Irrigation Training Toolbox
Irrigation System Design

Selecting Sprinkler Packages For Center Pivots

National Employee Development Center
Natural Resources Conservation Service
Fort Worth, Texas
October 1996

LESSON PLAN

LESSON	**SELECTING SPRINKLER PACKAGES FOR CENTER PIVOTS**
DEVELOPED BY	William Kranz, Extension Irrigation Specialist
OBJECTIVES	Participants will: Understand the operating characteristics of center pivot irrigation systems Identify the important features of different sprinkler packages Utilize CPNOZZLE computer program to match sprinkler package with soils and field conditions Conduct a center pivot water application uniformity test
REFERENCES	Nebraska Irrigation Guide, UNL NebGuides, CPNOZZLE Users manual
TRAINING AIDS	Course outline, CPNOZZLE Program, Sprinkler demonstration model, Figures referenced it the text are copied on the reverse side of the page.
ARRANGEMENTS	Field trip to conduct uniformity test and view sprinkler model, and computer access.
TIME REQUIRED	2.5-3 hours

COMMENTS **OUTLINE OF INSTRUCTION**

I. DEFINITIONS

Application Rate--is the rate water is applied to a given field area expressed in units of depth per time (inches/hour).

Canopy Evaporation Loss-- is that water that evaporates directly off the crop leaves during and immediately following an irrigation event.

Center Pivot--is an automated irrigation system consisting of a line of sprinklers rotating about a pivot point and supported by a series of self-propelled towers. Water is supplied at the pivot point and flows outward toward individual sprinklers.

Christiansen's Uniformity Coefficient--is a measure of the uniformity of irrigation water application. The average depth of irrigation water infiltrated minus the average absolute deviation from the average depth is divided by the average depth infiltrated.

Depression Storage--is water stored in surface depressions and does not contribute to runoff.

Detention Storage--is water applied in excess of the soil infiltration rate and depression storage. Most eventually runs off but some may infiltrate or evaporate.

Distribution Uniformity--is a measure of the uniformity of irrigation water application to a field area.

Water Distribution Pattern--is the water application depth to distance from the sprinkler or center pivot relationship (see Figure 1).

Elevation Head--is the relative energy possessed by a fluid due to its position when compared to a datum. Elevation head is positive for sprinklers below the datum and negative for sprinklers above the datum.

Electric Load Control-- occurs when the electrical supplier interrupts power to selected systems so that the peak power requirement can be controlled. In trade for the power interruptions, operators receive a cut in power cost commensurate with the level of control. Each power supplier has somewhat different methods of determining which systems are to be controlled on a given day. The types of control fit into three main categories:

Anytime control-authorizes the power supplier to interrupt the power supply for up to six 12-hour periods during a week. Field data show that shut down time seldom is above 42 hours per week though 72 hours of control are possible.

Two day control-allows power to be interrupted for two 12-hour periods during a week.

One day control-allows power to be interrupted for one 12-hour period during a week.

Flow Control Nozzle--is a device used to maintain constant flow rate out of a sprinkler regardless of sprinkler elevation changes (See NebGuide G88-888).

Gross System Capacity--is the amount of water that must be pumped to insure that crop water use requirements are satisfied. Gross system capacity is the net system capacity divided by the water application efficiency.

Interception--is the portion of the irrigation water applied by the system that is caught by vegetation and thus prevented from reaching the soil surface.

Irrigation Efficiency (IE)-- is the ratio of the average depth of irrigation water that is beneficially used to the average depth of irrigation water applied.

$$IE = \frac{(\text{Irrigation - Runoff - Deep Percolation - Evaporation Loss})}{\text{Irrigation}}$$

Irrigation Frequency--is the average time between the start times for successive irrigation events.

Low Energy-Precision Application (LEPA)--is a complete sprinkler irrigation concept that includes mounting sprinkler heads 12-18" from the soil surface, planting the crop in a circle, and creating and maintaining storage basins to store water applied with the system.

Nozzle--is a discharge opening of a sprinkler head used to control volume, distribution pattern and droplet size. Impact sprinklers

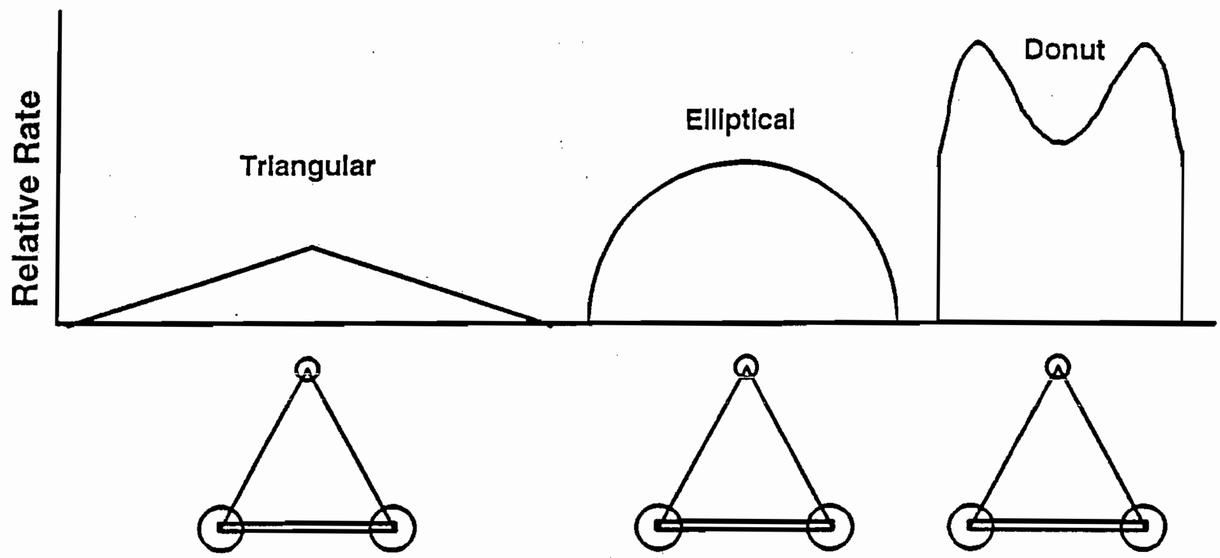


Figure 1. Typical water distribution patterns for sprinkler systems relative to the center pivot structure.

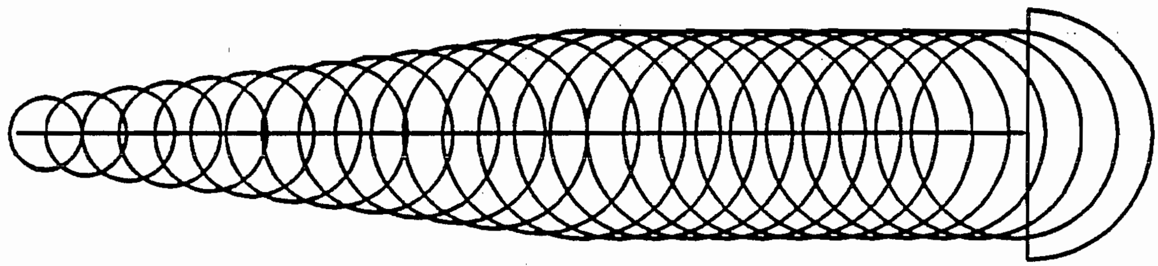


Figure 2. Sprinkler arrangement for constant spacing package.

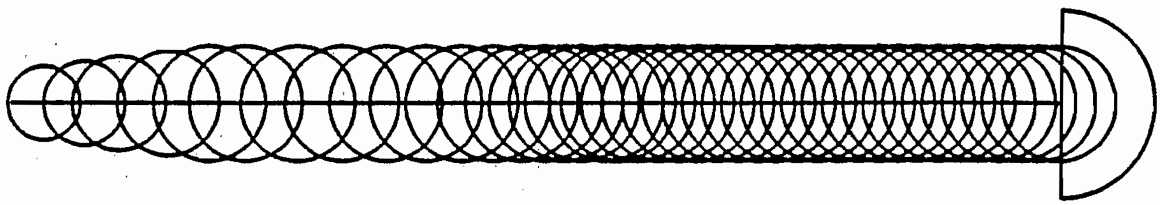


Figure 3. Sprinkler arrangement for variable spacing package.

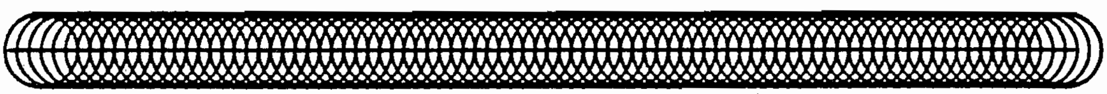


Figure 4. Sprinkler arrangement for narrow or spray nozzle package.

are equipped with a nozzle(s) and an impact arm. Spray heads are equipped only with nozzles.

Peak Application Rate--is the maximum water application rate applied by the sprinkler package (See Figure 1). For impact sprinklers the peak application rate is located at the pivot lateral. For some spray packages, the peak application rate occurs some distance (60-70% of the wetted radius) away from the lateral.

Potential Runoff--is the water applied in excess of the soil infiltration rate. Therefore, it is the water that could potentially run off the field if soil depression storage is unavailable. The runoff potential is typically greatest at the outer end of the pivot lateral and increases with decreasing sprinkler wetted radius or increasing system capacity.

Pressure Regulating Device--is a pressure decreasing device used to maintain constant pressure at the base of the sprinkler regardless of elevation changes (see NebGuide G88-888). For the device to function properly, the pipeline pressure must be 5 to 10 psi greater than the desired sprinkler pressure or pressure rating of the regulator.

Pump Output Curve--is a graphical representation of the change in pumping head resulting from a change in pumping rate. Use the pump curve for retrofitting a system with reduced pressure sprinklers or when determining the water application characteristics of the pivot.

Sprinkler Package-- the group of sprinklers installed on the irrigation system. Sprinklers may be mounted above the pivot pipeline, on the side of the pipeline or suspended on drop tubes below the pipeline. The package can have the following distributions among individual sprinklers:

> **Constant Spacing** (Figure 2)--sprinklers a placed at constant spacings along the system length but the size of the sprinkler is increased to account for the change in area irrigated. Thus, the wetted radius of the sprinkler tends to increase with distance from the pivot point.
>
> **Variable Spacing** (Figure 3)--Sprinklers are all the same size but the spacing between the sprinklers decreases with distance from the pivot point to account for the change in area irrigated. The wetted radius is similar for the entire system.

Narrow Spacing (Figure 4)--is used for spray nozzles. Different size nozzle openings are needed to compensate for differences in irrigated area but the spacing is narrower along the system due to their lower wetted radius.

Net System Capacity--is the amount of water that must be supplied to the crop or soil to replace crop water use or ET. The amount of water supplied should consider the estimated downtime, rainfall probability, water application efficiency, and soil water holding capacity (see NebGuide G89-932).

Water Application Efficiency (WAE)-- is the ratio of the average depth of irrigation water that infiltrates and is stored in the rootzone to the average depth of water applied. The average application efficiency of a center pivot is often assumed to be 80% in lieu of accurate field estimates.

System Wetted Radius (R_s)-- Wetted radius of the irrigation system taken as the distance from the pivot point to approximately 80% of the throw radius of the end sprinkler.

Sprinkler Wetted Radius (R_{sp})--Wetted radius of the sprinkler package. If the wetted radius of the sprinkler changes with the system length, the specific position on the system must be evaluated.

Wind Drift Loss-- is water transported away from the target location by wind. Drift loss often includes evaporation losses while the water droplet is in the air. Drift losses are affected by water droplet size, trajectory of the water stream, and environmental conditions.

II. BACKGROUND

Sprinkler irrigation systems and specifically center pivots have been adapted to operate on many different soils, to traverse extremely variable terrain, and to provide water to meet a number of different management objectives. A center pivot is merely an irrigation pipeline that rotates about the pivot point. Water is supplied to the system at the pivot point. Thus, the circular rotation results in two very unique and important design parameters.

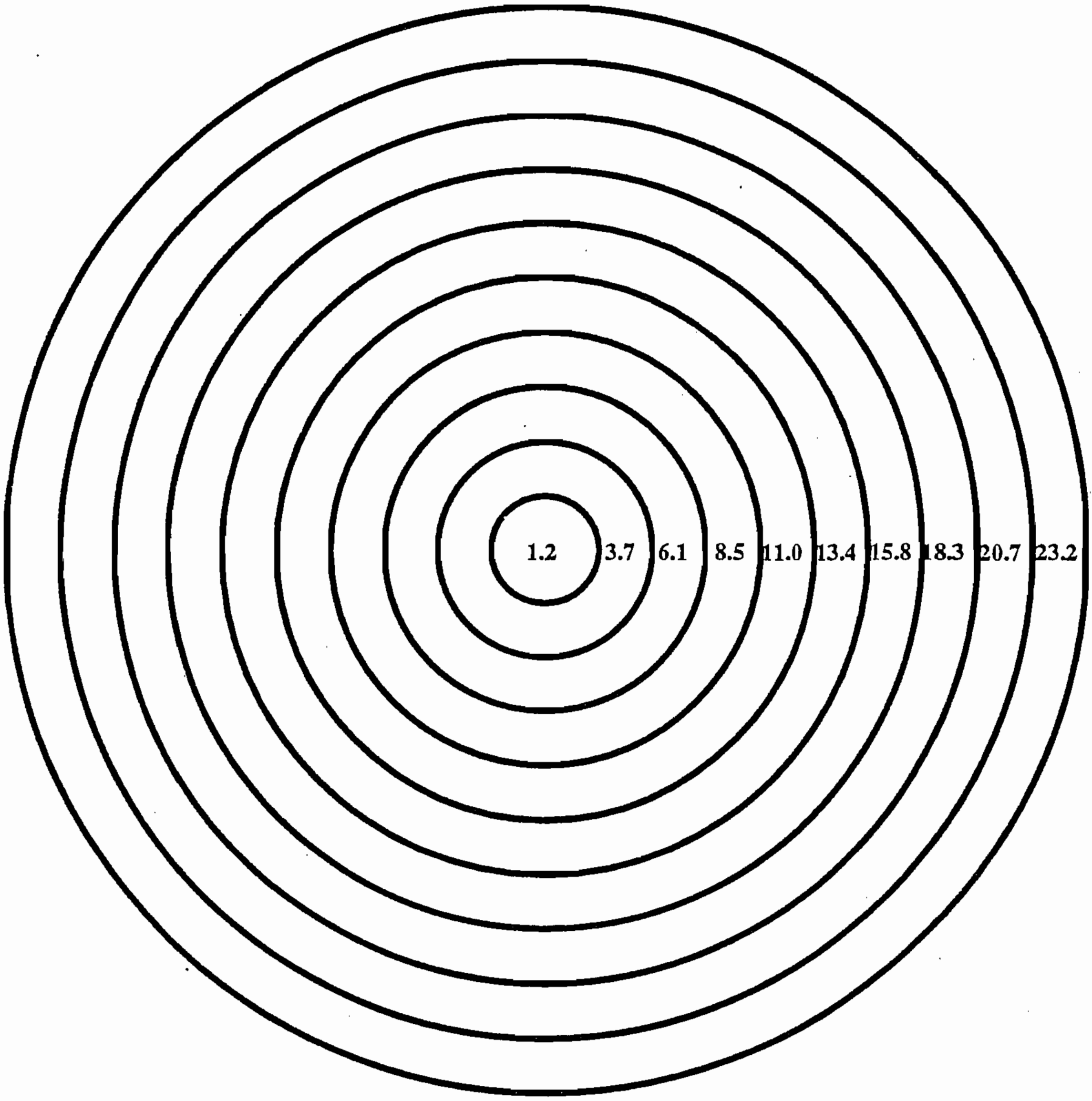


Figure 5. Acres irrigated by each 10% of the system length.

A center pivot making a complete circle irrigates an area equal to the area of a circle with a radius equal to the length of the system pipeline. Thus, the irrigated area increases as the system length squared. Figure 5 presents the area irrigated by each 10% of the system length. For a 1300 foot system, the first 130 feet of system length would irrigate 1.2 acres and the last 130 feet would irrigate 21 acres. This means that the last 130 feet of the system accounts for approximately 15% of the irrigated area.

Due to the radial distribution of water and the increase in the number of acres irrigated per foot, each additional foot of the irrigation pipeline must be supplied with a greater amount of water. Consequently, the water application rate of the center pivot system increases in a direct relation to the distance from the pivot point.

In the design process, due to the need for greater amounts of water at the outer end, the friction loss in the pipeline causes the greatest pipeline pressure to be at the pivot point and the least at the outer end. This is opposite that required for the size of sprinkler installed on the system.

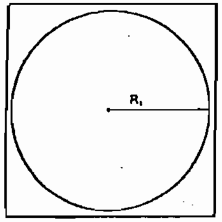
As the previous paragraph indicates, the process of making a sprinkler package selection involves a number of sometimes conflicting criteria. The operator is confronted with an array of different sprinkler types, many that are capable of performing adequately. However, the operator should make a selection based upon accurate field based information and careful consideration of the interaction among several factors. The information that will be discussed in this section will cover most of the important factors and how you can assist the operator in collecting the data. NebGuides and a computer program will be used to demonstrate the importance of having information that is accurate.

Let's begin by doing some hand calculations to identify the sort of information that should be recorded during a field visit. The data sheet included in the Nebraska Irrigation Guide provides a means of recording this information (See form No. NE-ENG-59). Record as much of this information as possible while at the field site.

Determine area irrigated by a center pivot:

As you become familar with more field installations it will become clear that few systems are alike. Figure 6 presents

STANDARD ELEC/WATER DRIVE

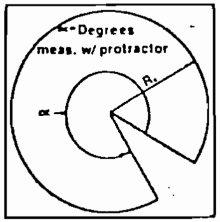


FULL CIRCLE W/O E.G.

$$\text{Area} = \frac{R^2\ \pi}{43560}$$

$$= \frac{1294 \times 1294 \times 3.1416}{43560}$$

$= 120.7$ Acres

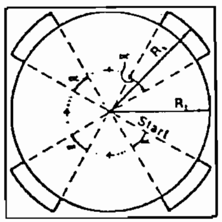


PART CIRCLE W/O E.G.

$$\text{Area} = \left(\frac{R^2\pi}{43560}\right) \times \left(\frac{\alpha}{360}\right)$$

$$= \frac{1294 \times 1294 \times 3.1416}{43560} \times \frac{330}{360}$$

$= 110$ Acres

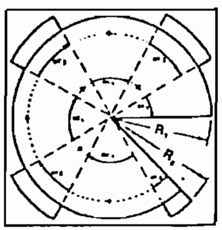


FULL CIRCLE WITH E.G.

$$\text{Area} = \left[\left(\frac{R_1^2\ \pi}{43560}\right) \times \left(\frac{360-\sum\alpha}{360}\right)\right] + \left[\left(\frac{R_2^2\ \pi}{43560}\right) \times \left(\frac{\alpha}{360}\right)\right]$$

$$= \left[\frac{1294 \times 1294 \times 3.1416}{43560} \times \frac{240}{360}\right] + \left[\frac{1364 \times 1364 \times 3.1416}{43560} \times \frac{120}{360}\right]$$

$= 125.2$ Acres



PART CIRCLE WITH E.G.

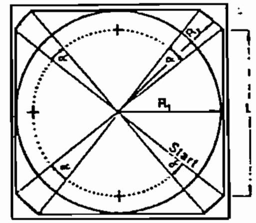
$$\text{Area} = \left[\left(\frac{R_1^2\ \pi}{43560}\right) \times \left(\frac{\sum\alpha_1}{360}\right)\right] + \left[\left(\frac{R_2^2\ \pi}{43560}\right) \times \left(\frac{\sum\alpha_2}{360}\right)\right]$$

$$= \left[\frac{1294 \times 1294 \times 3.1416}{43560} \times \frac{225}{360}\right] + \left[\frac{1364 \times 1364 \times 3.1416}{43560} \times \frac{210}{360}\right]$$

$= 109.55$ Acres

CORNER SYSTEMS

FULL CIRCLE - 4 CORNERS

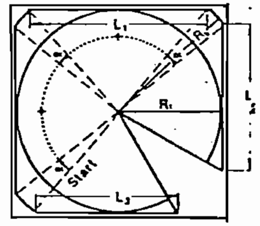


$$\text{Area} = \left[\frac{4\left(\frac{R_1\ L}{2}\right)}{43560}\right] + \left[\frac{R_2^2\ \pi}{43560} \times \frac{\sum\alpha}{360}\right]$$

$$= \left[\frac{4\left(\frac{1268 \times 2100}{2}\right)}{43560}\right] + \left[\frac{1581 \times 1581 \times 3.1416}{43560} \times \frac{56}{360}\right]$$

$= 160$ Acres

PART CIRCLE



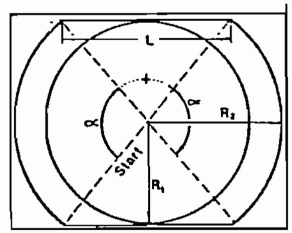
$$\text{Area} = \left[\frac{2\left(\frac{R_1L_1}{2}\right) + \left(\frac{R_1L_2}{2}\right) + \left(\frac{R_1L_3}{2}\right)}{43560}\right] + \left[\frac{R_2^2\ \pi}{43560} \times \frac{\sum\alpha}{360}\right]$$

$$= \left[\frac{2\left(\frac{1268 \times 2100}{2}\right) + \left(\frac{1268 \times 1800}{2}\right) + \left(\frac{1268 \times 1900}{2}\right)}{43560}\right] +$$

$$\left[\frac{1581 \times 1581 \times 3.1416}{43560} \times \frac{48}{360}\right]$$

$= 138$ Acres

RECTANGULAR FIELD

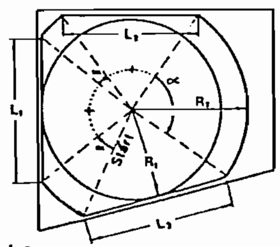


$$\text{Area} = \left[\frac{2\left(\frac{R_1L}{2}\right)}{43560}\right] + \left(\frac{R_2^2\ \pi}{43560} \times \frac{\sum\alpha}{360}\right)$$

$$= \left[\frac{2\left(\frac{1268 \times 2050}{2}\right)}{43560}\right] + \left(\frac{1581 \times 1581 \times 3.1416}{43560}\right) \times \left(\frac{220}{360}\right)$$

$= 169.77$ Acres

ODD SHAPE FIELD



As Required

$$\text{Area} = \left[\frac{\left(\frac{R_1L_1}{2}\right) + \left(\frac{R_1L_2}{2}\right) + \left(\frac{R_1L_3}{2}\right)}{43560}\right] + \left[\frac{R_2^2\ \pi}{43650} \times \frac{\sum\alpha}{360}\right]$$

$$= \left[\frac{\left(\frac{1268 \times 1650}{2}\right) + \left(\frac{1268 \times 1700}{2}\right) + \left(\frac{1268 \times 1600}{2}\right)}{43560}\right] +$$

$$\left[\frac{1581 \times 1581 \times 3.1416}{43560} \times \frac{133}{360}\right]$$

$= 138.7$ Acres

NOTE: Lengths & Angles must be measured in the field or from maps, etc./The above dimensions & angles are only typical examples.

Figure 684-5

(from SCS Nebraska Irrigation Guide, Section 684)

Figure 6. Formulas for calculating the irrigated acreage for various center pivot field layouts.

formulas for estimating the irrigated area of fields with corner systems, end guns that run intermittently, systems making a part circle and other field orientations. This figure is out of the Irrigation Guide, Section 684. Note the requirement to estimate the arc lengths for the end gun and corner system operations. Figure 7 is a graphical representation of how the irrigated acreage increases with system length for a full circle pivot. The acreage increases proportional to the system wetted radius squared (R_s^2).

Though the sprinkler system typically applies water beyond the end of the pivot lateral, the effective wetted radius varies as the system makes a revolution due to atmospheric conditions. The most significant atmospheric condition is the difference in wind direction and speed. Therefore, it is advisable to determine the irrigated acreage using a system length equal to the pivot length plus approximately 70% of the wetted radius of the last sprinkler or end gun. Beyond that point the water application pattern is often distorted and can be less than the crop water use rate.

--To calculate the area of a circle or part circle

Equation 1:

$$A = \pi \times R_s^2 \times P_r / 43560$$

where:

- A = irrigated area, acres
- π = constant, 3.1416
- R_s = wetted radius of the system, ft.
- P_r = portion of a full circle, decimal

EXAMPLE PROBLEM; **Given:** R_s = 1300 feet and P_r = 1.0

$$A = (3.1416) \times (1300)^2 \times 1.0 / 43560$$
$$A = 121.9 \text{ acres}$$

Determine flow rate required:

The flow rate required in Nebraska is virtually the same for all crops. The reason is that although the duration and timing of a specific crop's peak water use rate varies, the system must be capable of meeting that demand. Figure 8 shows the impact of peak water use on system flow rate. The pump flow rate determines how other factors will impact system operation. For

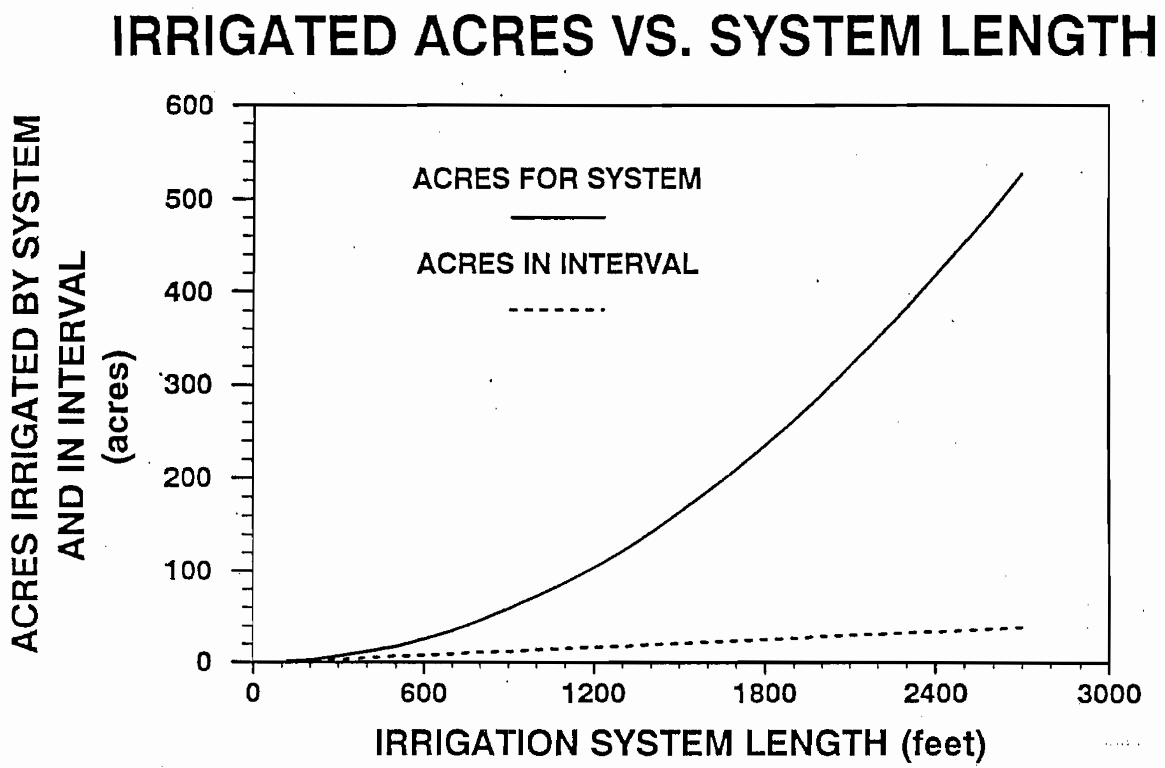


Figure 7. Increase in acres irrigated by the system and within the previous 100 foot interval of the system.

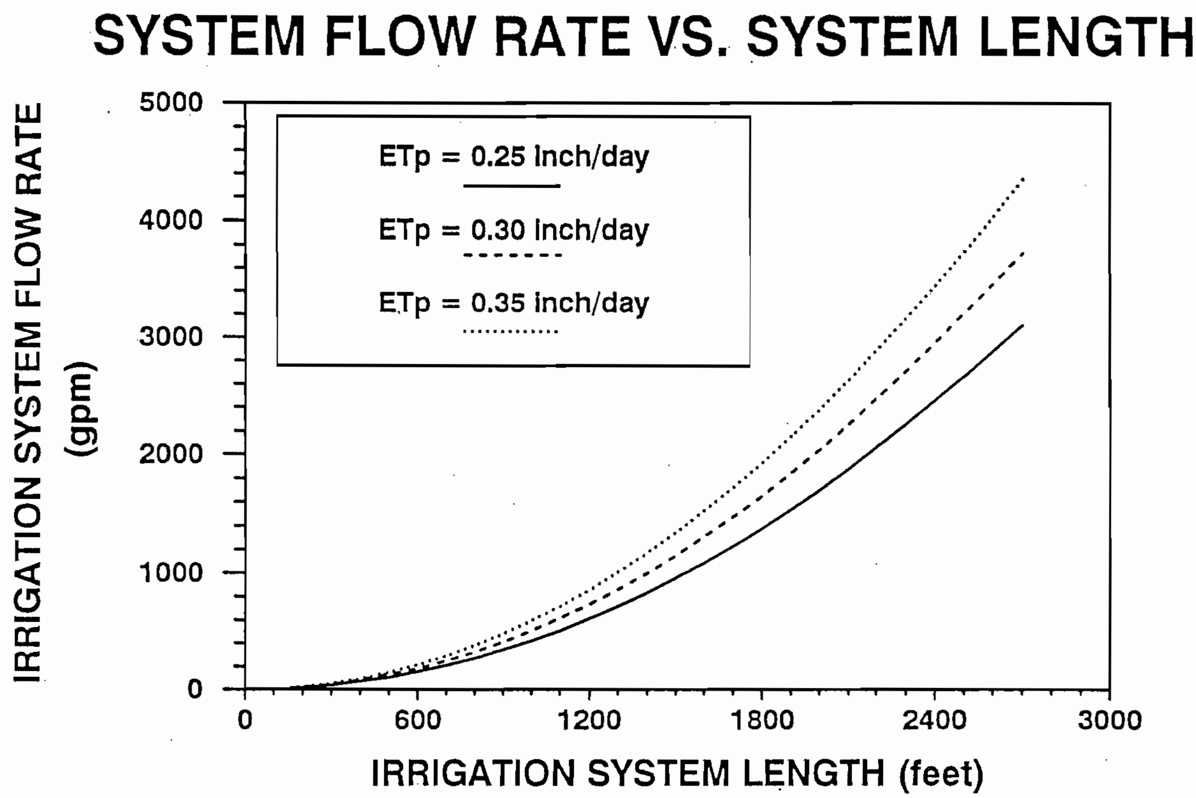


Figure 8. Impact of potential ET estimate on system flow rate for different irrigation system lengths.

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example, if the flow rate is greater than necessary, the peak water application rate of the system may cause runoff to occur toward the outer end of the system. The pump flow rate also determines the size of sprinkler head required at each location.

When developing an estimate of the system flow rate there are three additional considerations: a) environmental factors; b) system downtime for electric load management; and c) system down time for repair and maintenance activities. The most important environmental considerations are the likelihood of rainfall and the peak ET rate of the crop. The information presented in NebGuide G89-932 is based upon an estimation of how often the soil available water content was depleted below the 50% available level or the point where stress might occur. Data from different locations in the state were evaluated. The analysis identified areas where the system flow rate should be increased to account for lower annual precipitation and greater peak ET rates. Our best estimate is that systems located west of the 20 inch per year annual precipitation line should have greater flow rates. A state map is presented in the NebGuide.

Equation 2:

$$Q_p = (K \times ET_p \times A \times t_i) / (E_i \times t_f)$$

where:

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

EXAMPLE PROBLEM:

Given: $ET_p = 0.35$ in/day; $A = 121.9$ acres; $t_i = 3$ days; $E_i = 0.85$; $t_f = 3$ days

$Q_p = (18.9 \times 0.35 \times 121.9 \times 3)/(0.85 \times 3)$
$Q_p = 949$ gallons per minute

This example was based on the knowledge that the system, if operated continuously, could supply sufficient water for any crop during any portion of the growing season. However, if we use the water stored in the soil profile as a reservoir to supplement

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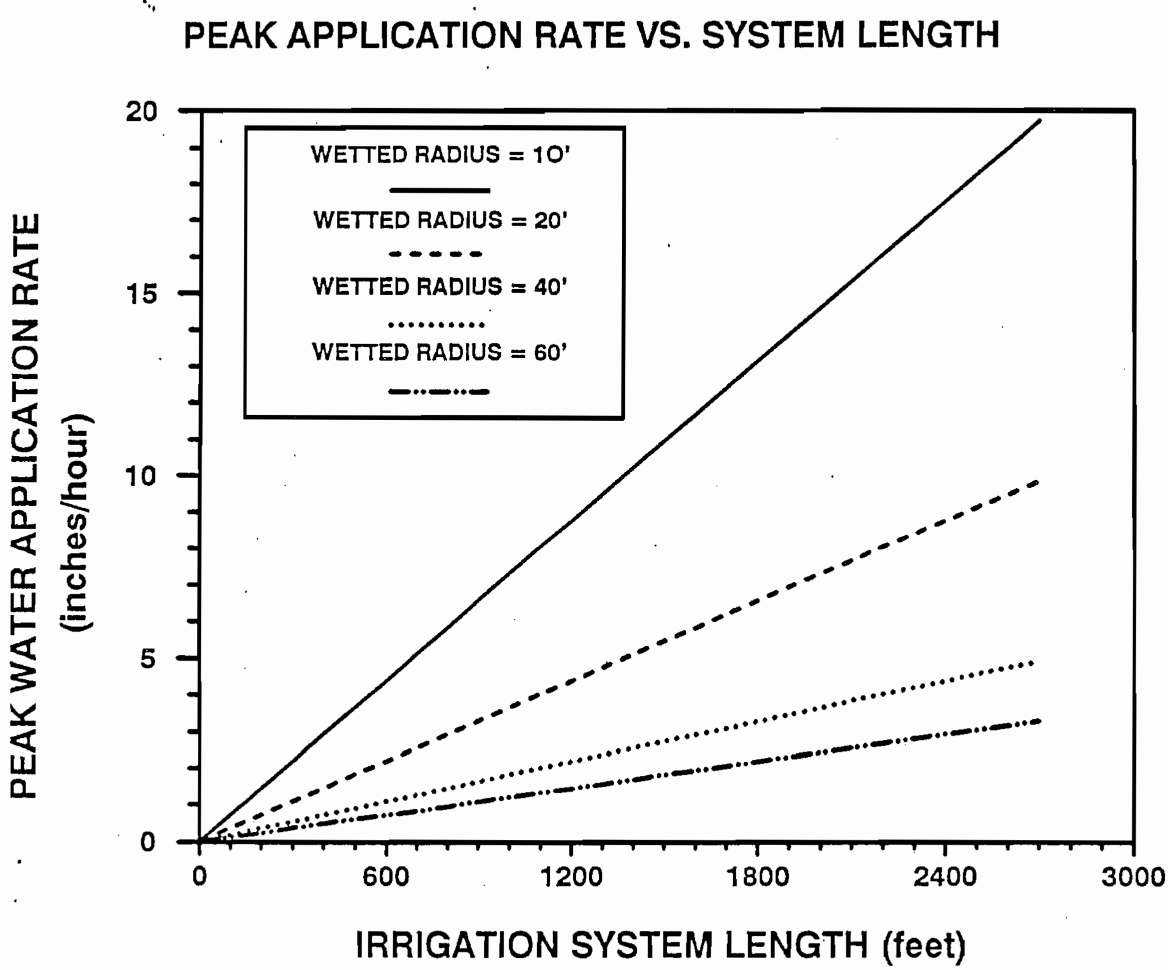


Figure 9. Impact of sprinkler wetted radius on peak water application rate when designed for 0.35"/day ETp.

the irrigation system during peak ET periods, the required flow rate could be decreased. For example, using Table I in NebGuide G89-932, if the system is located in Region 2 and the soil type is a silt loam w/silt loam subsoil, the estimated minimum flow rate for continuous operation would be 565 gpm. The potential savings derived by reducing the flow rate from 950 gpm to 565 gpm is very significant. The pump, gear drive, motor, pipeline diameter and pumping lift would all be lower and thus the main components could be downsized. However, there are reasons to adjust the pump flow rate upward.

If the system is powered by an electric motor, the operator typically has the opportunity to trade some length of electric service control for a reduction in power costs. Each 12 hours of control time (or system shutdown) per week, requires an increase in flow rate of 8.3%. Thus, if the operator agreed to be controlled two days per week, the flow rate should be increased from 565 gpm to 660 gpm. Table II in the NebGuide provides multipliers for each 12 hours of downtime.

The other source of downtime is the need to perform repair and/or maintenance. Again, each 12 hours of downtime per week should result in corresponding increase in the design system flow rate. If the estimated downtime is less than 12 hours, say 5 hours per week, the flow rate should be increased to 585 gpm (565 x [1 + (5/144)] = 585 gpm).

Both of the adjustments made for downtime assume that the system will always be available on Sunday. If repairs and maintenance are preformed on Sunday, the required increase in flow rate would be less because there are 168 hours in 7 days.

Determine peak water application rate:

One of the most important criteria for selecting a sprinkler package involves the peak water application rate for the system. Three factors affect the peak application rate--system length, system flow rate and sprinkler wetted radius. Since we have established by previous examples that the irrigated was 121.9 ac, the system length was 1300', and the flow rate was 949 gpm, the only factor remaining is the wetted radius of the sprinkler. Figure 9 shows how the peak water application rate increases with system length and wetted radius of the sprinkler.

PEAK APPLICATION RATES AT 1300 FEET

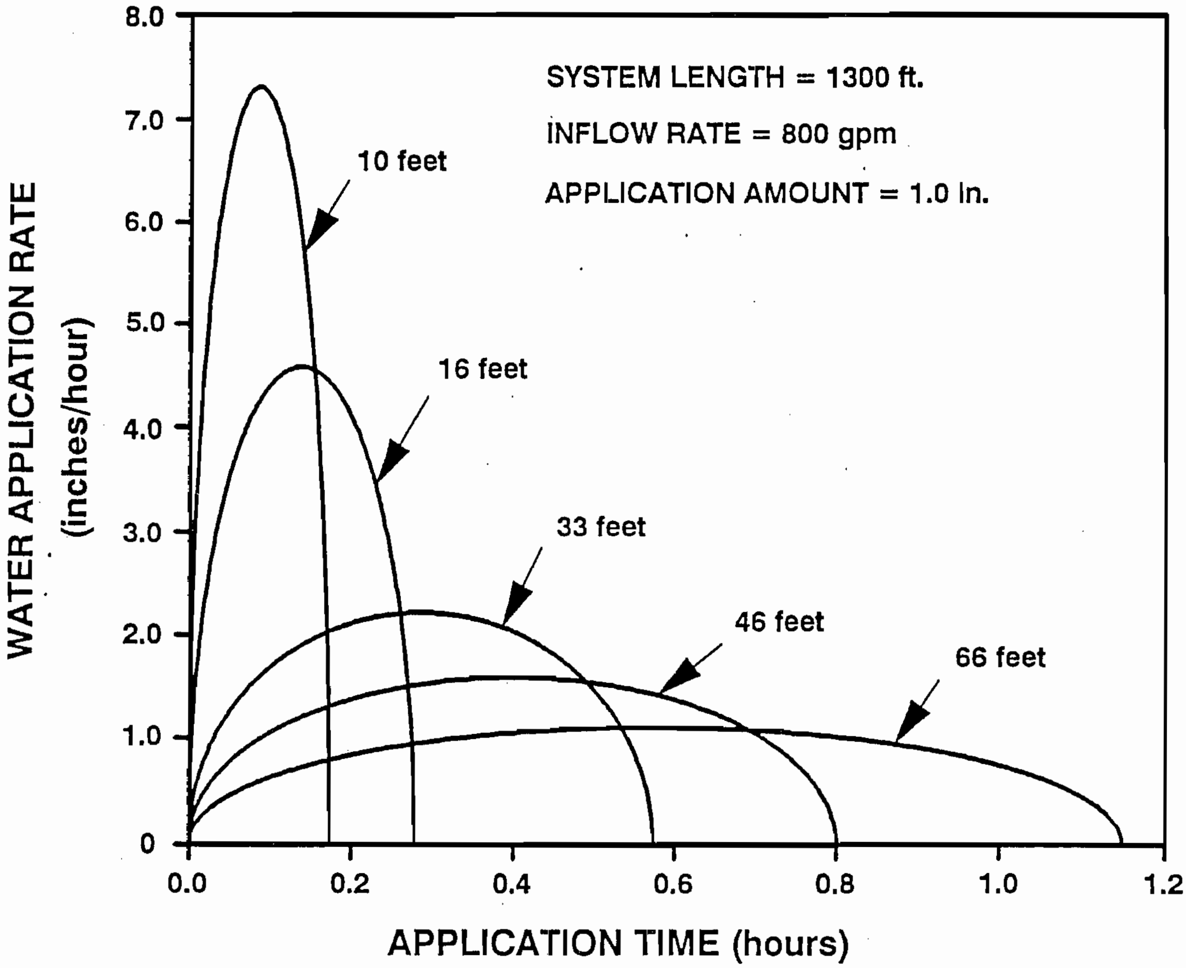


Figure 10. Water application patterns for sprinklers with wetted radii of 10', 20', 40', and 60' for an application of 1" of water.

Quite often an elliptical shaped water distribution pattern is used to simulate an application pattern (see Figure 1). With that assumption, Figure 10 shows the impact of the sprinkler wetted radius on the water application pattern of the sprinkler. Note that the application time is decreased with every decrease in wetted radius. Thus, the consequence of reducing the wetted radius (and thus the operating pressure) of the sprinkler is that the same amount of water must infiltrate into the soil during a shorter period of time. Selecting a sprinkler package with a peak water application rate that is too great could cause runoff to develop. The key is to select a sprinkler package such that the peak water application rate does not exceed the soil infiltration rate. Later we will use a computer program that overlays an elliptical water application pattern over a transformed water infiltration curve using the SCS Soil Intake Family Curves.

Equation 3:

$I_p \quad = (K_2 \times Q_p) / (R_s \times R_{sp})$

where:

K_2 = constant, 122.5
Q_p = irrigation system flow rate, gpm
R_s = irrigation system wetted radius,ft.
R_{sp} = wetted radius of sprinklers, ft.
I_p = peak water application rate,in/hr.

EXAMPLE PROBLEM:

Given: Q_p = 949 gpm; R_s = 1300 ft.; R_{sp} = 30 ft.

$I_p \quad = (122.5 \times 949) / (1300 \times 30)$
$I_p \quad = 2.98$ in/hr

Determine revolution time:

Each center pivot is likely to require a different length of time to make a revolution. This is true despite a system being the same length and the timer being set the same. The reason is that every field has different topography, and soils, no two are exactly alike. If the drive wheels slip while going uphill, the distance traveled for a given time period is less than when no slip occurs. In addition, it is quite difficult to set different systems at precisely the same speed. For these reasons, the speed of travel should be determined for each system. In fact, the speed of travel should be determined for a series of speed settings so that a table can be developed. Some producers may have a speed of travel table mounted in the pivot control box.

The speed of travel (for a given setting) may change with position in the field and with the time of the year. As was mentioned in the previous paragraph, wheel slip will decrease travel speed in hilly areas. If the drive wheels cause ruts in the field, wheel slip may increase during the season. Conversely, the system will travel slightly faster when going downhill because gravity is acting to force the system down the hill.

For special operations like chemigation, the tabular values are often not accurate enough. Travel speeds should be recorded periodically during the growing season and at various positions of the field.

If the timer is set to 100% the end tower drive wheels should turn continuously. However, a timer setting less than 100% causes the end tower to cycle on and off. To determine the approximate 'on time', take the timer setting, divide by 100 and multiply by 60 seconds per minute. In other words, the timer setting is the percent of one minute that the end drive wheels will turn/move.

The procedure for measuring system travel speed is quite simple. First, measure the distance from the pivot point to the center of the end tower drive wheel. Start the system and let the travel speed become consistent (approximately 1 hour). This is particularly important for lower speed settings. Equipped with a 100' measuring tape, a stop watch, and two flags proceed to the outer most tower. From here two procedures should be followed.

When the timer is set to 100%, set a flag adjacent to the axle of the foward drive wheel of the outer most tower and start the stop watch as you set the flag. Let the system run for at least 10 minutes. Then set a second flag adjacent to the axle of the same drive wheel and stop timing as you set the flag. In this procedure we are assuming that the wheel is moving continuously. If the drive wheels stop or cycle on and off, a slightly different procedure is more accurate.

When the timer is set to less than 100%, the end tower will cycle on and off. Thus, the flags should be set at the same point in the on/off cycle. For example, set the first flag adjacent to the axle of the foward drive wheel and start the stopwatch when the end tower begins to move. Let the system run for a least 10 minutes. Set a second flag adjacent to the axle of the same drive wheel and stop the stopwatch when the tower begins to move.

The accuracy of the speed of travel measurement is critical when estimating the revolution time of the system. Consequently, the longer the system is allowed to run and the more locations in the field a travel speed measurement is recorded, the more accurate the revolution time estimate will be.

Equation 4:

$T_r = (2 \times \pi \times L_e) / (S_t \times 60)$

where:

T_r = system revolution time, hours
π = constant, 3.1416
L_e = length pivot to end tower, ft.
S_t = system speed of travel, ft/hr

EXAMPLE PROBLEM:

Given: $L_e = 1250$ ft; $S_t = 3$ ft/min

$T_r = (2 \times 3.1416 \times 1250) / (3 \times 60)$
$T_r = 43.6$ hours per revolution

Determine water applied per revolution:

Once the irrigated acres, revolution time, and flow rate have been determined for the system, the calculation of the water application depth per revolution is easy. Just enter the data into equation 5. The water applied at different travel speeds can be calculated simply by changing the irrigation time per event or revolution time.

Equation 5:

$$I_d = (K_3 \times Q_p \times t_f) / A$$

where:

I_d = depth applied per revolution, in.
K_3 = constant, 0.053
Q_p = irrigation system flow rate, gpm
t_f = irrigation time per event, days
A = irrigated area, acres

EXAMPLE PROBLEM:

Given: $Q_p = 949$ gpm; $t_f = 3$ days; $A = 121.9$ acres

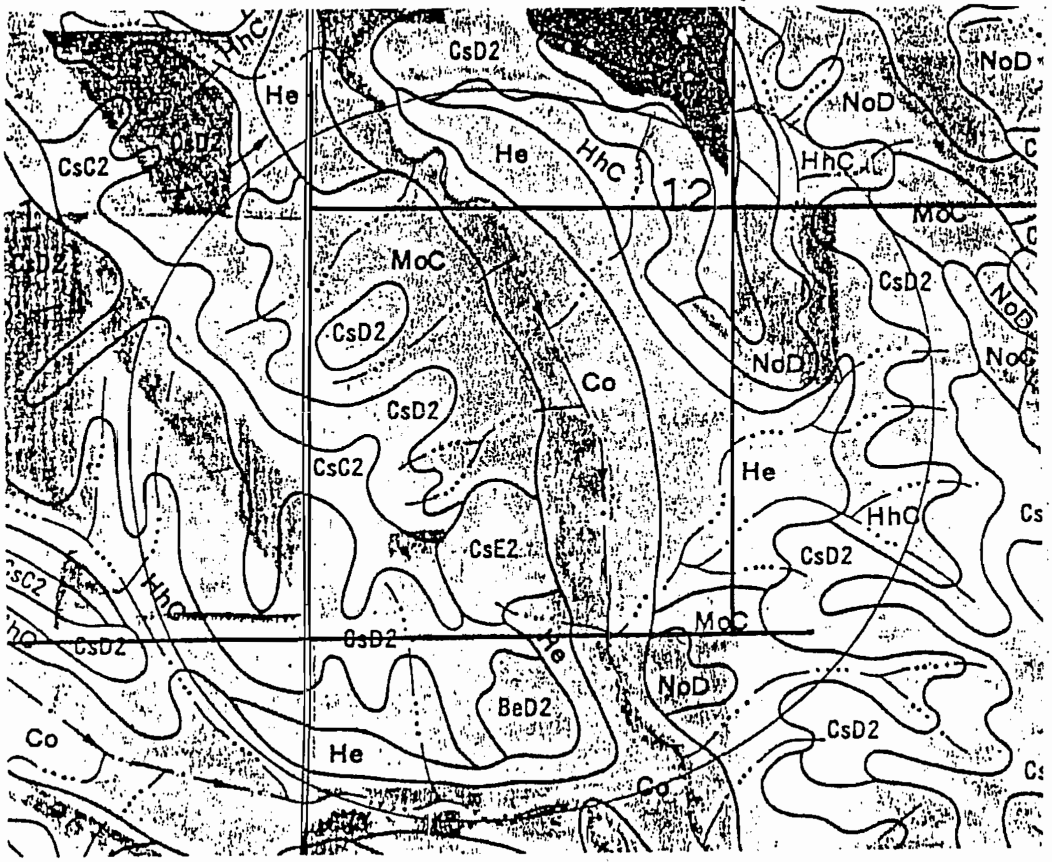
$I_d = (0.053 \times 949 \times 3) / (121.9)$
$I_d = 1.24$ inches

SITE SELECTION

Field data collection

-Soil Survey Maps. The Soil Survey provides an excellent source of estimates for average water infiltration rates, field slopes and soil water holding capacities. Figure 11 shows a copy of a quarter section located in Pierce county. Using a planimeter or some other means, determine the area of each mapping unit. Record the total number of acres of each unit in a table like that shown in Figure 11. Look up the soil intake family, average field slope, infiltration rate and the soil water holding capacity information on each mapping unit and record them in the table. When visiting with the farmer be sure that no soil moving has taken place that would alter the accuracy of the Soil Survey data.

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



SPRINKLER ANALYSIS

MAP SYMBOL	FIELD SLOPE (%)	INTAKE FAMILY NUMBER	WATER HOLDING CAPACITY (in/in)	FIELD AREA (ac)
Co	0-1	0.3	0.20-0.23	42.1
He	0-1	1.0	0.21-0.23	23.9
CsC2	1-7	1.0	0.20-0.23	11.0
HhC	1-7	1.0	0.21-0.23	36.8
MoC	1-7	0.5	0.19-0.22	5.3
CsD2	7-11	1.0	0.20-0.23	28.0
NoD	7-11	1.0	0.20-0.23	1.8
CsE2	11-17	1.0	0.20-0.23	11.1

TOTAL = 160 ac

Figure 11. Summary of Soil Survey information for site selection analysis prior to center pivot installation.

Many field sites will have more soil mapping units than this one. However, the process is educational for you because it clearly identifies which areas of the field could present problems. If well presented, the farmer will understand why a particular sprinkler package would be most appropriate. In addition, it is a good idea to run the program using information from more than one problem soil. Keep the tabular information handy because we will use some of this information to work an example using the computer program.

-Construct a surface topography map. Many sprinkler packages are selected without a field site visit. However, the field visit is one of the most important aspects of selecting a sprinkler package because the farmer rarely has all the information needed. For example, one of the most significant reasons for not selecting a particular sprinkler package is field slope. Though soil mapping units give some indication of average field conditions, the data is seldom sufficiently accurate to allow an educated decision. Therefore, a rough grid topography map (say 400' x 400') will determine if areas mapped as 7 to 11% slopes are closer to 7% or if the range describes the field accurately. The difference is not trivial.

Two other pieces of information are minimum requirements for selecting and designing a sprinkler package--the pump output pressure and flow rate, and the elevation difference between the pump and the highest elevation in the field. Without accurate estimates of these data, the sprinkler package design may be questionable.

Finally, the field visit can provide valuable information related to tillage and planting practices. A field farmed on the contour can safely use a sprinkler package that would otherwise generate small amounts of runoff. Crop residues left on the soil surface can absorb much of the impact energy of rainfall and irrigation, thus the soil infiltration rate would be more consistent. Soil residues reflect incoming radiation resulting in less soil evaporation. Each of these factors may cause you to make a slightly different recommendation. NebGuide G93-1154-A presents a summary of how crop residues impact sprinkler irrigation management.

SPRINKLER SELECTION

The main goal for water application systems is to apply water uniformly in sufficient quantities to meet crop water needs without generating runoff. In addition, the system should be able to meet the management scheme of the operator. We have covered many of the factors that may influence these goals. However, let's take another look and separate these goals into four parts.

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

Some of this may seem trivial but it is not uncommon to find a sprinkler heads located on the pivot incorrectly. Worn out sprinklers are often replaced by whatever is available at the time. Likewise, the spacing between sprinklers may not be correct. Problems due to sprinkler placement can be identified in two ways: a) get up on the pivot support truss and compare the sprinkler in Position 1 with a computer printout; and b) perform a water uniformity check. Either choice takes some time and effort.

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

In the absence of some sort of flow control, the topographic features of the field can greatly alter the water distribution uniformity of a center pivot. This is particularly true for low pressure sprinkler packages. Since each sprinkler has an orifice through which water is metered, alterring the pressure supplied to that orifice changes the sprinkler output. Thus, if the field is sloped uphill from the pivot point the sprinklers located at the highest elevation will be distributing less water and those close to the pivot will be distributing more water than is indicated on the design sheet. **The water distribution is inversely proportional to the field elevation.** For this reason, it is recommended that flow control devices be installed if the elevation difference results in a change of flow greater than about

10%. NebGuide G88-888 presents some considerations for different types of flow control devices.

Another factor that is generally ignored is the effect of the start-stop cycle of the drive towers. This factor will have little influence on uniformity of a medium or high pressure sprinkler package (wetted radii >35'). However, with low pressure spray nozzles and all in-canopy packages, the water uniformity can be reduced at low timer settings. This is because the tower moves at 6 to 8 feet per minute while moving, but may stand stationary for 20 to 40 seconds of each minute.

Considerations for meeting crop water needs is presented in NebGuide G89-932 and was presented above.

The zero runoff goal requires that the sprinkler package selected for the system be carefully matched to the field conditions and to the operators management scheme. To often the desire to reduce pumping costs clouds over the issue of water applicaton uniformity. Therefore, if the opportunity arises, an attempt should be made to direct the farmer away from improper sprinkler selections that could result in runoff. This requires that the water application pattern of the sprinkler be compared to the soil infiltration rate. If an accurate estimate of soil surface storage is available, it should be considered.

The computer program CPNOZZLE provides you with an opportunity to develop a rough estimate of how well suited the water application characteristics are to a field's soils and field slopes. The program is also useful in predicting how much the design criteria should be changed to eliminate a runoff problem. For example, if the normal operation of applying 1.25 inches of water per revolution produces runoff, the program can be used to determine a safer water application depth. If the farmer is in the process of alterring the sprinkler package, the program can be used to select an appropriate flow rate and sprinkler wetted radius.

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

The one thing that the computer program does not consider is the impact of water droplets. However, under many situations the results would be similar. The bottom line is that soils high in clay content do not mix well with sprinklers that produce large water droplets.

The distribution of water droplet sizes delivered by a sprinkler may be alterred by selecting a fine or medium grooved deflection plate for spray nozzles or installing controlled droplet size (or spreader) orifices in impact sprinklers. Either alternative reduces the average size of water droplets.

A note of CAUTION! The move toward smaller water droplets should be tempered by the knowledge that small water droplets are more likely to be transported by wind. Due to the increase in droplet surface area that results from the smaller size, evaporation loss in the air is greater for small water droplets than large droplets. Also, remember that good crop residue management can greatly reduce the negative impacts of large water droplets. For more information see NebGuide G93-1154A.

SPRINKLER TYPES

-**Pressure ratings** for center pivot sprinkler packages span a broad range. Within each major category the range in pressure could be 15 to 20 psi. The exact breakoff point between categories is always a point of discussion. Below is a general list of sprinkler package categories.

--High pressure impact (HPI)
---50 to 70 psi
--Medium pressure impact (MPI)
---40 to 55 psi
--Low pressure impact (LPI)
---30 to 45 psi
--Low pressure spray (LPS)
---10 to 30 psi

As you look for suitable options for a farmer, you must remember the existing pipeline and system. For example, a water drive system requires high pressure to operate the drive mechanism. Thus, it is impratical to install a reduced pressure sprinkler package. Likewise, older electric drive systems typically had wide spacings between sprinkler outlets. Hence more outlets would need to be added to install low pressure spray nozzles.

-Sprinkler orientation represents the largest change in sprinkler package options. The trend has been toward more narrow spacings but at largely constant spacings between sprinklers. This results in a larger number of sprinkler heads but limits the size of individual sprinklers at the outer end of the system. For low pressure spray nozzles 9 to 10 feet is a common spacing.

Low pressure spray nozzles can be mounted on top of the pipeline, or on drop tubes below the truss, at canopy level, or at various levels within the canopy. The most extreme case is to mount the nozzle about 12-18" above the soil surface. Each arrangement alters a number of water application factors--most notably, the peak water application rate. For example, nozzles capable of operating in the bubble mode apply water at a peak application rate of approximately 70 in/hr. **NO** soil can intake water that rapidly. Thus, some means of supplying soil surface storage is necessary (see NebGuide G91-1043). A typical spray nozzle mounted at truss level may have a peak application rate of 8-10 in/hr.

Positioning the sprinkler near or in the plant canopy reduces the impact of wind drift and canopy evaporation. Therefore, the potential to save water is a motivation. However, it may cause two negative outcomes. In general, the closer the nozzle is to the ground the greater the water application rate. If the nozzle is positioned well into the canopy in a field with a very sandy soil, plant stems and leaves may eventually cause poor water distribution. Extremely poor uniformity may result in decreased production.

SPRINKLER LOSSES

The potential water losses fit into five categories--soil evaporation, runoff, deep percolation, in-air, and canopy evaporation loss. These five areas combine together to reduce the amount of water available for plant use.

Air losses refer to the water that evaporates between the sprinkler head and the soil or plant surface. In-air evaporation is typically in the 3-5% range. Evaporation is in direct relation to the surface area of the water droplet. As stated previously small water droplets represent greater surface area and hence greater air evaporation loss. To reduce air losses the water should spend little time in the air (short transport time). This can be accomplished by directing the water stream toward the soil rather than up into the air. Water application rates and thus the potential for runoff will increase.

Canopy losses are direct evaporation of water that is intercepted by the plant foliage on its way to the soil surface. Canopy evaporation losses could range from 0 to 10% depending on the atmospheric conditions. Canopy evaporation cools the plant, reducing transpiration. However, current theory is that transpiration is reduced less than the level of canopy evaporation. Thus the net difference is toward the evaporation loss side.

Canopy evaporation occurs for the length of time water is on the leaf surface. High pressure impact sprinkler packages have the most canopy loss because the irrigation time is the greatest. In-canopy sprinkler packages irrigate for extremely short time periods and do not wet the entire canopy. Consequently, canopy evaporation is minimized.

Runoff loss is the water that reaches the soil but does not infiltrate. Runoff losses could range from 0 to 60% of the water applied. Runoff water is redistributed to other portions of the field (usually low lying areas) or leaves the field boundaries. The amount of runoff loss depends on the matchup of the sprinkler package with the soil and slope conditions. Sprinkler packages with high application rates, matched with soils with steep slopes and low infiltration rates will produce maximum runoff if soil surface storage is not provided. Conversely, low water application rates, flat slopes and high infiltration rates produce little runoff.

Soil evaporation loss is water that evaporates directly from the soil surface. Soil evaporation is not a characteristic of most sprinkler systems, but is an important component of overall irrigation efficiency. Work conducted at North Platte indicates that soil evaporation accounts for about 30% of total crop water use but is generally in the 5 to 10% range for an individual irrigation event. In-canopy spray nozzles, because they do not wet the entire soil surface, minimize soil evaporation losses. High pressure impact sprinklers wet 100% of the soil surface, so soil evaporation is much greater. Crop residues left on the soil surface reduce soil evaporation by reflecting incoming radiation and creating a barrier that decreases the movement of water toward the soil surface between irrigation events.

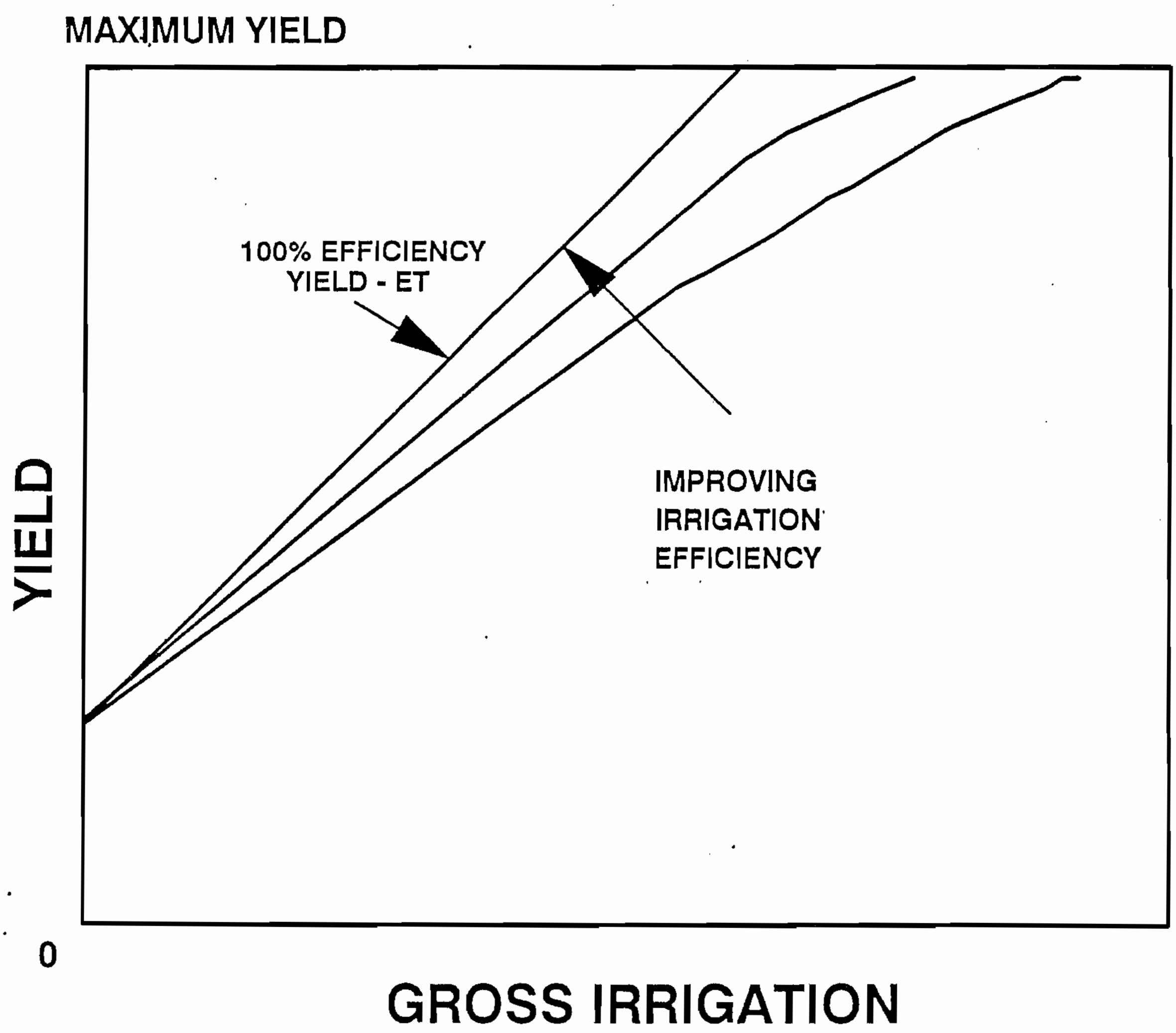


Figure 12. Conceptual drawing of impact of irrigation efficiency on the Yield-irrigation relationship.

Deep percolation loss is water applied in excess of the soil water holding capacity. It is water that passes directly through the soil profile and does not contribute to plant growth. Deep percolation losses are easy to control with sprinkler irrigation systems. Water application should not occur unless the soil is able to hold it. Most deep percolation does not result from the irrigation event but from a rainfall event that occurs immediately after or during the irrigation event. The way to minimize deep percolation loss is to reserve a portion of the soil's water holding capacity for rainfall. Beyond tassle emergence the operator could reserve up to 0.5" even in a sandy soil. Up to 1" could be reserved for a silt loam or clay soil. Another key is to watch the weather reports closely and minimize the number of times one irrigates when the potential for rain is above 50%.

In summary, because atmospheric conditions vary daily and within each day, the sum total of all five components of water losses during sprinkler irrigation can be in the range of 3 to 60% of the water applied. Obviously few fields experience the maximum level of loss for all five factors. Irrigating during conditions of low air temperature, humidity, and wind velocity, and under cloudy skies would maximize the amount of water reaching the soil surface. Properly matched sprinkler packages and soils would limit runoff losses and crop residue management or limiting the area to which water is applied (i.e. in-canopy sprinklers) would minimize soil evaporation losses.

IRRIGATION EFFICIENCY

Irrigation efficiency involves more than just the getting the water into the soil. Irrigation efficiency includes how effectively the water applied is utilized to produce grain or forages. To maximize irrigation efficiency means minimizing water losses, minimizing water left in the soil at harvest time, and maximizing uptake by the plant. We've talked about how to minimize the losses, let's spend a minute to look at how system management may enter the picture.

Each of has a mental picture of what a curve representing yield versus evapotranspiration might look like. If we were 100% efficient, that curve would be a straight line (see Figure 12). The difference between the straight line and the typical curve is due to a decrease in irrigation efficiency. Certainly much of the difference can be attributed to irrigation losses, but system management also has a role.

We have discussed the impact of atmospheric conditions on water application efficiency. Thus, if possible the system should not be operated when high in-air and canopy losses are expected. In some cases the crop and the operator's pocketbook would benefit. This is a management decision and requires time to monitor each irrigation event.

Water savings are quite possible when the soil water content is carefully monitored early in the season and late in the season. For rowcrops, the rootzone is enlarging rapidly and rainfall is still quite probable early in the year. Irrigating too early tends to encourage soil surface crust development, and wind erosion. If the crop has developed a partial canopy the opportunity for crust development and wind erosion is greatly diminished. Sometimes a week's time is all that is necessary.

Late in the season the question is will there be enough soil water to take the crop to maturity. By monitoring soil water content carefully and estimating the water needs of the crop accurately, saving one revolution of the system is common. Remember that crop water use rates are decreasing rapidly during the last 2-3 weeks of the season. NebGuide G82-602 presents an excellent procedure for maximizing use of water applied late in the season.

The impact of atmospheric conditions can add up with every irrigation event if the irrigation system reaches a given point in the field at the same time of the day. For example, if a field area were irrigated at 1:00 pm every time the field was irrigated, less total water would reach the soil than field areas irrigated at 1:00 am. Staggering the startup time 6-12 hours staggers the time of day each portion of the field is irrigated. Using this practice, total available water would be more consistent throughout the field.

Soil evaporation is maximum immediately after an irrigation event. Therefore, applying more water per irrigation event and fewer events would tend to minimize soil evaporation impacts. However, minimizing the number of events means that the soil profile will be near capacity after irrigations, increasing opportunites for deep percolation loss. In addition, the soil water holding capacity interaction with depth of application tends to limit how far this scenario can go. So even this approach must be tempered.

Finally, most seasons have some rainfall events that can supplement the water applied by the irrigation system. Irrigating straight through such events means they were not used to the maximum benefit. Likewise, starting up the irrigation system one day after a 2" rain is probably not the best use of the rainfall. It is often difficult to determine how much water infiltrated unless soil water contents are closely monitored. For example, did runoff occur? If so, how much? How much rain did I really get on field No. NW15? These questions should not be answered with guesses. Soil water monitoring can allow the operator to develop more accurate estimates. Again the difference could mean eliminating one irrigation event.

CPNOZZLE PROGRAM

Determining the potential for runoff or matching field conditions and management practices with sprinkler packages is important. A copy of the user's manual for the CPNOZZLE program is included with you training materials. The manual takes your through the program step by step. Help screens are included to help you develop an appropriate response to the question posed by the program. In each case, limits have been placed on the response the computer will accept. Thus, if you enter a value that is out of range or inappropriate, the computer will ask you to re-enter the value. The bottom line is that if the entered sprinkler characteristics result in runoff, another package or different operating parameters should be investigated. System flow rate, application depth, soil surface storage, and sprinkler wetted radius are parameters to start with.

APPLICATION UNIFORMITY

Evaluating the water application uniformity of a center pivot system is described in Chapter 689 of the Nebraska Irrigation Guide. At least a discussion of the computer program is there. This section will describe how to conduct a application uniformity test and recommend a way to evaluate the data.

Like many other topics discussed in this session, the accuracy of the water application uniformity test depends on how thoroughly the test is conducted. Since there is a broad range of sprinkler packages installed on center pivots, there could potentially be an equal number of testing protocols. But the American Society of Agricultural Engineers recommends that a standard testing procedure be used for all center pivots.

The test should include two lines (or rays) of catch cans installed not more than one wetted radius apart. Catch cans should begin close to the pivot point (say 100-200' away) and continue at equal spacings. A common spacing would be 10'. This means that you would need about 260 catch cans to run the test.

run the test. Obviously some information can be obtained by conducting the test using a single line and a wider spacing between catch cans. However, with spray nozzles spaced at 9-10', wider spacing could entirely miss one or more sprinklers.

If a crop such as corn is growing in the field, the catch cans should be mounted on stakes so that the lip of the can is above the crop canopy. The concern here is that splash from leaves is not caught in the catch can. Thus, if the crop height is below the top of the catch can, the cans could be placed on the soil surface. Take care to insure that the can openings are perfectly horizontal.

The center pivot should be set to apply at least 0.75" per revolution. Evaporation loss from catch cans may be substantial. A small application depth would make it possible for all the water caught to be evaporated. One way to reduce the impact of evaporation loss is to place a small amount of vegetable oil in each catch can. Oil floats on water and prevents evaporation. If oil is not used, be sure to record catch volumes immediately after the system has passed by. Begin recording data from the outer end of the system.

One key factor for conducting an application uniformity test is that wind velocity be less than 10 miles per hour. Conducting the test in wind velocities greater than 10 miles per hour would negate the accuracy of the test. Wind drift distorts the true water application pattern. This would suggest that early morning tests should provide the most accurate results.

One of the main uses of a uniformity test is to isolate areas where the sprinkler system is not functioning properly. In order to isolate an area, there must be a clear trend in the data (i.e., several cans with substantial higher or lower catch volumes). The reason for caution is that variation is common in these data due to the way the system passes over the ray of cans. But if several cans have a similar trend, you have reason to suspect a problem. If you can isolate such an area, it is often due to improper sprinkler placement, or the impact sprinkler is not rotating. One other possibility is that a series of pressure regulators are not functioning properly. Pressure regulator operation can be checked with a pitot tube with an accurate pressure gage attached.

Another thing to look for is a general trend in all catch volumes. For example, if the pump is not supplying water at the appropriate flow rate, the trend will depend on the field topography at the test site. If the field is sloping downward away from the pivot, the catch volumes will tend to increase with distance from the pivot point. The opposit is true if the test site goes upward from the pivot point.

In the final analysis, the water application uniformity should be 85% or higher for most situations. That's assuming that the wind speed is not above 10 mph. It quite common for center pivots to have a water application uniformity of 90 to 95%. But the most significant thing to come of a uniformity test is being able to isolate problems, not the magnitude of the number obtained from the computer.

SPRINKLER DEMONSTRATION

Demonstrate sprinkler characteristics. A small model equipped with various sprinkler types will be demonstrated. The idea is to show what the sprinklers look like, how they distribute water and the various selections an operator of sprinklers may have. We won't collect any data this time.

-Wetted radius
-Water droplet impact
-Water application rate
-Soil surface storage impact