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Operating Characteristics of Center Pivot Sprinklers

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The purpose of this NebGuide is to discuss the operating characteristics that can affect the suitability of a sprinkler package for a given field site.

During the past 20 years, sprinkler manufacturers have developed and marketed a large number of different sprinkler technologies that produce relatively large wetted diameters at reduced pressures. Thus, center pivot operators have a greater number of sprinkler packages to meet goals of reduced wind drift, reduced energy costs and increased water application efficiency.

The goal of every sprinkler or spray nozzle package is to apply water uniformly to the soil surface where it can be used by plants to produce grain or dry matter. Some performance characteristics can affect the suitability of a package for a specific set of field conditions. Such items as the type of sprinkler or nozzle, the type and size of the orifice, the mounting position and spacing and the operating pressure greatly affects the performance of a package. Each of these factors is interrelated, so for presentation purposes we will begin with a few definitions.

Sprinkler package	group of sprinklers/nozzles installed on a center pivot to irrigate a specific field area.
Nozzle	opening in a sprinkler or spray nozzle used to control water flow rate out of a sprinkler.
Impact sprinkler	water application device equipped with one or two nozzles and an impact arm to cause sprinkler rotation and water stream breakup *(Figure 1a)*.
Spray nozzle	water distribution device equipped with a stationary, rotating or oscillating deflection pad used to distribute water in 180 to 360-degree circles *(Figures 1b-1d)*.
stationary pad	spray nozzle with a deflection pad that does not move when impacted by the water stream leaving the nozzle.
oscillating pad	spray nozzle with a deflection pad that oscillates when impacted by the water stream leaving the nozzle.
rotating pad	spray nozzle with a deflection pad that rotates in a 360 degree circle when impacted by the water stream leaving the nozzle.
Drop tubes	plastic, rubber hose, or metal tubes used to deliver water to a spray nozzle mounted below the pivot pipeline.
Mean droplet size	weighted average size of water droplet produced by a sprinkler/nozzle at a specific operating pressure *(Figure 3)*.
Potential runoff	water applied by a sprinkler/nozzle package in excess of the soil infiltration rate. Without surface storage, this water could move from the point of application *(Figure 5)*.

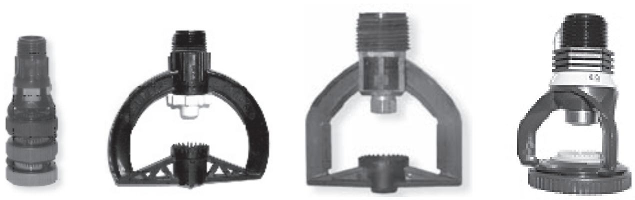
Figure 1 presents examples of sprinklers that are commonly found on center pivot irrigation systems. Sprinkler packages consist of three main types: 1) impact sprinklers; 2) stationary pad sprays; and 3) rotating or oscillating pad sprays. Each type of sprinkler is designed for a specific set of operating conditions (operating pressure, field soils and slopes). *Table I* lists general operating characteristics for sprinklers available for center pivots.

Water flow rates are controlled by the operating pressure and the size and shape of the nozzle opening on the sprinkler. Most sprinklers have circular openings but some specialized sprinklers have straightening vanes, tapered or straight entrances, spreader vanes, or noncircular openings to extend the wetted diameter, change water distribution pattern, or achieve water droplet breakup. *Figure 2* shows nozzle options available for the three main types of sprinklers.

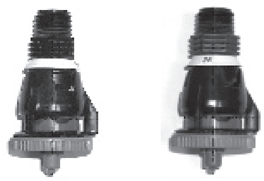
Impact sprinklers can be purchased with spreader nozzles or noncircular nozzles to affect water droplet breakup and to supply water more uniformly to the soil surface. Spreader nozzles are used to deliver water in the intermediate area between the impact arm splash and the outside edge of the pattern. For example, the large range nozzle on the impact sprinkler in *Figure 2* distributes water more than 50 feet from the sprinkler if operated at 70 psi. The impact arm causes splash that delivers water in the range from 0 to 10 feet from the sprinkler. The distance between 10 and 40 feet receives little water from the large nozzle. To even the water application pattern out, a spreader nozzle is added *(Figure 2)*.

The spreader nozzle has a narrower wetted diameter partially because of its smaller nozzle opening and partially because a portion of the water stream is redirected into more of a spray that reaches the area between about 10 and 30 feet from the sprinkler.

1a. High and low pressure impact sprinklers.



1b. Low pressure spray heads with stationary deflection pads.



1c. Low pressure spray heads with rotating deflection pads.

1d. Low pressure spray heads with oscillating deflection pads.

Figure 1. Examples of different sprinkler/nozzles types from various manufactures used on center pivot irrigation systems.

Table I. General operating characteristics for various sprinkler options.

Sprinkler Type	Material	Trajectory Angle	Droplet Size	Operating Pressure (psi)	Wetted Diameter (feet)
Impact	PL or BR				
Low pressure	Plastic	5 to 15°	M to L	20 to 40	55 to 80
High pressure	Plastic	10 to 20°	M to L	40 to 80	60 to 150
360° Spray					
w/moving pads					
Rotating pads	Plastic	-12 to 35°	M to L	15 to 45	40 to 75
Oscillating pads	Plastic	12 to 21°	M to L	10 to 40	35 to 60
360° Spray Nozzle					
w/stationary pads					
Fixed pad	Plastic	-5 to 15°	S to M	5 to 30	10 to 40
Multiple pad	Plastic	-5 to 15°	S to M	5 to 20	10 to 40

PL = Plastic, BR = Brass

Operating Pressure

Each sprinkler is designed to operate within a range of water pressures. Typically, impact sprinklers can be operated over a wider range of pressures than low pressure spray nozzles. For example, a high pressure impact sprinkler is suitable in a range from 40 to 80 psi while an oscillating low pressure spray nozzle would be suited to pressures between 10 and 40 psi *(Table I)*. In the next sections, water application characteristics will be discussed that are directly influenced by the pressure supplied to the base of the sprinkler.

Droplet Size

Operating pressure controls two of the factors presented in *Table I* — wetted diameter and mean water droplet size. As pressure increases, the mean drop size decreases as shown by the 45 psi curves moving to the left in *Figure 3*. If sprinklers

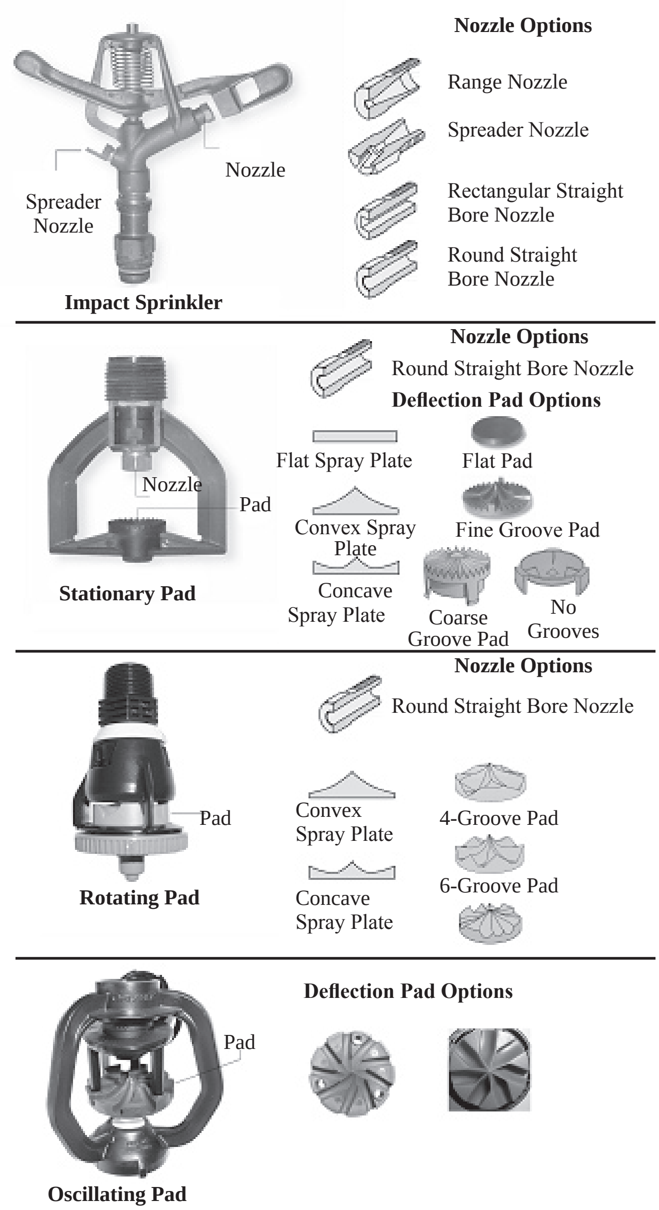


Figure 2. Examples of nozzle openings and deflection pads used in impact and spray type sprinklers.

are operated at design pressure, water droplets become somewhat segregated within the pattern. *Figure 4a* shows where the different size water droplets tend to be distributed around an impact sprinkler if the pressure is adequate. Larger droplets tend to reach the outside edge of the pattern due to their mass and velocity as they leave the nozzle. Thus, a small percentage of water droplets at the outside edge of the pattern can be categorized as small water droplets. However, the inside portion of the pattern is dominated by smaller water droplets.

If sprinkler pressure is too high, normal distribution of water droplet sizes is changed, and a nearly singular water droplet size results. Typically, the energy contained in the water as it leaves the nozzle is excessive, causing immediate water droplet breakup and small water droplets to dominate the pattern. Small water droplets do not have enough mass to reach great distances from the sprinkler. This means that a sprinkler operating above the design pressure can have lower wetted diameter than the same nozzle operated at the design pressure. This scenario is depicted in *Figure 4b*.

At the other extreme, sprinklers operating well below the design pressure produce many large water droplets. The energy contained in the water as it exits the nozzle is low enough that

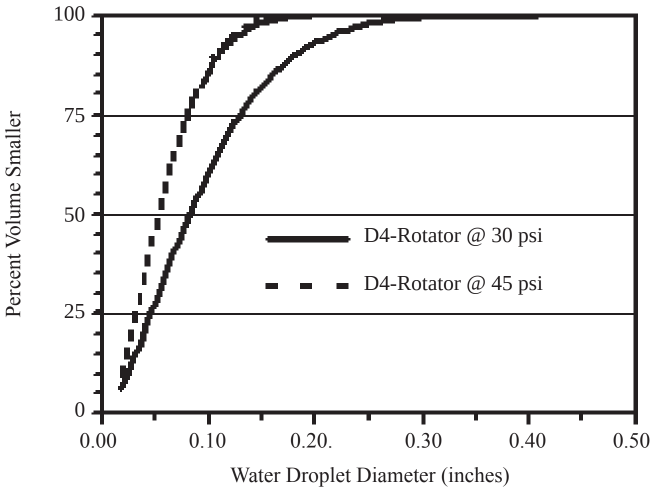


Figure 3. Influence of sprinkler operating pressure on relative water droplet sizes for a low pressure spray head with a rotating deflection plate.

minimal water droplet breakup occurs. Despite their larger size, lower energy also reduces how far the water droplets reach from the sprinkler. Thus, pressure that is too low means the pattern is dominated by large water droplets and a reduced wetted diameter is produced compared to a nozzle operating at the design pressure. This scenario is shown in *Figure 4c*. If the pressure is extremely low, the impact arm may cease to function and a steady stream of water would exit the nozzle with almost no sprinkler rotation or water droplet breakup.

Water Trajectory

Water leaving a sprinkler or spray nozzle exits at an angle relative to horizontal. The path taken by water on its way to the soil surface is referred to as its trajectory. Similar to a bullet shot from a rifle, gravity forces the water droplets to the soil surface. If the stream is directed slightly upward from horizontal, it will reach farther from the nozzle unless the trajectory is into a wind.

Impact sprinklers and spray nozzle packages each may distribute water at a variety of angles. *Table I* lists a range in common trajectory angles available for each type of sprinkler or spray nozzle. *Figure 5a* shows the effect of trajectory angles on the wetted diameter of a high pressure impact sprinkler mounted on top of the pivot pipeline. *Figure 5b* shows the effect of deflection pad curvature on the wetted diameter produced by a low pressure spray nozzle with a stationary pad. By directing the water slightly upward, the concave pad produces a wider wetted diameter than the flat or convex (downward) pads.

Sprinkler Position

To increase performance, some low pressure spray nozzles are mounted on drop tubes below the pivot pipeline. This is done with rigid drop tubes or a combination of a rigid gooseneck and flexible hose to some distance from the soil surface. When making a final selection, the owner should note that mounting the nozzle closer to the soil surface reduces the wetted diameter of the package. As mentioned earlier, gravity forces the water droplets toward the soil surface as they travel through the air. Wetted diameter is controlled by the velocity of the water leaving a particular nozzle and the distance between the water stream and the soil surface. Thus, each time the distance between the nozzle and the soil surface is decreased, wetted diameter decreases. *Figure 6* shows the impact of mounting height on the wetted radius produced by a spray nozzle.

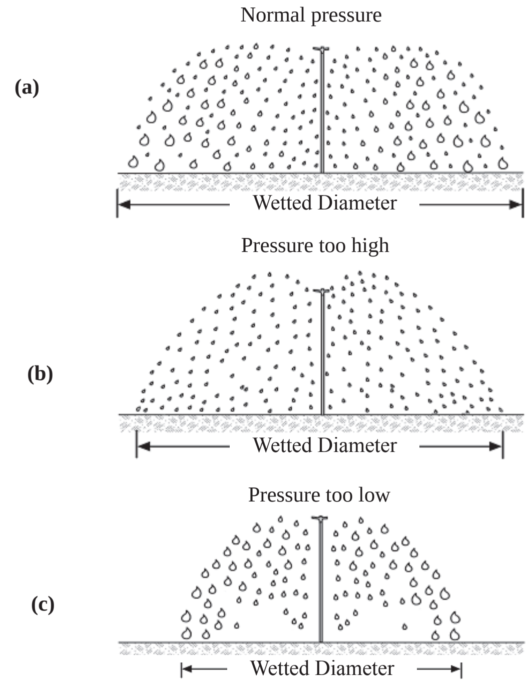


Figure 4. Impact of adequate pressure (4a), too high of pressure (4b) and too low of pressure on the water droplet size distribution from a high pressure impact sprinkler.

Water Distribution Pattern

One of the more recent changes resulting from new nozzle designs is related to water application patterns. The design process sought to achieve the largest wetted diameter and lowest operating pressure combination possible. This has resulted in application patterns that in some cases have been described as single or double humped or donut shaped due to the water application pattern shape. *Figure 7* shows water application patterns recorded for two different pad configurations of a rotating pad under laboratory conditions in California. The nozzles were the same diameter and were operated at the same pressure and height off the ground. The high peak toward the outside edge of the pattern for the four-groove pad is indicative of relatively large water drops so the pattern is affected less by wind. Note that two areas of the pattern for the six-groove pad have higher water application rates and that the wetted radius is narrower. This is indicative of relatively small water droplets meant for soils that are prone to crusting.

The spike in water application near the outside edge of the pattern is due to the number of large water droplets delivered in that portion of the pattern. If the soil is unprotected by a crop canopy or residue, large water droplets tend to detach and consolidate small particles at the soil surface, causing surface sealing or crust to develop. Surface sealing can greatly reduce soil infiltration rates resulting in surface runoff. Soils with high clay content in the surface layer are particularly at risk for crust formation.

To address crust formation, low pressure impact sprinklers may be purchased equipped with controlled droplet size nozzles. Low pressure spray nozzles have options for a higher number of grooves which tend to reduce the water droplet size and impact energy imparted to the soil surface. For example, the rotating spray nozzle with 6-grooves depicted in *Figure 7* is an option meant for use under low wind conditions and soils that are prone to crusting.

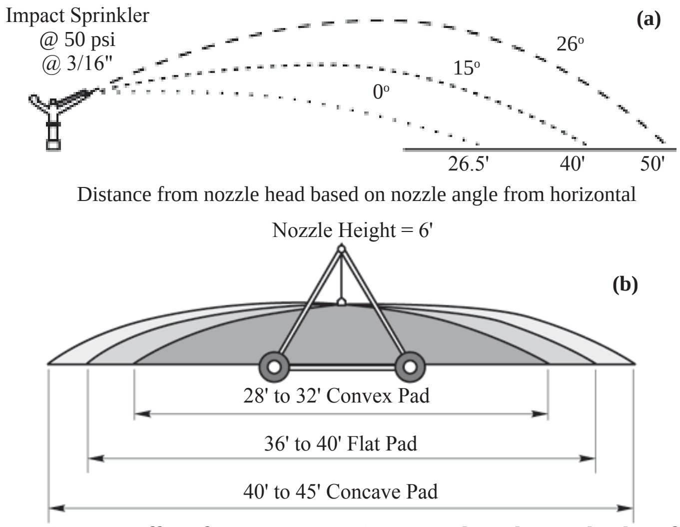


Figure 5. **Effect of water stream trajectory angle on the weted radius of a high pressure impact sprinkler 5(a) and the deflection pad curvature on the wetted diameter of a low pressure spray nozzle mounted 6 feet from the ground 5(b).**

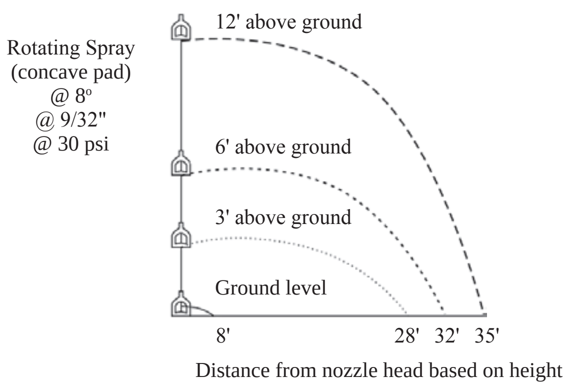


Figure 6. **Influence of nozzle elevation on the wetted diameter produced by a rotating pad spray nozzle.**

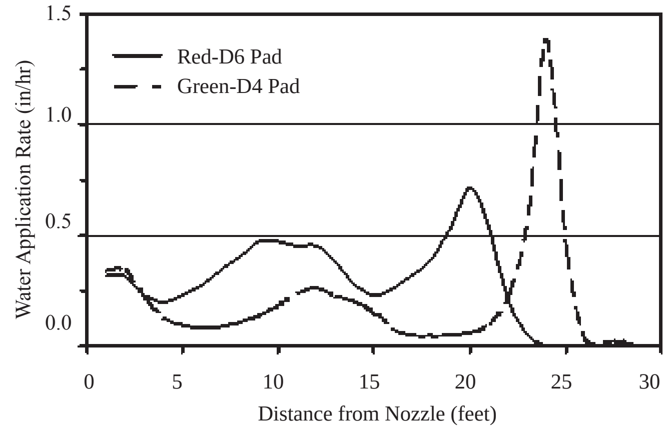


Figure 7. **Impact of the deflection pad design on the water application patterns produced by four-groove and six-groove pads of rotating pad spray nozzles.**

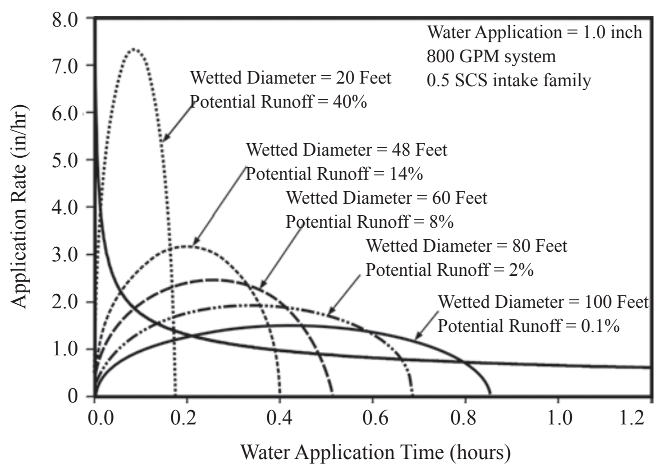


Figure 8. **Effect of wetted diameters on the potential for runoff.**

Wetted Diameter

A major factor affecting which sprinkler package should be installed is controlled by wetted diameter. Wetted diameter of a sprinkler/nozzle is the distance between the sprinkler and dry soil on both sides of the sprinkler as shown in *Figure 4*. The wetted diameter is controlled by the operating pressure of the device, the trajectory angle the water leaving the device, and where the device is mounted relative to the soil surface. Hence, for any type of sprinkler/nozzle, a range of wetted diameters is possible. NebGuides G88-870, *Selecting Sprinkler Packages for Center Pivots*, and G96-1305, *Water Runoff from Sprinkler Irrigation—A Case Study* describe how selecting the wrong sprinkler wetted diameter can affect the suitability of a sprinkler package. Narrow wetted diameters cause high water application rates and a greater potential for the application rate to exceed the soil infiltration rate. *Figure 8* shows the impact of wetted diameters on the potential for surface runoff. Runoff reduces water application efficiency that can erase energy and water savings of lower operating pressures.

Summary

Water application characteristics vary greatly from one sprinkler package to another. A configuration of impact sprinklers or spray nozzles can be purchased that are suitable for water application to nearly any field situation. The key is to consider the impact of a sprinkler package's water application characteristics on water infiltration and potential runoff.

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