop water use removes water from the profile and increases depletion. Rain and irrigation reduce depletion. To help remind you, the depletion formula appears on Table 3. Column 7 has a plus (+) sign to indicate it adds to depletion while columns 2 & 3 have negative (-) signs to indicate they subtract from depletion.

Example: Schedule calculation

New Soil Depletion = Previous Soil Depletion +ET - NIR - RAIN

Prev = 1.00 ET = 0.25 NIR = 0.75 RAIN = 0

NEW = 1.00 + 0.25 - 0.75 - 0

= 0.50 inches

You are now ready to complete Table 3. In Table 3 Etr values are listed for a 21 day period along with stages of growth for corn. Use Figure 1 to select an appropriate Kco value and calculate ET (Column 7). Remember in the real world you would only get one day at a time. The stage of growth progress more rapidly than what a normal corn crop. This was done to help illustrate the selection of Kco values from Figure 1. Select a Kco from Figure 1 and record this in Column 6. Kco values are sometimes determined by calculation using days past emergence or growing degree days or fraction of the growing. Any of these Kco selection methods make computerization of scheduling easier.

At date 0, soil water depletion values were determined (assumed for this exercise) to be 0.90 inches. The allowable depletion from line E is 2.34. The remaining soil water then is (2.34 - 0.90) 1.44 inches. If crop ET was 0.25 inches/day, this means almost 6 days (1.44 inches/ 0.25in/day) of water supply remains in profile. Then net irrigation capacity is 0.22 inches/day and a 4.5 day irrigation is planned which applies a net irrigation of 1.00 inches. Since the NIR and the soil depletion are approximately equal at Day 0, irrigation can begin.

Complete Table 3 assuming the first irrigation is started on day 1 and effective rainfall of 0.78 and 0.23 occurs on day fourteen and fifteen. You determine when to start or stop all subsequent irrigations.

Table 1: Average Water Holding Capacities of Kansas Soils
(Source: NRCS Kansas Irrigation Guide)

	Percent Water Content				Inches per Foot			
Soil Texture	Wet Bulk Density At F.C	1/ F.C.	2/ W.P.	3/ A.W.C.	4/ W.P. F.C.	1/ F.C.	2/ W.P.	3/ A.W.C.
Sand	1.70	7.0	3.0	4.0	43	1.44	0.60	0.84
Loamy sand	1.70	10.0	4.2	5.8	42	2.04	0.84	1.20
Sandy loam	1.65	13.4	5.6	7.8	42	2.64	1.08	1.56
Fine sandy loam	1.60	18.2	8.0	10.2	44	3.48	1.56	1.92
Loam	1.55	22.6	10.3	12.3	46	4.20	1.92	2.28
Silt loam	1.50	26.8	12.9	13.9	48	4.80	2.28	2.52
Silty clay loam	1.45	27.6	14.5	13.1	52	4.80	2.52	2.28
Sandy clay loam	1.50	26.0	14.8	11.2	57	4.68	2.64	2.04
Clay loam	1.50	26.3	16.3	10.0	62	4.68	2.88	1.80
Silty clay	1.40	27.9	18.8	9.1	67	4.68	3.12	1.56
Clay	1.35	28.8	20.8	8.0	72	4.68	3.36	1.32

1/ Field Capacity
2/ Wilting point
3/ Available water capacity
4/ Percent of field at wilting point

Table 2. Probable Range of Irrigation Application Efficiency for Various Sprinkler Packages with No Runoff*

System Type	Application Efficiency Range (%)
High pressure - high angle impact	70 to 80
Medium pressure - low angle impact	75 to 85
Spray on top truss	75 to 85
Spray on drop	80 to 90
In-canopy spray	75 to 95
Bubble mode or sock LEPA	85 to 95

*See K-State Bulletin L-908, *Considerations for Sprinkler Packages on Center Pivot*, for more information.

Table 3. Soil Water Balance Worksheet

A. Field Example E. Crop Example

B. Root Zone Depth ____ feet F. Root Zone Available Water Holding Capacity ____ inches

C. Soil Type Sandy Loam G.% Allowable Depletion ____ %

D. Available Water Holding Capacity ____ in/ft H. Allowable Depletion ____ inches

New Depletion = Soil Depletion + Et - Net irrigation - Rainfall

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Date	Effective Rainfall Inches (-)	Net Irrigation Inches (-)	Etr Inches	Stage of Growth	Kco Crop Coefficient	Crop ET Inches +	Soil Water Depletion Location 1	Soil Water Depletion Location 2	Comments
0							0.90	0.90	
1			0.28	7 Leaf					
2			0.27	7leaf					
3			0.30	8 leaf					
4			0.31	8 leaf					
5			0.18	9 leaf					
6			0.19	leaf					
7			0.28	10 leaf					
8			0.31	10leaf					
9			0.29	11 leaf					
10			0.36	11 leaf					
11			0.39	12 leaf					
12			0.42	12 leaf					
13			0.48	14 leaf					
14	0.78		0.41	14 leaf					
15	0.23		0.21	16 leaf					
16			0.35	16 leaf					
17			0.20	Silk					
18			0.22	Silk					
19			0.28	Blister					
20			0.30	Blister					
21			0.24	Dough					

Table 4. Soil Water Balance Worksheet

A. Field________________________________ E. Crop____

B. Root Zone Depth__________________feet F. Root Zone Available Water Holding Capacity________inches

C. Soil Type ___________________________ G.% Allowable Depletion______________________________%

D. Available Water Holding Capacity______in/ft H. Allowable Depletion___________________________inches

New Depletion = Soil Depletion + Et - Net irrigation - Rainfall

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Date	Effective Rainfall Inches (-)	Net Irrigation Inches (-)	Etr Inches	Stage of Growth	Kco Crop Coefficient	Crop ET Inches +	Soil Water Depletion Location 1	Soil Water Depletion Location 2	Comments
0									
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									

Table 5. Soil Water Balance Worksheet

A. Field Example — E. Crop Example

B. Root Zone Depth 3 feet — F. Root Zone Available Water Holding Capacity 4.68 inches

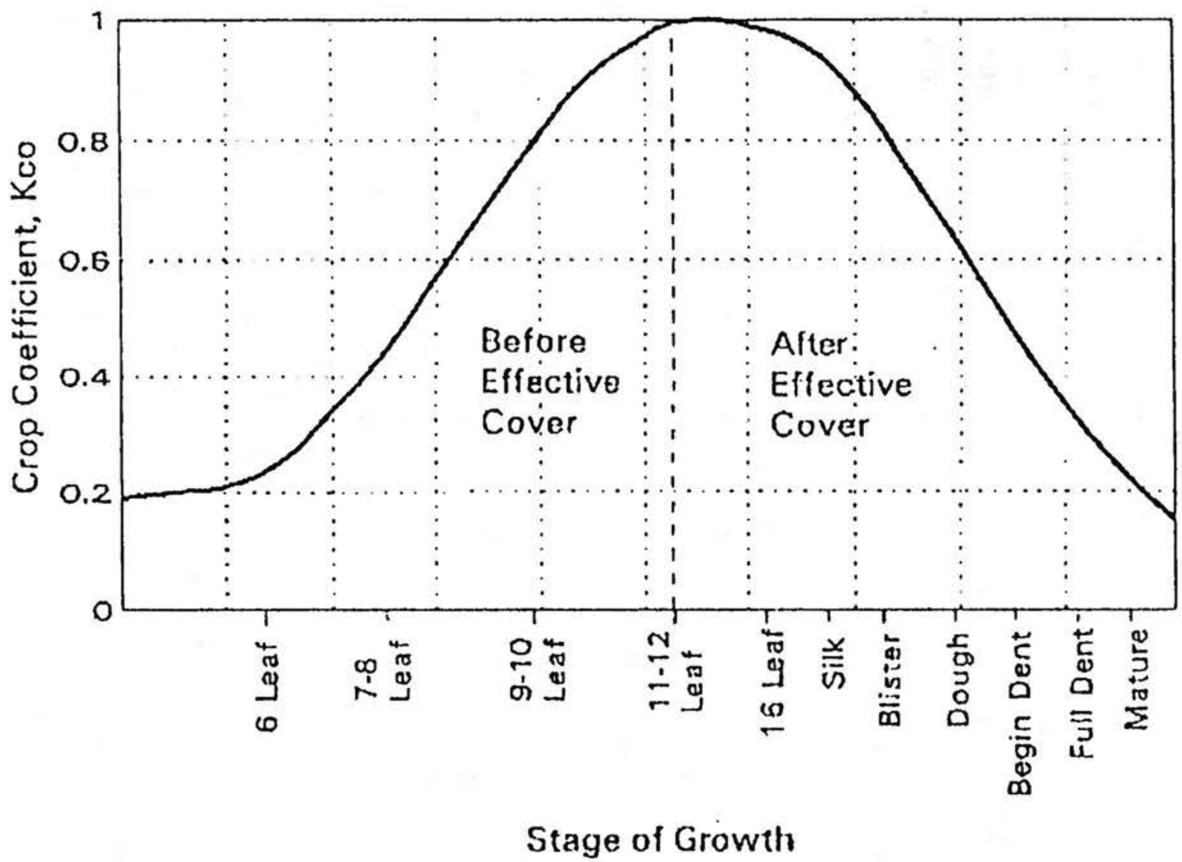
C. Soil Type Sandy Loam — G.% Allowable Depletion 50 %

D. Available Water Holding Capacity 1.56 in/ft — H. Allowable Depletion 2.34 inches

New Depletion = Soil Depletion + Et - Net irrigation - Rainfall

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Date	Effective Rainfall Inches (-)	Net Irrigation Inches (-)	Etr Inches	Stage of Growth	Kco Crop Coefficient	Crop ET Inches +	Soil Water Depletion Location 1	Soil Water Depletion Location 2	Comments
0							0.90	0.90	
1		1.00 1	0.28	7 lf	0.45	0.13	0.03	1.03	Begin 1st
2		2	0.27	7 lf	0.45	0.12	0.15	1.15	
3		3	0.30	8 lf	0.60	0.18	0.33	1.33	
4		4	0.31	8 lf	0.60	0.19	0.52	1.52	
5		4.5	0.18	9 lf	0.80	0.14	0.66	0.66	End 1st OFF
6			0.19	9 lf	0.80	0.15	0.81	0.81	
7		1.00 1	0.28	10 lf	0.90	0.25	0.06	1.06	Begin 2nd
8		2	0.31	10 lf	0.90	0.28	0.34	1.34	
9		3	0.29	11 lf	0.95	0.28	0.62	1.62	
10		4	0.36	11 lf	0.95	0.34	0.96	1.96	
11		4.5 / 1.00	0.39	12 lf	1.00	0.39	1.35 / 0.35	1.35 / 1.35	End 2nd / Begin 3rd
12		1	0.42	12 lf	1.00	0.42	0.77	1.77	
13		2	0.48	14 lf	1.00	0.48	1.25	2.25	
14	0.78	3	0.41	14 lf	1.00	0.41	0.88	1.88	
15	0.23	4 4.5	0.21	16 lf	1.00	0.21	0.86	0.86	End 3rd
16		1.00 1	0.35	16 lf	1.00	0.35	0.21	1.21	Begin 4th
17		2	0.20	Silk	0.95	0.19	0.40	1.40	
18		3	0.22	Silk	0.95	0.21	0.61	1.61	
19		4	0.28	Blister	0.90	0.25	0.86	1.86	
20		4.5 / 1.00	0.30	Blister	0.90	0.27	1.13 / 0.13	1.13 / 1.13	End 4th / Begin
21		1	0.24	Dough	0.60	0.14	0.27	1.27	5th

Figure 1. Corn Crop Coefficient vs. Stage of Growth



DESIGN AND MANAGEMENT CONSIDERATIONS FOR SUBSURFACE DRIP IRRIGATION SYSTEMS

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INTRODUCTION

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

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HYDRAULIC DESIGN

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

Crops and Soils Considerations

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

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

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

Field Size, Shape, and Topography

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

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

Dripline Hydraulic Characteristics

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

$$Q = k H^x$$

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

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

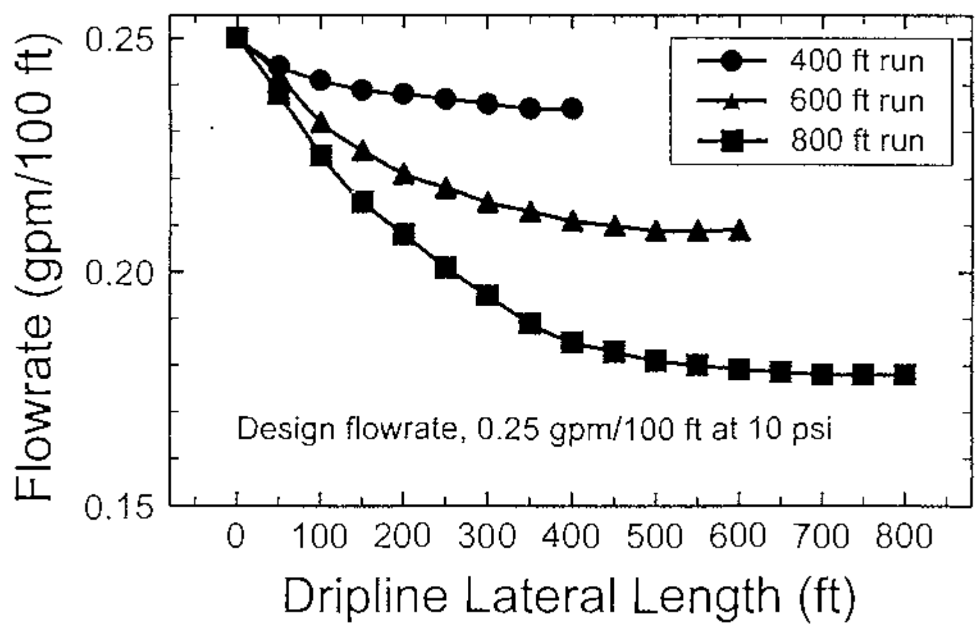

Figure 1. Calculated dripline flowrates on level slopes as affected by length of run.

Table 1. Dripline Uniformity Criteria

	Flow variation, Qvar = 100 x ((Qmax -Qmin)/Qmax)
Desirable	< 10%
Acceptable	10 - 20%
Unacceptable	> 20%

	Statistical Uniformity U_S	Emission Uniformity E_U
Excellent	95-100%	94-100%
Good	85-90%	81-87%
Fair	75-80%	68-75%
Poor	65-70%	56-62%
Unacceptable	< 60%	< 50%

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

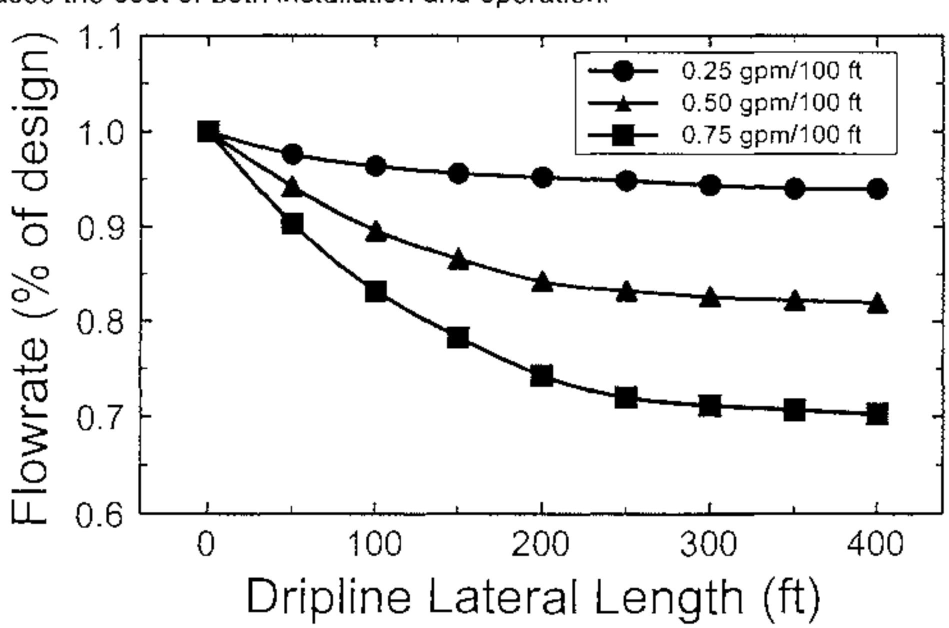

Figure 2. Calculated flowrates on level slopes as affected by dripline capacity.

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

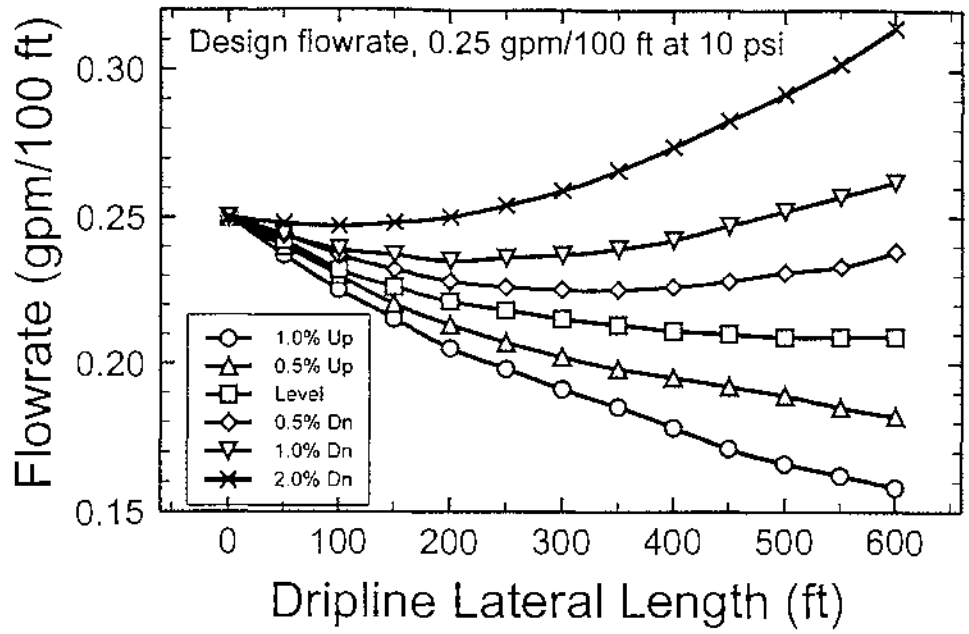

Figure 3. Calculated dripline flowrates as affected by slope.

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

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

FILTRATION, FLUSHING, AND WATER TREATMENT

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

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

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

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

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

MANAGEMENT CONSIDERATIONS

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

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

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

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

CONCLUDING STATEMENT

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

KSU RESEARCH FOR CORN PRODUCTION USING SDI

F. R. Lamm, W. E. Spurgeon, D. H. Rogers and H. L. Manges[1]

ABSTRACT

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

INTRODUCTION

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

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

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PROCEDURES

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

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

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

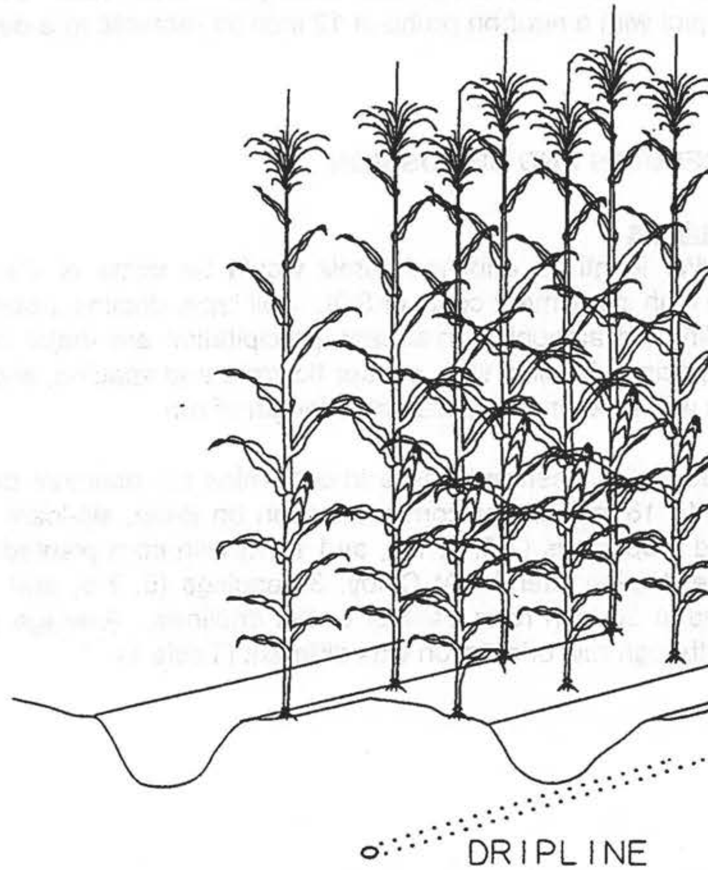

Figure 1. Arrangement of corn rows on permanent bed system in relation to the dripline.

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

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

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

RESULTS AND DISCUSSION

Spacing and Length of the Driplines

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

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

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

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

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

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

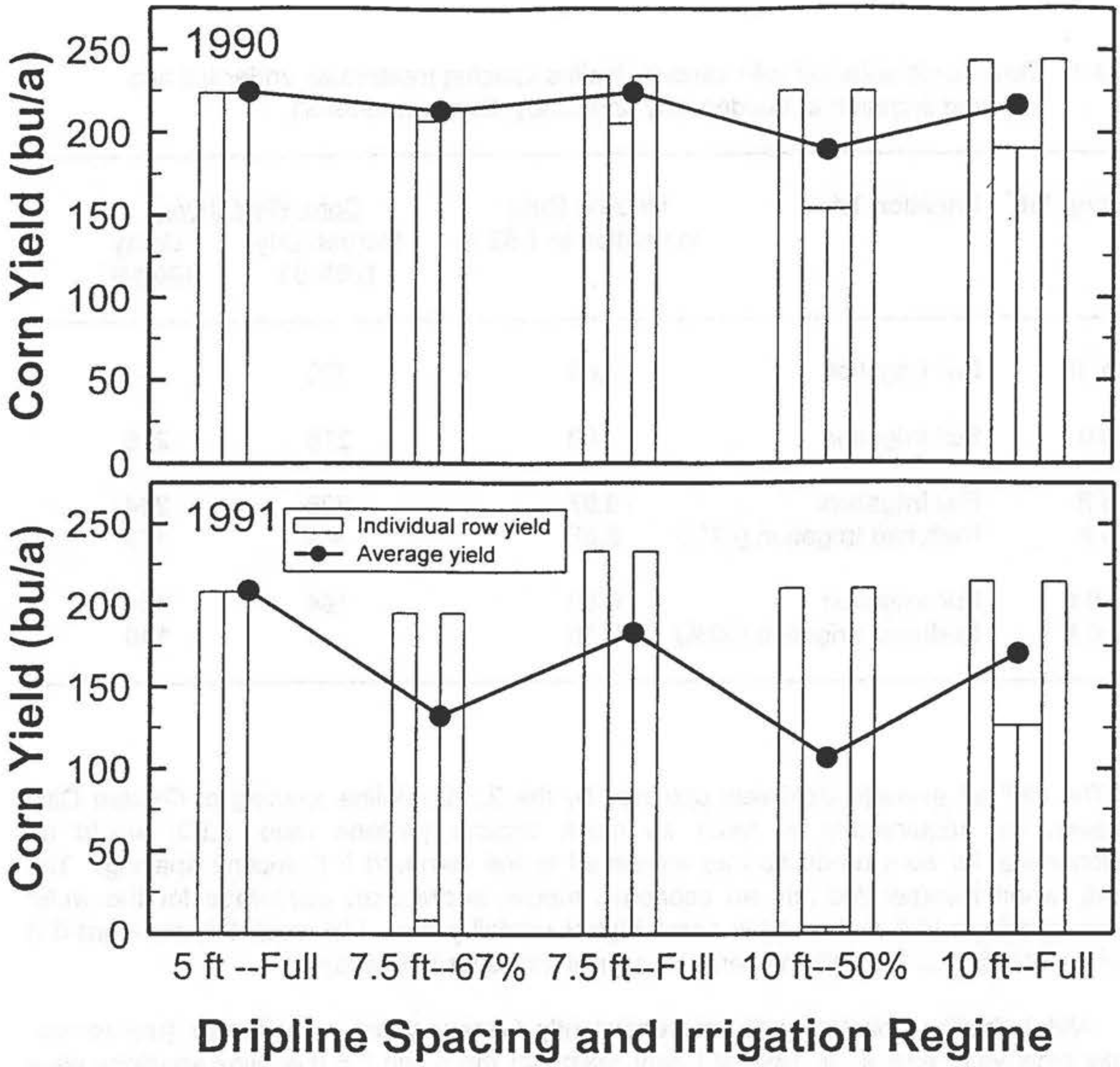

Figure 2. Corn yield as affected by dripline spacing and irrigation regime, Colby KS, 1990-91. Note: Bars represent the individual corn row yields between two adjacent driplines.

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

Frequency of Subsurface Drip Irrigation

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

Water Requirement of Subsurface Drip-Irrigated Corn

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

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

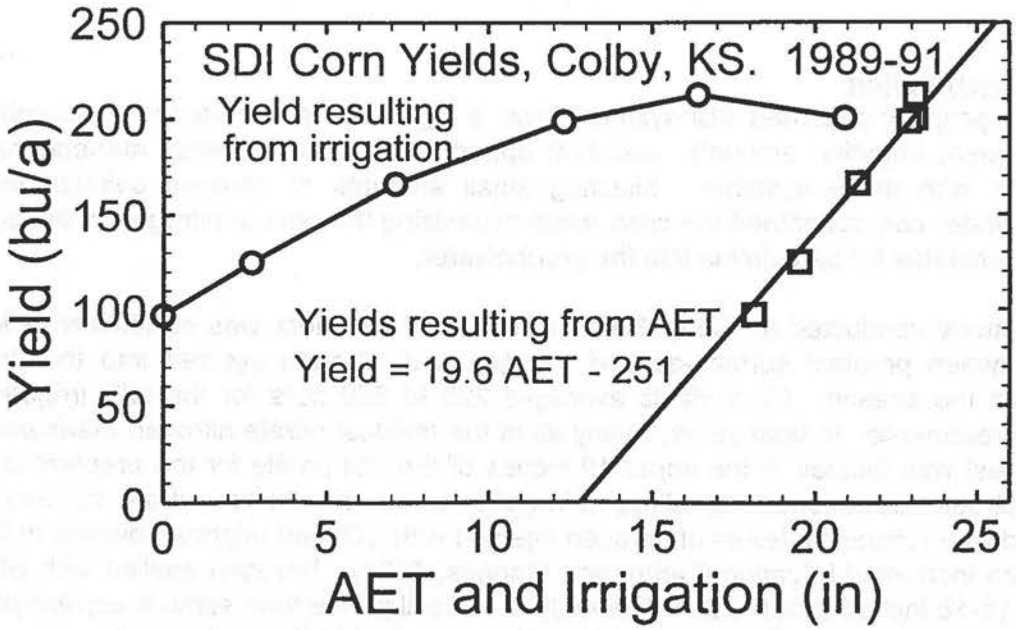

Figure 3. Corn yield as related to irrigation and calculated evapotranspiration (AET) in a SDI study, Colby, KS., 1989-1991.

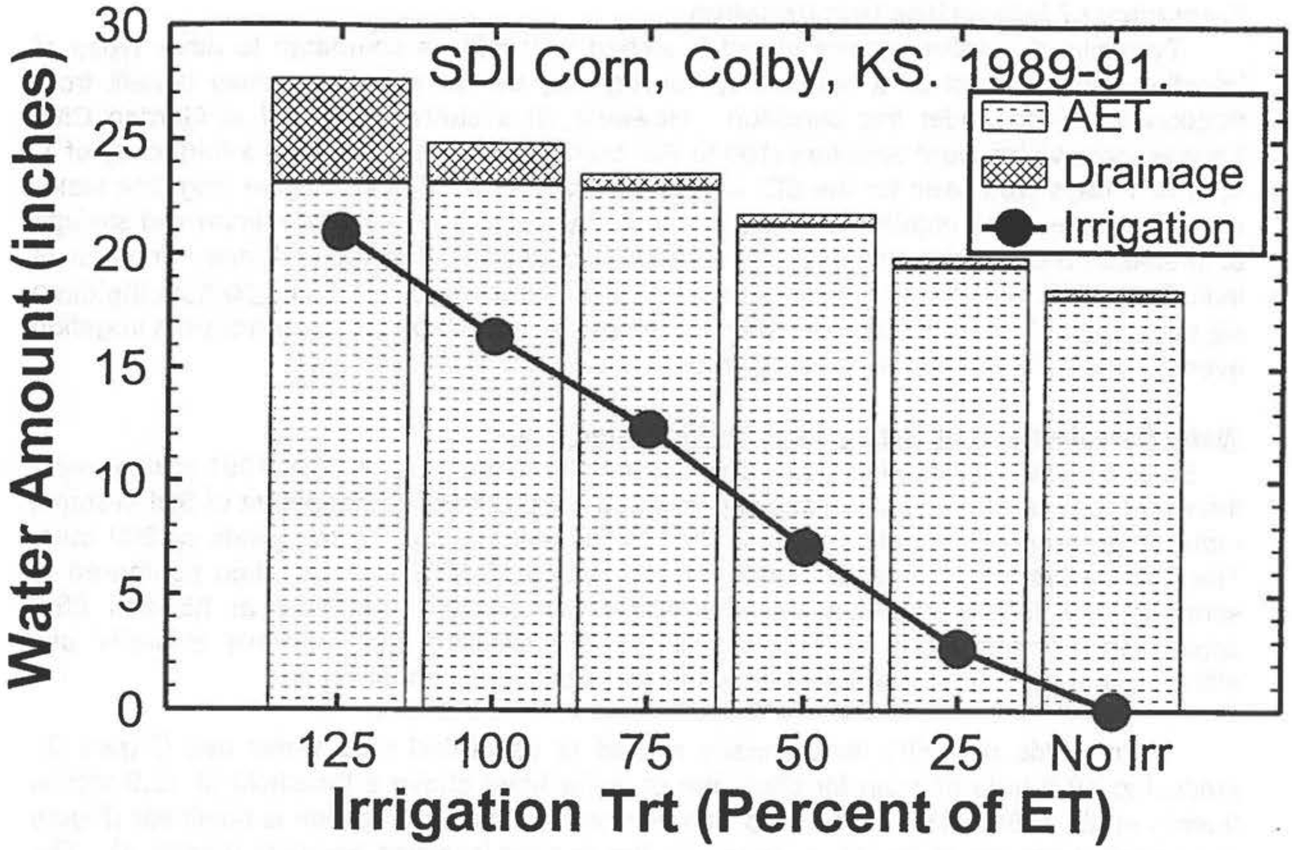

Figure 4. Calculated evapotranspiration (AET) and seasonal drainage as related to irrigation treatment in a SDI study, Colby, KS., 1989-1991.

Nitrogen Fertigation

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

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

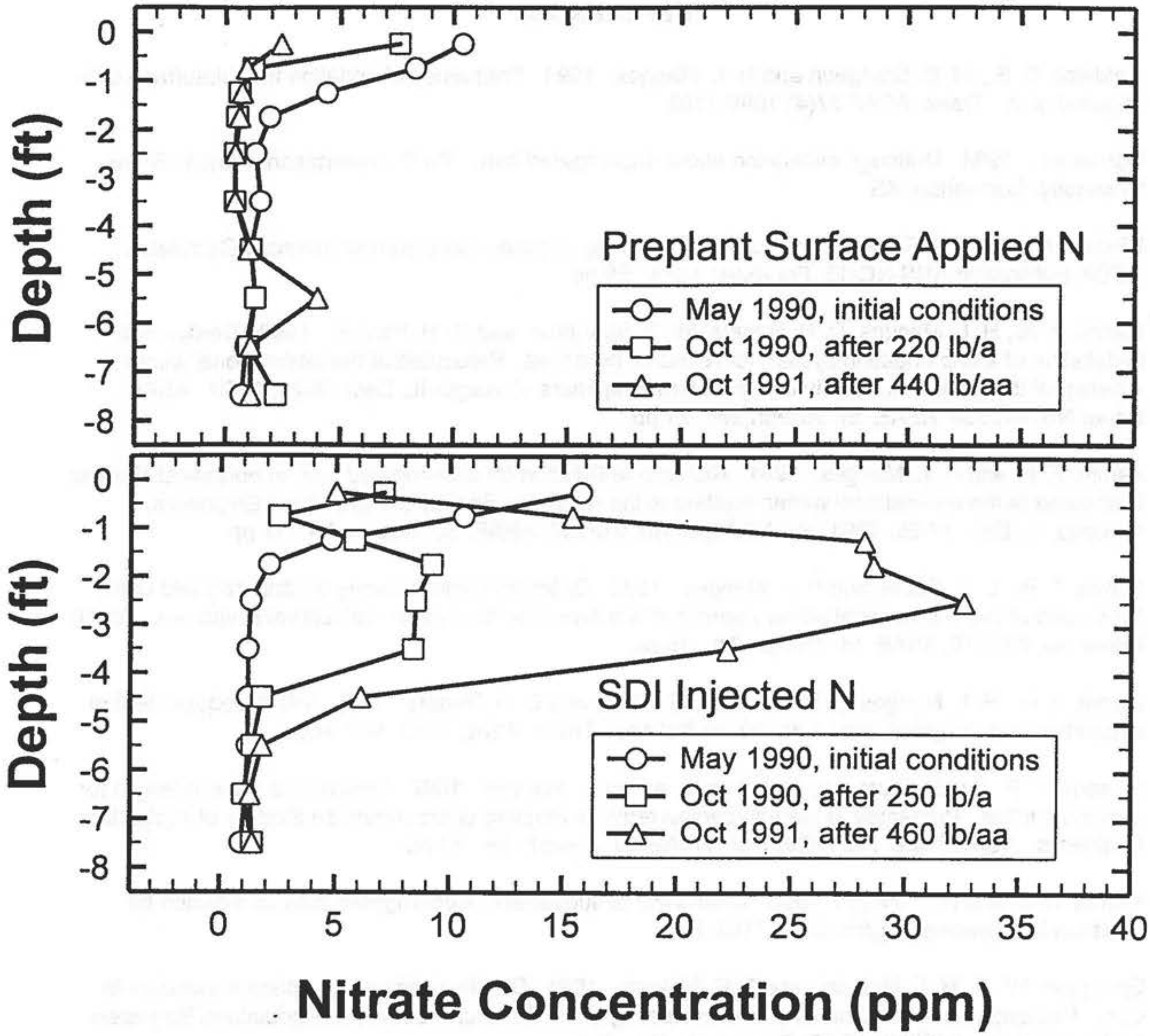

Figure 5. Nitrate concentrations in the soil profile for preplant surface-applied and SDI injected nitrogen treatments, Colby, Kansas, 1990-91. Data is for selected nitrogen fertilizer rate treatments with full irrigation (100% of AET).

CONCLUSIONS

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

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

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IRRIGATION SYSTEM ECONOMICS AS AFFECTED BY FIELD SIZE

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INTRODUCTION

Sprinkler irrigation systems have an economic advantage over subsurface drip irrigation (SDI) systems for fields where full size center pivots can be utilized. In these scenarios, center pivots gain important cost economies from spreading system investment costs over the maximum number of acres.

This paper considers a number of factors that affect the relative profitability of the irrigation systems. First, how are the cost economy advantages of center pivot systems over SDI systems affected as field size decreases and field shapes change? Important factors to consider are a) variation in irrigation system investment cost economies by field size and shape (i.e, the capital or fixed cost effects), b) potential differences in crop revenue for cropping systems that fully utilize all acres in irrigated crop enterprises as opposed to those that must include nonirrigated production, and c) differences in water application efficiencies for center pivot and SDI systems (i.e., the variable or operating cost effects).

This analysis is the assumes that a field is currently being flood irrigated, but is to be transformed into either a center pivot or SDI irrigation system. It is also assumed that the existing well is centrally located at the edge of the field, is fully depreciated out, but not yet in need of replacement. From this starting point, cost estimates for alternative irrigation systems together with Extension crop enterprise budgets for irrigated corn and summer fallow wheat in western Kansas will be used to project annual profitability for the alternative irrigation and cropping systems. An objective of this paper is to compare center pivot and SDI system costs per acre as field sizes and shapes change.

FACTORS AFFECTING THE CHOICE OF IRRIGATION SYSTEM

Center pivot irrigation systems have a cost advantage over SDI systems on large land tracts (i.e. 1/4 sections) where per acre investment costs can be lowered by spreading them out over a large number of acres. However, center pivot investment costs tend to be "chunky" or "sticky" as acreage decreases for less than 125 acre center pivots or for irregularly shaped fields. Some "sticky" center pivot cost factors may include the following items: the pivot pad, the underground pipe from the well to the pivot system, installation labor, generator and electric wiring, etc.

The expected life of an irrigation system is another concern. The center pivot is assumed to have a 20 year life, with a range of from 15 to 25 years. The SDI system is assumed to have a 10 year life, with a range of from 5 to 15 years. Life of the system has a major impact on profitability as the initial investment cost per acre is amortized out over the expected life of the system. This is especially critical for SDI systems, where uncertainty about expected system life can dramatically impact the costs a farmer is willing to assume in budget projections.

The replacement cost or salvage value of each system is another major consideration in this analysis. In these budgets, both systems are assumed to have 0% salvage value. This is a common assumption and practice in western Kansas. However, in some cases center pivots will have some salvage value after 20 years. For this analysis, it is assumed that at the end of 10 years, the full current cost of an SDI system will be incurred to renovate the old system, without consideration of inflation costs, etc.. More information is needed regarding the projected costs of renovateing, repairing, and/or replacing an existing SDI system with a new SDI system in the future.

Irrigation water application efficiency may effect the choice of irrigation system. In this study, it is assumed that SDI water applications are 10% more efficient than center pivot applications. Center pivot systems are assumed to apply 18 inches of water while SDI systems are assumed to apply 16 inches. Because of reduced water application, SDI systems will have lower fuel, oil, and electricity costs, and marginally lower repair and operating interest costs than center pivot systems.

There will also be revenue differences among center pivot and SDI-oriented cropping systems. The primary factor affecting relative profitability will be lower revenue produced from nonirrigated farmland in center pivot corners as compared to higher revenue on these same acres in SDI systems. A major issue for farmers considering center pivot versus SDI will be which cropping system produces the highest net revenue across all acres - including both dryland and irrigated crop enterprises.

A number of other factors are not accounted for in this analysis. Lower production and income risk for the irrigated as opposed to nonirrigated cropland in the center pivot system is not studied here, but is a factor that would be expected to favor the 100% acreage coverage available with SDI systems. There are potential irrigation water application uniformity benefits for SDI as opposed to center pivot irrigation systems which are not dealt with here. Also, with declining water tables in some local areas of western Kansas, and therefore limited irrigation time horizons, the increased efficiency of SDI systems could potentially reduce the rate of water use, lengthen the life of the local aquifer, and better match the expected investment time horizon of the irrigated enterprise in areas where declines are most precipitous.

In summary, fixed or capital costs per acre will be affected by initial irrigation system costs as well as the expected life of the system and the cost to renovate it (especially for SDI systems). Variable operating costs per acre will be affected by the irrigation water application efficiencies of each system. Cropping system gross and net revenues will be affected by the number of nonirrigated acres necessary in center pivot cropping systems relative to fully irrigated SDI cropping systems.

ANALYSIS

Framework Used for Analyzing Irrigation System Economics

An enterprise budget framework is used to analyze the profitability of the alternative irrigation system investments for each field size scenario. Projected crop production system net returns to land and management are calculated as follows.

First, gross revenue is projected for each field size scenario for both a center pivot-oriented cropping system (with a combination of irrigated corn and non-irrigated summer fallow wheat acreage) and an SDI-oriented cropping system (with 100% irrigated corn acreage). Differences in crop returns will show the effect upon total and net revenue per acre of combined irrigated / dryland cropping systems for center pivots and irrigated acres-only cropping systems for SDI. Then, variable costs of production for the

Table 2, Subsurface Drip Irrigation System Capital Requirements for Alternative Field Sizes

Item	$/Unit	Subsurface Drip Irrigation System Scenarios					
		Base (O)	A	B	C	D	E
Number of SDI Acres		160 acres	127 acres	95 acres	64 acres	32 acres	80 acres
8" Mainline pipe	$1.30/ft	$6,006	$2,293	$1,763	$1,086	$761	
6" Lateral / submain pipe	$0.75/ft	1,020	3,528	3,051	1,253	439	$3,565
4" Flushlines	$0.60/ft	7,104	5,645	3,661	2,004	1,416	3,168
Drip tape	$0.03/ft	41,976	33,193	24,829	16,733	8,354	20,909
Drip tape connectors	$0.75/ft	3,168	2,820	1,829	1,002	708	1,584
8x8x8x8 Cross	$200/cross	400					
8x8x6x6 Cross	$200/cross		200				
8x8x8 T	$340/T						
8x6 Reducing coupling	$25/coupling	100	25		25	25	
8x8x6 T	$340/T			340			
8" Pressure control valve	$440/valve	1760				440	
6x6x6 T	$145/T		145	145	145		435
6" Endcaps	$45/cap		180	270	90	45	180
6" Valves	$375/valve		1,500	1,125			
6" Elbows	$95/elbow			95			190
6"x 4" Reducing couplings	$20/cplg	80					
4" Elbows	$30/elbow	360	480	300	240	120	480
4" Valves	$375/valve						1,500
4" x 2" Reducing bushing	$18/bushng	216	288	180	144	72	288
2" Plugs	$6/plug	72	96	60	48	24	96
Air vents	$25/vent	350	350	350	350	150	350
PVC glue		250	250	200	200	200	250
Trenching	$0.68/ft	10,322	9,196	6,455	3,975	2,400	5,384
Filter		4,500	4,500	4,500	4,500	4,500	2,200
Pressure gauges	$20/gauge	360	360	280	280	140	360
Producer labor (installation)	$8/labor hr	7,200	6,376	4,360	2,384	1,240	3,792
Tractor use (installation)	$7/tractor hr	966	833	595	378	217	525
Total Costs		$86,210	$72,258	$54,388	$34,836	$21,251	$45,606
System Costs / Irrigated Acre		$539 /acre	$569 /acre	$573 /acre	$544 /acre	$664 /acre	$570 /acre

In Table 2, the results in the last row for Total Cost Per Acre do not indicate the same degree of diminishing cost economies (i.e., higher capital cost per acre for smaller fields) in this example for SDI irrigation systems as exists for center pivot systems (see Table 1). Although initial SDI irrigation system costs begin at a higher level than pivot systems for the full 160 acre scenario O ($539 per acre for SDI vs $326 per acre for pivot systems), per acre investment costs do not dramatically change as field size diminishes. Investment cost for an 80 acre SDI system ($570 per acre) are comparable to those for a Wiper pivot system ($532 per acre, Table 1).

The per acre capital requirements for SDI systems in Table 2 imply a higher degree of proportional adjustability to changes in field size than do center pivot irrigation system costs. As field size diminishes in these scenarios, the SDI system costs are more nearly stable on a per acre basis than are those for center pivot irrigation systems.

Crop Enterprise Budget Framework

The differing enterprise acreages, variable costs and fixed costs of each cropping system are examined within the framework of two KSU Farm Management crop enterprise budgets. The net revenue from irrigated acres is estimated using a 190 bushel per acre yield scenario, together with prices and costs for irrigated corn production in western Kansas as represented in the 1996 version of MF-585, Center Pivot Irrigated Corn (Table 3). The net revenue from non-irrigated acres is estimated using the 40 bushel per acre yield scenario from MF-257, Summer Fallow Wheat in Western Kansas (Table 4).

Tables 3 and 4 represent the irrigated corn and dryland wheat cost-return budgets used in scenario O (Full Circle Center Pivot). The only changes for other pivot irrigation scenarios would occur due to different pivot investment costs per acre (lines 21-22 in Table 3). These changes would correspond with the total investment costs per acre indicated in the last column in Table 1. For comparative SDI scenarios, the pivot investment costs would differ from lines 21-22 in Table 3 in accordance with results in the last row of Table 2. An additional change for SDI would occur in the variable cost of irrigation water applied (lines 7, 9, and 15). Note that no opportunity interest costs to land, real estate taxes, or land rental costs are included in these budgets. Also, no management charges are included. Therefore, the net returns calculated represent net returns to both land and management.

Table 3. Irrigated Corn Cost-Returns Budget for Western Kansas (125 Acre Center Pivot)

VARIABLE COSTS	Income/Expense
1. Labor (2.35 hrs/acre × $9.00 /hr)	$21.15
2. Seed (32 lbs/acre × $1.05 /lb)	33.60
3. Herbicide	33.12
4. Insecticide	41.57
5. Fertilizer (Anhydrous: 180 lbs × $0.17 /lb = $30.60)	46.20
(N Dry: 10 lbs × $0.30 /lb = $3.00)	
(Phosphorous: 45 lbs × $0.28 /lb = $12.60)	
6. Fuel and Oil - Crop	10.45
7. Fuel and Oil - Pumping (18 inches water applied × $2.71/inch)	48.78
8. Crop Machinery Repairs & Maintenance	23.20
9. Irrigation Equipment Repairs & Maintenance (18 inches water applied × $0.30/in)	5.40
10. Crop Insurance	6.75
11. Drying ($0.10/bu × 190 bu/acre)	19.00
12. Custom Hire	0.00
13. Crop Consulting	6.50
14. Miscellaneous	7.00
15. Interest on 1/2 Variable Cost (10% operating interest)	15.14
A. Total Variable Costs (Excluding management charges or returns)	$317.85 /ac
FIXED COSTS	
16. Real Estate Taxes (($650/acre land + $290/a well) × 0.5%), but 0% here	$0.00
17. Interest on Land and Well (($650/ac land + $290/a well) × 6%), but 0% here	0.00
18. Rent for Rented Land	0.00
19. Depreciation on Crop Machinery ($236/a investment, 35% salvage value of $83/a, 10 yr straightline depreciation)	15.34
20. Interest on Crop Machinery (10% interest on average machinery value: (($236 + $83) ÷ 2) × 10%)	15.93
21. Depreciation on Irrigation Equipment (Power+Motor = $50/a, 7 yrs, 0% slvg; Irrigation System = $326/a, 20 years, 0% slvg; 0% deprec for Well)	23.46
22. Interest on Irrigation Equipment & Well (10% int. on avg irrig. equip. value: (($50 + $326) ÷ 2) × 10%)	18.81
23. Insurance on Crop & Irrigation Equipment (0.25% × ($236 + $50 + $326))	1.53
B. Total Fixed Costs (Excluding land opportunity interest or rent)	$75.07 /ac
C. TOTAL COSTS (Excluding land and management costs: A + B)	$398.38 /ac
D. Yield	190 bu /ac
E. Price Per Bushel	$2.50 /bu
F. Production Flexibility Contract Payments (Irrigated land in Thomas Co., KS)	$35.00 /ac
G. RETURNS / acre ((D x E) + F)	$510.00 /ac
H. Returns Over Variable Costs / acre (Excluding management cost: G - A)	$192.15 /ac
I. RETURNS OVER TOTAL COSTS / acre (Excluding land and management costs: G - C)	$111.62 /ac

Table 4. Summer Fallow Wheat Cost-Return Budget for Western Kansas

VARIABLE COSTS	Income/Expense
1. Labor (1.2 hrs/acre × \$9.00/hr)	\$10.80
2. Seed (50 lbs/acre × \$0.20/lb)	10.00
3. Herbicide	14.82
4. Insecticide	0.00
5. Fertilizer (Anhydrous: 40 lbs × \$0.17/lb = \$6.80)	15.20
(Phosphorous: 30 lbs × \$0.28 /lb = \$8.40)	
6. Fuel and Oil	6.95
7. Crop Machinery Repairs & Maintenance	10.92
8. Crop Insurance	4.89
9. Drying	0.00
10. Custom Hire	0.00
11. Crop Consulting	6.50
12. Miscellaneous	5.00
13. Interest on 1/2 Variable Cost (10% operating interest)	3.93
A. Total Variable Costs (Excluding returns to management)	\$82.51 /ac
FIXED COSTS	
14. Real Estate Taxes ((\$525 /a land ÷ 2 year rotation) × 0.5%), but 0% here	\$0.00
15. Interest on Land ((\$525 /a land ÷ 2 year rotation) × 6%), but 0% here	0.00
16. Rent for Rented Land	0.00
17. Depreciation on Crop Machinery (\$190/a investment, 35% salvage value of \$67 /a, 10 yr straightline depreciation)	12.35
18. Interest on Crop Machinery (10% interest on average machinery value: ((\$190 + \$67) ÷ 2) × 10%)	12.83
19. Insurance on Crop Machinery (0.25% × \$190)	0.48
B. Total Fixed Costs (Excluding land opportunity interest or rent)	\$25.65 /ac
C. TOTAL COSTS (Excluding land and management: A + B)	\$108.16 /ac
D. Yield	40 bu /ac
E. Price Per Bushel	\$3.65 /bu
F. Production Flexibility Contract Payments (Nonirrigated land in Thomas Co., KS)	\$10.00 /ac
G. RETURNS / acre ((D x E) + F)	\$156.00 /ac
H. Returns Over Variable Costs / acre (Excluding management cost: G - A)	\$73.49 /ac
I. RETURNS OVER TOTAL COSTS / acre (Excluding land and management costs: G - C)	\$47.84 /ac

RESULTS

Table 5 indicates that pivot-oriented cropping systems have a marked net revenue advantage over SDI cropping systems for large fields, such as for the 160 and 127 acre fields in Scenarios O and A. The net return advantage of the pivot cropping system over the SDI cropping system in scenario O is $22 per acre over the total cropland acreage as indicated in the "Total Returns / Acre (Pivot – SDI)" row in the Net Returns section of Table 5. As total acreage decreases to 127 acres in Scenario A, and 95 acres in Scenario B, the pivot-oriented cropping system maintains a positive but diminishing net returns advantage over the SDI-oriented system (i.e., from $23 to $17 per acre, respectively). As field size diminishes further to 64 acres in Scenario E and 32 acres in Scenario D, SDI-oriented cropping systems gain in relative net returns. In Scenario E, returns are essentially equal ($1 per acre advantage for pivot-oriented cropping systems), while in Scenario D, the SDI-oriented cropping system has an $11 per acre advantage. In the 80 acre Wiper Scenario, the pivot-oriented cropping system has a $12 per acre advantage over the SDI-oriented cropping system.

The inclusion of nonirrigated acreage in the pivot-oriented cropping system brought about large differences in total income and expenses. However, when examined on a per cropland acre basis, this income effect was fairly consistent across scenarios. In Table 5, the "Total Income" row in the Crop Income section shows the differences in gross revenue brought about by including lower revenue nonirrigated acreage in the pivot cropping system. As indicated in the "Income Difference per acre (SDI – Pivot)" row, the total income difference remains consistently in the $86-$95 per cropland acre range across all acreage scenarios.

Another factor affecting relative net returns of these cropping systems are differences in fixed costs as indicated in the "Fixed Costs" row of the Crop Cost section in Table 5. The pivot-oriented cropping systems consistently had lower total fixed costs than the SDI systems. However, the fixed cost advantage of pivot-oriented systems diminished as field size decreased. These differences are driven by the irrigation system investment cost differences specified in Tables 1 and 2, and are the major reason why the SDI systems become relatively more profitable as field size decreases.

A third factor affecting relative net returns are differences in variable costs caused both by inclusion of lower variable cost nonirrigated acres in the cropping system, and by improved water application efficiencies with SDI systems. The total variable cost differences between the cropping systems, as indicated in the "Variable Costs" and "VC /ac Difference" row of the Crop Cost section of Table 5. These differences remain consistently in the $49 to $54 per cropland acre range across all the field size scenarios, supporting the idea that while variable cost differences are an important factor, they are not the major determinant of differences in profitability between these two alternative cropping-systems. The major determining factor in net revenue differences in this analysis are the differences in fixed investment costs between the center pivot and the SDI irrigation systems.

Sensitivity Of Results To Changes in Key Factors

Sensitivity analysis were used to determine how sensitive these results were to changes in certain key economic factors. Changes caused in the projected net returns of scenarios O (160 acres) and D (32 acres), and the Wiper scenario (80 acres) were calculated in Tables 6, 7, and 8. These scenarios were selected because they represent the extremes in field sizes (scenarios O and D) and a difference in pivot point location (Wiper scenario).

Table 6 shows the effect of price and yield variation on projected returns. Across all scenarios, as corn yields or prices decline the pivot-oriented system becomes relatively more profitable than the SDI system. For Scenario O, the pivot-oriented cropping system has markedly higher net returns than the SDI-oriented cropping system over most of the range of yields and prices presented in Table 6. However, at high yield

Table 5. Summary Income Comparison Across Crop Acreage and Irrigation System Scenarios

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

and price combinations, the SDI system becomes economically competitive. This is the case for the Wiper Scenario as well, where the pivot-oriented cropping system remains more profitable in all cases except for high yield and price combinations. However, the differences in net returns between the cropping systems are less for the 80 acre Wiper scenario than for the 160 acre full circle base Scenario O. In small acreage Scenario D, the SDI cropping system has higher net returns except low yield and price combinations.

Table 7 shows the effect of variation in the life of both the pivot and SDI irrigation systems on projected returns. Across all field size scenarios, changes in the life of the SDI system has a more dramatic effect on net returns than do changes in the life of the center pivot system. While changes in the life of a pivot from 15 to 25 years increases projected net returns per acre by $7 to $20, increases in SDI system life from 5 to 15 years increases projected net returns per acre by approximately $70 to $90. The impact is most pronounced in Scenario D where a increasing SDI irrigation system life from 5 to 10 years while holding pivot life constant at 20 years leads to $66 per acre change in net returns, causing SDI to be more profitable than pivot irrigation. In the Wiper Scenario a 15 year SDI irrigation system life gives an SDI-oriented cropping system a net returns advantage over a corresponding pivot-oriented cropping system with either a 15, 20, or 25 year life.

Table 8 shows the effect of variation in SDI driptape installation cost on projected returns from the two cropping systems. Drip tape costs have a major impact on SDI irrigation systems costs. But for both Scenario O and Scenario D, drip tape cost variation has little effect on whether the pivot-oriented and SDI-oriented cropping systems are more profitable. The pivot cropping system remains the most profitable system for Scenario O and the Wiper Scenario all across the range of drip tape costs considered. However, at the lowest drip tape cost considered in the Wiper Scenario (i.e., $0.02 per foot), the pivot profitability advantage is only $3 per acre. For Scenario D, the SDI cropping system remains the most profitable system across all except the highest cost drip tape alternative (i.e., $0.04 per foot).

Table 6. Effect of Price and Yield Variation on Projected Returns for Center Pivot and SDI Cropping Systems (Pivot Minus SDI Cropping System Returns / Acre)

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

* 190 bushel per acre irrigated corn yields and $2.50 cash price are the standard assumptions in the preceding analysis.

Table 7. Effect of Variation in Irrigation System Life on Projected Returns for Center Pivot and SDI Cropping Systems (Pivot Minus SDI Cropping System Returns / Acre)

Base Scenario O: (125 ac. Pivot + 35 ac. W-F) vs 160 ac. SDI			
	Center Pivot Life		
SDI System Life	15 years	20 years*	25 years
5 years	$72	$76	$78
10 years*	$18	$22*	$25
15 years	($0)	($4)	($7)
"Wiper" Scenario: (64 ac. Pivot + 16 ac. W-F) vs 80 ac. SDI			
SDI System Life	15 years	20 years*	25 years
5 years	$62	$69	$73
10 years*	$5	$12*	$16
15 years	($14)	($7)	($3)
Scenario D: (25 ac. Pivot + 7 ac. W-F) vs 32 ac. SDI			
SDI System Life	15 years	20 years*	25 years
5 years	$43	$55	$63
10 years*	($24)	($11)*	($3)
15 years	($46)	($33)	($26)

* 20 year center pivot life and 10 year SDI system life are standard assumptions in the preceding analysis

Table 8. Effect of Variation in SDI Drip Tape Cost on Projected Returns for Center Pivot and SDI Cropping Systems (Pivot Minus SDI Cropping System Returns / Acre)

Base Scenario O: (125 ac Pivot + 35 ac W-F) vs 160 ac. SDI		
SDI Drip Tape Cost Per Foot	SDI System Costs Per Acre	CP – SDI Net Returns Per Acre
$0.02	$452	$9
$0.025	$495	$15
$0.03*	$539*	$22*
$0.035	$583	$29
$0.04	$626	$35
"Wiper" Scenario: (64 ac Pivot + 16 ac W-F) vs 80 ac. SDI		
SDI Drip Tape Cost Per Foot	SDI System Costs Per Acre	CP – SDI Net Returns Per Acre
$0.02	$483	$3
$0.025	$527	$7
$0.03*	$570*	$12*
$0.035	$614	$16
$0.04	$657	$21
Scenario D: (25 ac. Pivot + 7 ac. W-F) vs 32 ac. SDI		
SDI Drip Tape Cost Per Foot	SDI System Costs Per Acre	CP – SDI Net Returns Per Acre
$0.02	$577	($24)
$0.025	$621	($18)
$0.03*	$664*	($11)*
$0.035	$708	($4)
$0.04	$751	$2

* The assumed drip tape cost in the preceding analysis is $0.03 per foot.

CONCLUSIONS

This cropping system-oriented analysis demonstrates a distinct net returns advantage for pivot-oriented cropping systems over SDI-oriented cropping systems for fields of 160 acres. However, as field size decreases, the net returns advantage of pivot-oriented cropping systems over SDI systems declines to the point where SDI cropping systems returns are projected to be greater.

The primary factor affecting relative profitability is the per acre investment cost required to establish either the pivot or SDI irrigation systems on the size of field in question. SDI systems have greater proportional adjustability than do center pivot irrigation systems. This is illustrated by the steady, if not dramatic, increase in per acre pivot irrigation system costs as field size declines in comparison to the relatively steady per acre cost levels for SDI irrigation system investments. Differences in variable and fixed costs, revenue, and net returns between the irrigated corn and the nonirrigated summer fallow wheat enterprises impact the comparison of overall net revenue between the pivot and SDI-oriented cropping systems, resulting in lower gross revenue and variable costs for the pivot-oriented cropping systems. However, relative capital or fixed costs between pivots and SDI are the key determinants of the relative profitability of these two cropping systems.

These results are most sensitive to assumptions about the life of the SDI irrigation system. Although assumed to have a 10 year life, if an SDI system only lasts 5 years, it essentially becomes non-competitive in a net returns sense with pivot-oriented cropping systems across all the field size scenarios. Conversely, if an SDI system has a 15 year life, it becomes more profitable in all scenarios. Changes in prices and yields have a major impact on the projected net returns of the cropping systems. However, such price and yield changes do not have a noticeable impact on the choice among alternative irrigation systems based on comparative net returns results. To a lessor extent, changes in drip tape costs affect the relative profitability of pivot versus SDI-oriented cropping systems, but do have a major effect on the profitability of SDI-oriented cropping systems.

Future research should be oriented toward developing reliable information on the longevity of SDI irrigation systems and on the costs of renovating them. Also, further work is needed to document the potential water use efficiencies and uniform application benefits for SDI irrigation systems relative to center pivot irrigation systems. Additionally, an analysis is needed about how, in western Kansas, increased production risk and lower projected income for nonirrigated acres relative to irrigated acres may influence a crop producer's willingness to select irrigation systems that provide higher proportions of irrigated acreage for a given piece of farmland. From a farm financial management perspective, potential implications of placing a center pivot on a flood irrigated field may have land valuation and tax management impacts that should be understood. Finally, ongoing efforts are needed in the design and development of efficient, low cost center pivot and SDI irrigation systems.

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