IRRIGATION
MANAGEMENT
S E R I E S

# Considerations for Sprinkler Packages on Center Pivots

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Surface irrigation used to be the dominant irrigation method but now approximately one-half of the irrigated acreage in Kansas is watered by center pivot systems. In some areas they represent a vast majority. Center pivots reduce the amount of labor associated with irrigation and usually supply water to a crop more efficiently and uniformly than flood irrigation. Because of declining aquifer levels, different package options for sprinkler systems have been developed to improve the efficiency of the system and to distribute effectively a limited water supply over a large area.

It is important, when designing a new system or converting an older system, to keep in mind the general sprinkler performance requirements. If these general requirements are not followed closely, a reduction in the system efficiency could occur due to such things as runoff or reduced yields from under-watering. This bulletin covers general sprinkler performance requirements. To provide a better understanding of conditions which reduce efficiency, it discusses the different types of water losses associated with sprinkler systems. Finally, a broad discussion of sprinkler package options and the effects they have on system performance will be presented.

## GENERAL SPRINKLER PERFORMANCE REQUIREMENTS

There are many sprinkler system design considerations, but the following are essential in determining adequate system performance: (1) application rate, (2) depth of application, (3) system capacity, and (4) uniformity of application.

**APPLICATION RATE.** Traditionally, the application rate is matched to the maximum soil intake rate. This involves determining the type of soil or soils that the system will be irrigating. The Soil Conservation Service (SCS) has determined infiltration rates for most soils in the country. Soils with like infiltration rates were grouped into Intake Families. Each of these soil Intake Families has a specific soil intake curve shown in Figure 1. The soil type(s) for any field of interest can be determined by referring to soil maps which are available at county extension or SCS offices. Soil intake curves are a good place to start when determining the maximum application rate.

Average application rates produced by different sprinkler packages, shown in Figure 2, illustrate that sprinkler packages with smaller wetted diameters have higher average application

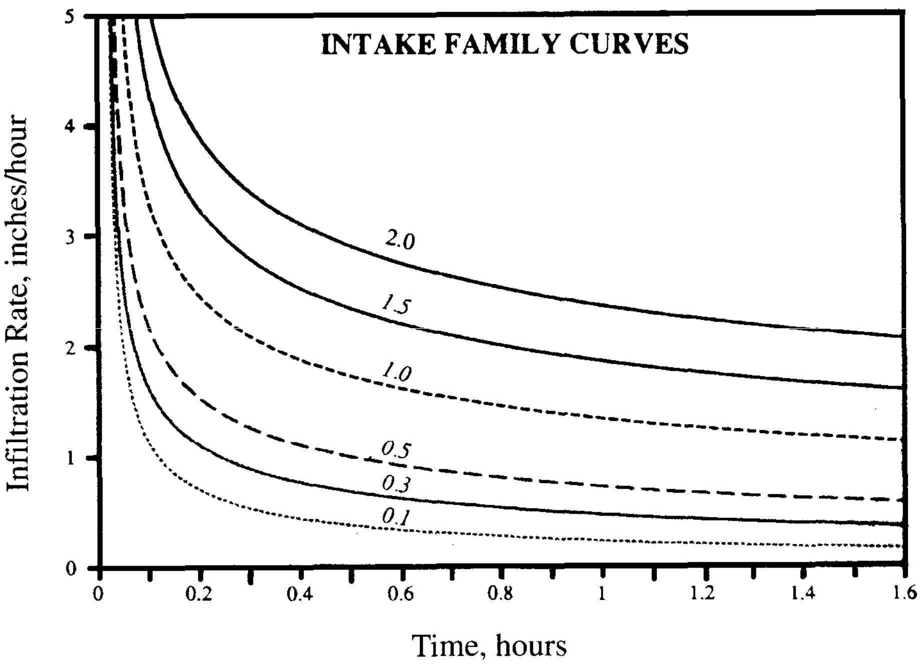


**Figure 1.** *Infiltration rate curves for major Soil Conservation Service intake families. (Kranz, W., Central Plains Proceedings, 1994)*

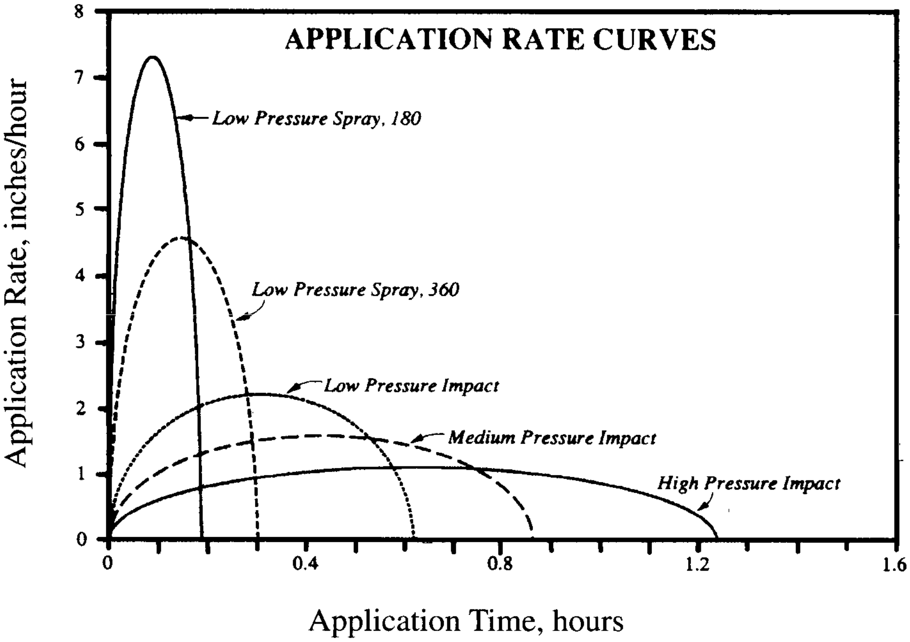


**Figure 2.** *Water application patterns for different sprinkler types for a 1.1-inch application amount. (Kranz, W., Central Plains Proceedings, 1994)*

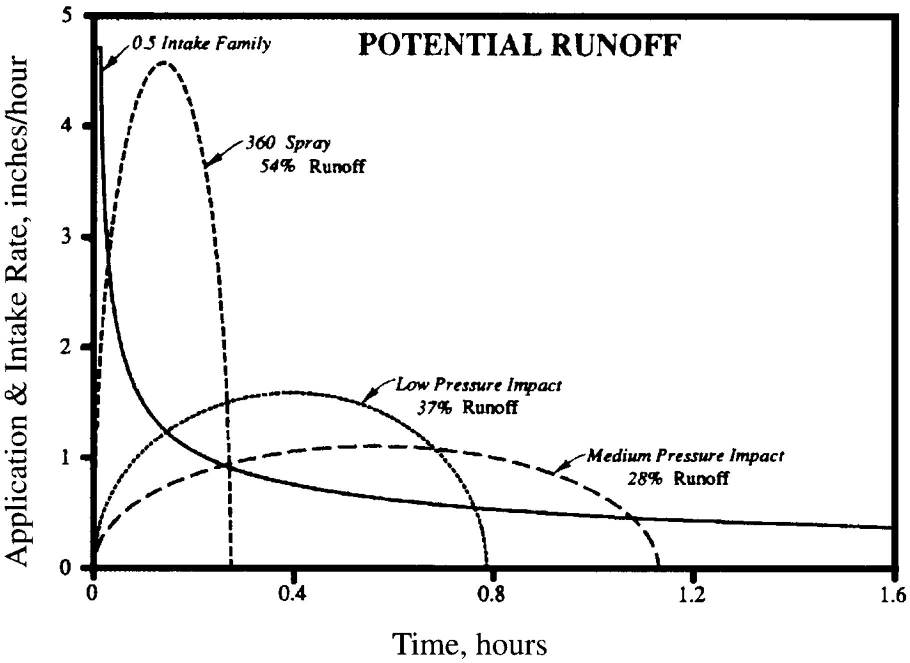


**Figure 3.** *Potential runoff for a silt loam soil receiving a 1.1-inch water application without surface storage. (Kranz, W., Central Plains Proceedings, 1994).*

rates and vice versa. When trying to match the application rate of a system to the intake rate of the soil, it is helpful to put the intake rate curve and the application rate curve on the same figure. This is shown in Figure 3 with the intake rate curve for the 0.5 SCS Soil Intake Family and application rate curves for three different wetted radii (nozzle packages). The areas in Figure 3 where the application rate curves extend above the intake rate curve represent water that must be stored on the surface until infiltrated, and therefore has a potential to runoff. If this stored surface water does run off, it results in a reduction in system efficiency. Sprinkler packages with a higher wetted radius have a lower application rate, less water stored on the soil surface and therefore produce less runoff. Application rate is important when trying to eliminate runoff, and thus improve system efficiency.

**DEPTH OF APPLICATION.** The amount of water applied during an irrigation should not exceed the volume of water that the root zone can hold. If excess water is applied, water will be lost to deep percolation, thus reducing the efficiency of the system. Different types of soils have different soil water-holding capacities. For optimal irrigation results, it is best to keep the soil water level between field capacity and about 50 percent of the available water in the crop root zone for the type of soil being irrigated. These levels are based on the tension required to extract water from the soil. Field capacity is defined as the level of water remaining in a soil after gravitational water has been removed.

The permanent wilting point is defined as that level of water at which the forces holding the water in the soil are equal to or greater than the maximum force that a plant can exert to extract this water. At this level, water is unavailable to the plant and the plant can no longer survive. The soil water between field capacity and the permanent wilting point is the amount of water that is available for plant use. Application of water above field capacity results in soil that becomes saturated. Water may be lost to runoff or deep percolation. Applying too little water will result in plant stress.

Table 1 gives typical soil water levels for three soil textures. The root zone of the crop to be irrigated, along with the available water holding capacity for the soil being irrigated, determine the maximum application amount. Table 2 summarizes crop water use characteristics for many irrigated crops and includes the root zone for several crops common to the central plains region. Multiplying the root zone depth for the crop of interest by the available water-holding capacity for the soil being irrigated, the total available water-holding capacity in the root zone is determined. This is the most water that can be stored without water loss to deep percolation. The maximum amount that can be applied is less than this since the general irrigation management guideline is to

**Table 1.** *Water-Holding Capacities of Soils.*

| Soil texture | Water per foot depth of soil | | Water available for plant use |
|---|---|---|---|
| | Field Capacity (in. per ft.) | Wilting Point (in. per ft.) | (in. per ft.) |
| Sandy | 0.75 | 0.25 | 0.50 |
| Sandy Loam | 1.30 | 0.30 | 1.00 |
| Silt Loam | 2.00 | 0.50 | 1.50 |
| Clay Loam | 3.00 | 1.00 | 2.00 |

prevent more than 50 percent soil water depletion.

SYSTEM CAPACITY. The system capacity should be adequate enough to replenish the water at a rate equal to the peak water use rate of the crop being irrigated. The crop water use rate is variable from day to day and from season to season, depending on factors such as the type of crop, the stage of growth of the crop, and weather conditions. The net irrigation for the crop to be irrigated will determine the lower limit for the system capacity. Daily peak water use values are shown in Table 2; however, soil water storage provides a buffer so irrigation system capacity is generally much less than peak daily use rate. Deep rooted crops and high water-holding capacity soils will need less capacity for reliable crop production than shallow rooted crops and sandy soils.

Many irrigation systems have a capacity at much less than the peak use rate. Systems in Kansas with capacity above 0.25 inches per day are generally low-risk when operated on high holding capacity soils.

The system capacity can be estimated using the following equation:

$$\text{System Capacity} = \frac{(K \times ET_p \times A \times t_i)}{(E_i \times t_f)}$$

where:

$K$ = conversion 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

An example may help illustrate this concept:

A 1,280-foot-long system is used to irrigate a crop with a peak water use rate of 0.35 inches per day. The system will run continuously (i.e., $t_i = t_f$). The configuration of the system has a water application efficiency of 80 percent.

$$\text{Thus: system capacity} = \frac{(18.9 \times 0.35 \times 130 \times 4.5)}{(0.80 \times 4.5)} = 1{,}075 \text{ gpm}$$

Notice that in this example the irrigation time per event is equal to the irrigation interval, giving continuous operation of the system. Other factors to take into account when calculating the system capacity are possible load control and downtime needed for system maintenance or repair. For the percent of time that the system must be shut down, the capacity will have to be increased to compensate for the lost irrigation time. Figure 4 shows the

**Table 2.** *Seasonal Crop Water Use (ET), Typical Irrigation Capacity Requirement, Daily Peak Water Use, Critical Growth Stages, Typical Root Depth, and Typical Manage Depth for Various Crops Common to the Central Plains Region. (Shawcroft, R. W., Central Plains Proceedings, 1989)*

| CROP | Seasonal crop water use (ET) (inches) | Typical irrigation capacity required | Daily peak usage | Critical growth stages | Typical root depth | Typical manage depth |
|---|---|---|---|---|---|---|
| | | -------(in. per day) ------- | | | -------(feet)------- | |
| Alfalfa | 32–48* | 0.40 | 0.55 | after harvest | 6–10 | 3–4 |
| Corn | 24–30 | 0.35 | 0.50 | tasseling, silking | 4–6 | 3 |
| Dry Beans | 16–24 | 0.30 | 0.40 | early bloom | 3–4 | 2–3 |
| Wheat | 16–22 | 0.29 | 0.40 | boot-heading | 4–6 | 3 |
| Sorghum | 16–22 | 0.31 | 0.40 | boot-heading | 4–6 | 3 |
| Sunflowers | 16–20 | 0.26 | 0.30 | flowering, maturity | 4–6 | 3–4 |
| Soybeans | 18–24 | 0.31 | 0.40 | germination bloom-podding | 4–6 | 3 |
| Vegetable Crops | 16–20 | 0.29 | 0.30 | reproductive stages | 1–3 | 1 |

**Forage crops generally respond directly to the amount of water available. Alfalfa can use large amounts of water when growing seasons are long.*

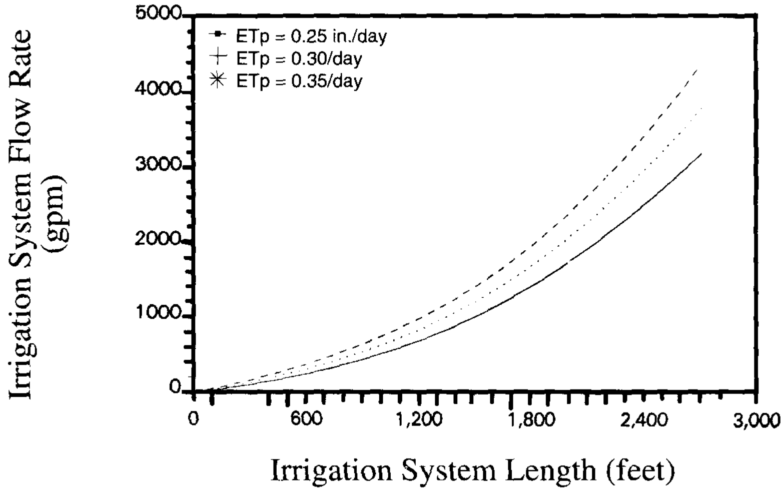


**Figure 4.** *Impact of potential ET estimate on system flow rate for different irrigation system lengths. (Kranz, W., Central Plains Proceedings, 1994.)*

relationship between system capacity and system length for three different peak water use rates.

**UNIFORMITY OF APPLICATION.** When designing sprinkler irrigation systems, it is important to provide as uniform application as possible. A non-uniform application will result in areas of under-watering as well as areas of over-watering. This will result in reduced yields as well as decrease system efficiency. The uniformity is determined by the spacing and wetted radius of the sprinkler nozzles and design by the irrigation dealer. Uniformity is decreased if system pressure is not kept at the design pressure and with wear of nozzles. Canopy interference also effects distribution uniformity.

## TYPES OF WATER LOSSES

The limiting factor for most sprinkler system application efficiencies is water loss. Water that does not reach the root zone of the crop is not available to the plant and is considered lost. The reduction in water made available to the plant reduces the water application efficiency of the entire system. Water losses occur in three areas: (1) air loss, (2) foliage loss, and (3) ground loss and are illustrated in Figure 5.

**AIR LOSS.** The two types of air water loss are drift and droplet evaporation. Drift involves wind blowing the water droplets off of or to different areas of the field. This causes non-uniformity in the water application, and crops located in areas not receiving the proper amount of water will become stressed. Droplet evaporation is the case where sprinkled water actually evaporates before it reaches the crop canopy or the soil. By producing larger droplets or by moving the discharge point closer to the ground, these types of losses can be reduced.

**FOLIAGE LOSS.** Upon entering the canopy of the crop, water can be lost to interception or to evaporation. Interception is when water is "caught" and held by the plant, ultimately evaporated back to the atmosphere. To reduce water losses in the canopy, discharge points have been moved even closer to the ground.

**GROUND LOSS.** Once the water reaches the ground, it can be lost in several ways. If water application rates are higher than the soil intake rates, water can either run off or be held in surface storage. Runoff water can either leave the field or just move to different locations on the field. This causes non-uniformity in the application, and reduces the efficiency of the application.

Water being held in surface storage will either infiltrate or evaporate. The

(1) LEPA
(2) Spray Nozzles
(3) Rotators
(4) Small Impacts—Modified Nozzles
(5) Small Impacts—Round Hole Nozzles
(6) Large Impacts—Round Hole Nozzles
(7) Larger Impacts— (l¼") Round Nozzles
(8) Impact End Gun—Modified Nozzle
(9) Impact End Gun—Round Hole Nozzle
(10) Gun Type End Gun—Modified Nozzle
(11) Gun Type End Gun—Round Hole Nozzle

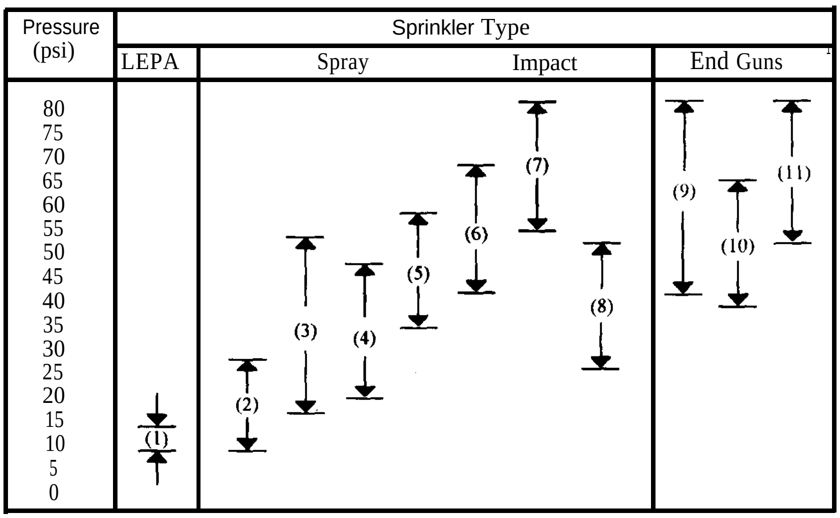


**Table 3.** *Minimum end pressures on center pivots and linear move systems for various sprinkler devices. (Kranz, W., et. al., Central Plains Proceedings, 1990)*

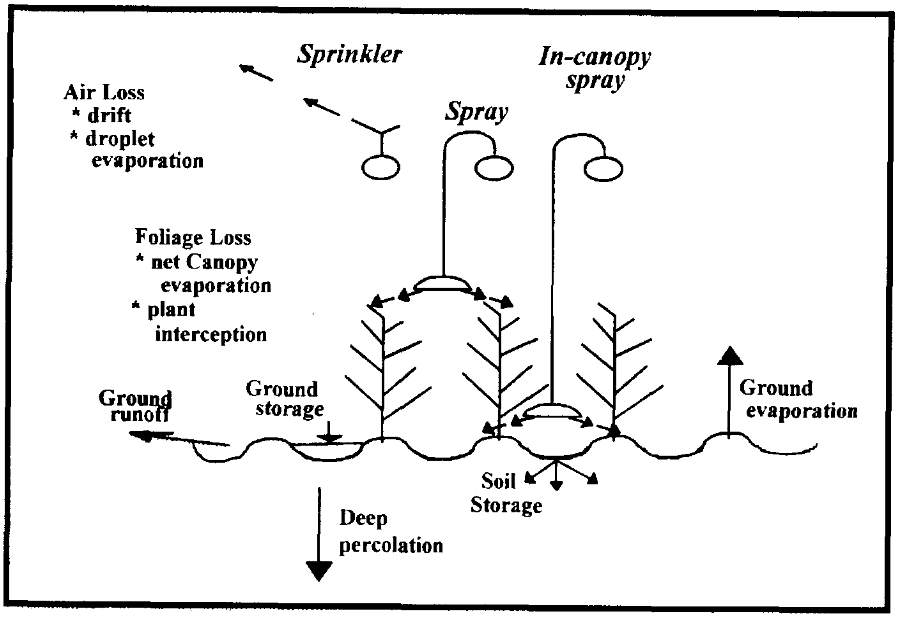


**Figure** 5. *Illustration of different types of water losses associated with sprinkler systerns. (Schneider, A.D. and T.A. Howell, Central Plains Proceedings, 1993.)*

stored water lost to evaporation reduces the application amount, and thus the application efficiency. If the depth of application exceeds the soil water storage capacity within the root zone, water will be lost to deep percolation. This is when water infiltrates below the root zone of the plant. Ground level losses of water can be reduced by using different tillage techniques and closely managing the water application.

## SPRINKLER PACKAGE OPTIONS

There are hundreds of choices among sprinkler packages. Sprinkler heads are designed to provide a specific water release pattern when provided with a specified pressure. If these heads are not used with the given specifications, they will not perform as designed, and may reduce application efficiencies significantly.

Table 3 shows the relationships between the sprinkler types and their designed pressures. As might be expetted, different sprinkler nozzles provide different output and application characteristics. Table 4 gives the rating of output characteristics for Sprinklers 2 through 7 from Table 3. These characteristics determine the types of water losses each nozzle is susceptible to.

**AVERAGE APPLICATION RATE.** The average application rate is calculated by dividing the application amount by the time of application. Sprinkler nozzles operating at different pressures provide a different wetted radius. It has already been noted that smaller wetted radii (lower operating pressures) provide a higher average application rate. Table 4 shows that Sprinkler 2, with the lowest operating pressure, has the highest average application rate. If the average application rate for a nozzle of interest is significantly higher than the intake rate of the soil to be irrigated, the potential for runoff is high.

**PEAK APPLICATION RATE.** The peak application rate is the rate at which water is supplied to the soil at a given point in time and at a specified location. Selecting a sprinkler package with a peak application rate that is too great could cause runoff to develop. The key is to match the peak application rate to the soil infiltration rate. Three factors that affect the peak application rate are (1) system length, (2) system capacity, and (3) sprinkler wetted radius. The following equation can be used to calculate the peak application rate:

$$I_p = \frac{(K \times Q_p)}{(R_s \times R_{sp})}$$

where:

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

This equation indicates that as the system length increases (along with the needed increase in system capacity to meet the peak water use rate), the peak application rate increases. Figure 6 provides a visual representation of how wetted radius impacts the peak application rate as system length increases.

**WETTED RADIUS.** The wetted radius of a sprinkler is the distance water will travel from the nozzle before striking the ground. Sprinklers that have a large wetted radius also have a large droplet size and operate at higher pressures as indicated in Table 4. Wetted radius is also an indication of the average application rate. A larger wetted radius will have a lower average application rate, and thus the potential for runoff will be lower.

**WATER DROPLET SIZE.** The water droplet size is determined by such things as operating pressure, size and shape of the opening on the nozzle, and what type of pad or arm the nozzle is equipped with. The important properties of water droplet size to remember are: (1) large droplets have a high instantaneous application rate that can cause crusting on unprotected soil, which can increase the potential for

**Table 4.** *Rating of output characteristics of sprinklers 2 through 7 from Table 3. (Kranz, W., et. al., Central Plains Proceedings, 1990)*

| Characteristic | Sprinkler with the Highest | Sprinkler with the Lowest |
|---|---|---|
| Average application | (2) | (7) |
| Instantaneous application rate | (7) | (2) |
| Wetted radius | (7) | (2) |
| Water droplet size | (7) | (2) |

runoff; and (2) small droplets are more susceptible to drift and evaporation losses. Table 4 gives water droplet size comparisons.

A trend in recent years has been to use lower pressure nozzles which reduces the overall pressure required for the system and lowers pumping costs. Since lower pressure nozzles have a smaller droplet size, they have been moved closer to the ground to reduce evaporation and drift losses. Lower pressure nozzles also increase the average application rate, requiring that special attention being given to reducing the potential for runoff.

**LEPA NOZZLES.** The LEPA (Low Energy Precision Application) nozzle was not included in the above comparisons. The operating pressure and the position of the nozzle close to the ground means the wetted radius of a LEPA nozzle is very small. This also means that the average application rate is very high. LEPA can be considered to a degree as a type of traveling flood irrigation, and because of its characteristics, must be used in conjunction with special practices. LEPA nozzle spacing must be 5–6 feet, requiring extensive modifications when converting older systems. To reduce runoff, planting in a circle using the wheel track of the center pivot as a guide, and special tillage methods such as dammer-diking must be used. Further information on LEPA irrigation is available in other extension bulletins.

## SUMMARY

Center pivot systems are becoming more popular because of their ability to provide a more efficient and uniform application than other irrigation methods while they reduce the amount of labor associated with irrigation.

There are many different options associated with sprinkler systems, and consideration must be given to the overall system rather than to “fixing” one problem. A trend in recent years has been to use lower pressure nozzles which reduces the overall pressure required for the system, which reduces operating costs. Since lower pressure nozzles have a smaller droplet size, they are more susceptible to drift and evaporation losses. Lower pressure nozzles also increase the average application rate, increasing the potential for runoff. The capacity needed to effectively water a given field may not be met by a system whose pressure has been reduced solely for the purpose of reducing pumping costs. This is a good example of how focussing on one aspect of the system can lead to other problems elsewhere on the system. When designing a new system or converting an older system, consideration should be given to the general sprinkler performance requirements as well as to cost reduction and water loss reduction.

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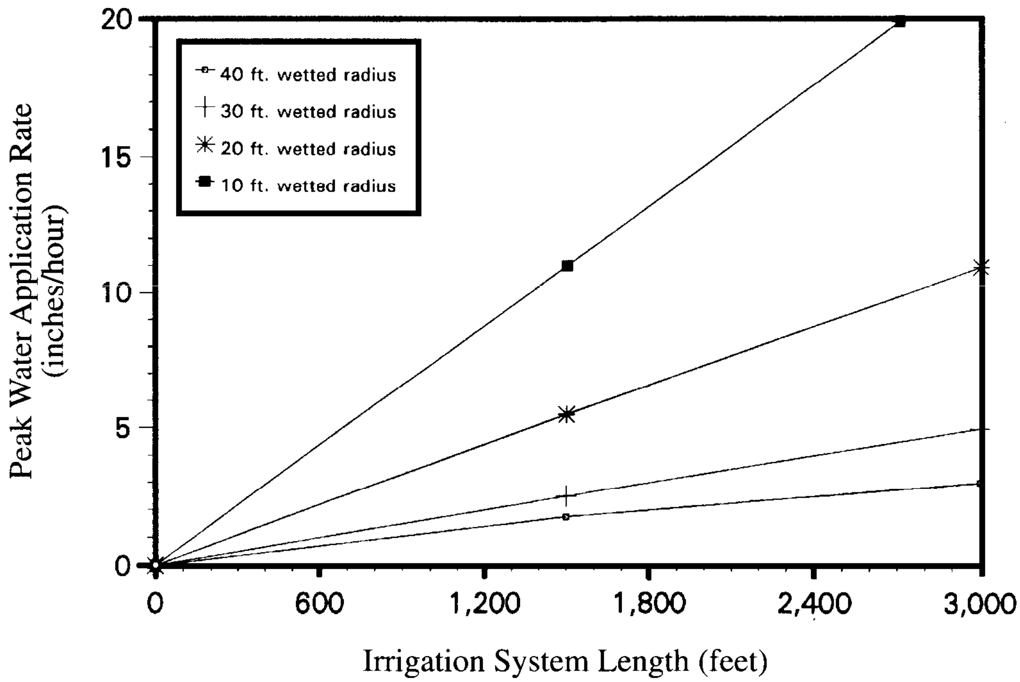


**Figure 6.** *Impact of sprinkler wetted radius on peak water application rate when designed for 0.35’’ day ETp. (Kranz, W., Central Plains Proceedings, 1994)*

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