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IN-CANOPY VS. ABOVE-CANOPY SPRINKLERS, WHICH IS BETTER SUITED TO YOUR FIELD?

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INTRODUCTION

Selecting the proper sprinkler package for a center-pivot or lateral-move machine is essential to efficient operation. New pivots with the latest control options but a poorly designed sprinkler package will not perform adequately. Frequently, insufficient consideration is given to selection of the best type of sprinkler device for a new pivot or when updating an existing system. Sprinkler devices and their associated operating pressure are often selected based on traditional choices, new promotions, or what is the lowest capital cost without adequate consideration of local conditions. Characteristics specific to the field, supply pump and sprinkler package should be considered.

Our objective is to highlight consequences of design choices and explain how decisions affect the uniformity, application efficiency and quantity of water lost from a center pivot. An important consideration is the placement of sprinklers in or above the crop canopy. The definition of above canopy sprinklers for the purpose of the paper is any device operating above the crop including truss rod height even when corn tassels are up around them. The top of the corn canopy is fairly open and has minimal effect on the pattern.

We explain the selection of sprinkler devices and considerations for the mounting height, the flow rate in gallons per minute for the pivot, and the sprinkler operating pressure. After determining these factors, the details of the design can be developed in consultation with sprinkler or pivot distributors or manufacturers.

DETERMINING WHEN TO REPLACE AN EXISTING SPRINKLER PACKAGE

Planning for a new pivot, or renovation of an existing pivot, requires a decision on what sprinkler package to purchase. Sprinkler devices generally do not last as long as the pivot itself and should be replaced as needed. The industry recommends replacement after 10 years or 10,000 hours of operation, whichever comes first and is extremely dependent on water quality. Additionally, newer sprinkler designs offer more options and can be designed to better suit field conditions than older packages. In many situations, updating to a newer design is worth consideration. Pressure regulators may wear out or break before sprinkler devices and/or new sprinkler packages may require a different pressure than the original design; therefore, pressure regulators should be replaced as part of a new package.

WATER LOSSES FROM CENTER PIVOTS

Improving the application efficiency of the center pivot is often the goal of lowering sprinkler devices into the canopy. Operators should understand what factors affect water losses and the magnitude of the losses.

Water "losses" from a pivot are caused by several factors:

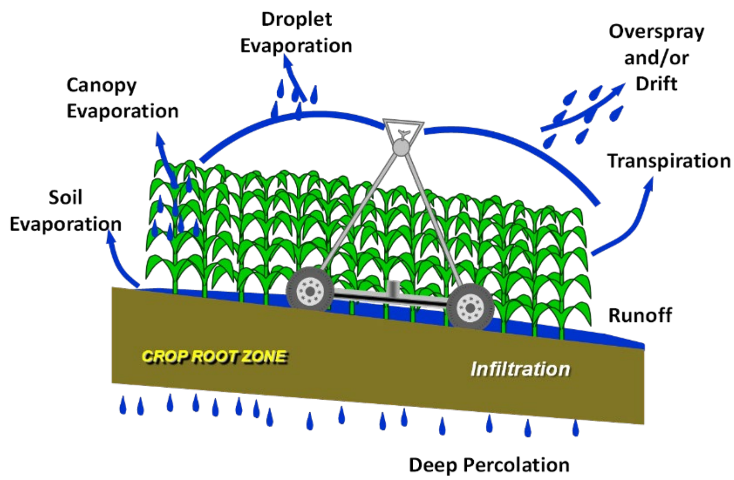

Figure 1. Pathways for water distributed from a center pivot.

1. Droplet evaporation while water travels through the air,
2. Drift of droplets from the field or to a location with a dry canopy,
3. Canopy evaporation after wetting crop leaves,
4. Evaporation directly from the soil,
5. Runoff from the field or to low areas within the field causing deep percolation losses,
6. Deep percolation from the crop root zone—due to excess application or poor uniformity, and
7. Transpiration through plant leaves.

Research at Bushland, TX showed that impact sprinklers placed on top of the center-pivot pipeline were about 85% efficient in applying water to the soil, while spray heads on drops at truss-rod height were about 92% efficient, and LEPA systems could be up to 98% if operated perfectly. The experiment for these results was conducted during the middle of a day with temperatures of 88°F, wind speeds above 15 mph, and a relative humidity of about 36%. The water supply rate was about six gallons per minute per acre with an application of one inch of water after the corn canopy had reached its full height.

The 2% loss from the LEPA system was from soil evaporation during the day of application. The 8% loss from the spray devices was determined to be 1% from droplet evaporation and drift, 3% from canopy evaporation during the application, and 4% after the water was applied as the canopy dried. The 15% loss from the impact sprinklers on top of the lateral was determined to be 3% from droplet evaporation and drift, 8% evaporation from the canopy during the application, and 4% from canopy evaporation as the crop dried. The soil in the field where the experiments were conducted was a Pullman clay loam soil and the field was quite flat. The LEPA portion of the field included basins to store water applied at rates that exceeded the infiltration rate of the soil. Thus, the soil/plant conditions and field slope were well matched to optimal performance for LEPA systems. Runoff and/or redistribution due to reduced uniformity from local runoff were also minimal. Thus, the losses for the experiment reflect losses due to evaporative effects and not runoff or nonuniformity.

Evaporative losses must be considered relative to the depth of water applied. The study utilized an application depth of one inch, resulting in a 4% or 0.04-inch loss after the sprinkler had passed—*i.e.*, while the canopy dried. The loss following irrigation as the canopy dries is unrelated to the depth of water applied as long as the canopy is thoroughly wetted. Thus, when only 0.5 inches is applied, the loss would still be 0.04 inches resulting in an 8% loss and conversely if 2 inches were applied, the loss would only be 2%. Evaporation from the canopy while water is applied depends on the duration of the application and thus the depth of water applied. If the amount of water applied for the year is the same for different application depths, then cumulative losses that depend on the depth of water applied per irrigation will be the same for the year because the canopy will be wetted the same amount of time.

Evaporation and transpiration depend on the amount of energy available to evaporate water. The energy comes from solar radiation and hot-dry winds, which are the same for all areas of the field. Research has shown that transpiration is suppressed while the crop is wetted; thus, energy is available to increase evaporation rates when transpiration decreases. There is more resistance to vapor flow for transpiration than evaporation from the canopy; thus, the reduction in transpiration may be less than the amount of evaporation from the canopy while irrigating and/or drying.

An experiment was conducted where a portion of the field was irrigated with spray devices at the truss rod height and impact sprinklers atop a lateral-move system. The experiment also included a portion of the field that was previously irrigated so that the soil water was adequate to avoid crop water stress; thus, that portion of the field was not irrigated. The partitioning of the transpiration and evaporation fluxes is shown in Fig. 2. The transpiration for a dry canopy was about 0.26 inches/day, while transpiration for spray devices was about 0.22 inches/day and 0.20 inches/day for the impact sprinklers. Thus, the reduction of transpiration was about 0.06 inches/day for impact sprinklers and 0.02 inches/day for spray devices. The transpiration rate for the irrigated areas returned to about the same rate as the non-irrigated area once the canopy dried. Evaporation from the canopy was approximately 0.1 inches/day for impact sprinklers with a larger diameter of throw than spray devices where the canopy evaporation is about 0.04 inches/day. Therefore, the net canopy evaporation for impact sprinklers is about 0.04 inches/ day and about 0.02 inches/day for spray devices. Irrigation also increased soil evaporation for the day of irrigation. The increase in soil evaporation above that for the nonirrigated area was about 0.05 inches/day for either sprinkler device—note that evaporation from wetted

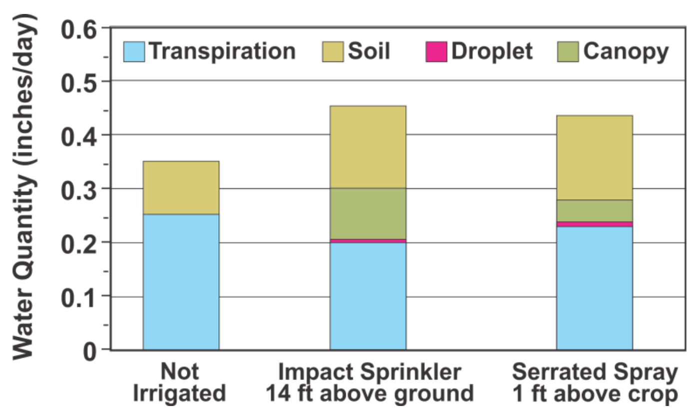

Figure 2. Transpiration and evaporation components of water applied with a lateral-move irrigation system for a hot-dry day in the Southern High Plains.

soil may extend beyond one day. These results are representative of a typical system during a near normal day in the Southern High Plains; however, different systems and days would produce variations of these results.

Sprinkler package design can affect many of the water pathways shown in Fig. 1; therefore, designs should consider how to minimize losses while considering effects on the overall function and economics of the system. For example, evaporation of water while drops travel through the air is strongly affected by the size of the droplet. Large drops are less affected by wind and evaporate at a much smaller rate than drops smaller than 0.04 inches in diameter. Newer sprinklers are much better at controlling the size of drops allowing for minimization of droplet evaporation while avoiding damage to unprotected soils.

Research shows that even in a hot-dry windy climate like the Southern High Plains, the water loss from the sprinkler to the soil is small and a small amount of runoff that causes water to move within the field will more than offset gains from locating sprinklers in the canopy. The primary objective for the sprinkler package must be to have the water uniformly infiltrate into the soil.

SPRINKLER PACKAGE DESIGN

Sprinkler packages should be designed to apply irrigation water uniformly and efficiently while continuing to be feasible. The design must account for characteristics of the specific pivot, the available water supply and various attributes of the field where the center pivot will be installed. Several factors must be considered including: the capacity of the water source, the soils and slopes in the field, the tillage practices that will be used, the crops to be watered and the amount of irrigation needed each year. Serval design factors must be optimized for suitable designs. These factors include: system capacity, wetted diameter of sprinklers, system operating pressure, sprinkler spacing, cost of the package, sprinkler mounting height, water droplet size and nozzle size. This paper is intended to highlight considerations about in-canopy vs. above-canopy sprinkler placement and not describe the entire design process. Refer to the recently published University of Nebraska Extension Circular *EC3017-Center Pivot Management Handbook* for more information on sprinkler package design. Elements for deliberation in the design include:

- **System capacity**—the system capacity, *i.e.* the flow into the pivot, is often limited by the water source; however, if the available flow rate is plentiful then the design needs to determine the required capacity. It is desirable for the capacity to be high enough to quickly irrigate the field, but low enough to prevent runoff. Capacities above six gallons per minute per acre of land (gpm/ac) are usually unnecessary for the High Plains.
- **Wetted diameter**—the wetted diameter of a sprinkler is the width water is applied by individual sprinklers along the pivot lateral. The wetted diameter is also the distance that water is thrown perpendicular to the pipeline. The wetted diameter should be large enough to prevent runoff across the field when applying the desired depth of water, but as small as possible to reduce evaporation. The recommended water application depth for design is one inch each time the pivot passes. The soil intake rate and slope as well as the capacity of the water source and the length of the pivot are critical factors. No-till practices can increase the soil intake rate, which reduces runoff potential. Limiting system capacities to 6 gpm/ac will allow selection of application devices with wetted diameters that minimize runoff while using and economical pressure requirements. The wetted

diameter can be smaller for low capacity systems (3–4 gpm/ac) or with level fields and no-till production. The system length significantly affects the required wetted diameter. Longer pivots require sprinkler packages with larger wetted diameters at the distal end of the pivot.

- **System operating pressure and pressure regulators**—the operating pressure needs to be high enough to operate the sprinklers correctly based on the design requirements, but as low as possible to minimize energy costs. Pressure regulators need to be used on most systems designed for less than 25 psi. The main exception is when pumping dirty water that may plug nozzles and regulators like livestock waste or water from an open canal. Sometimes in this application, regulators are not used and the pressure is raised to 40 to 60 psi to help move debris through orifices. Good filtration is usually better in these situations because it allows for lower pressures and then requires pressure regulators.
- **Sprinkler spacing**—the spacing of sprinklers needs to be close enough to provide good uniformity based on the design criteria, but as wide as possible to lower capital investment costs. Sprinkler design software should always be used to determine the best spacing to achieve high uniformity. The smaller the wetted radius, the closer the sprinklers will need to be to achieve high uniformity. When devices are lowered into the crop canopy the flight of water droplets is obstructed and the wetted diameter of the sprinkler is decreased. The spacing of sprinkler devices along the pipeline must be decreased to maintain uniformity when devices are in the canopy.
- **Sprinkler mounting height**—traditional designs place sprinklers high enough to prevent the crop canopy from distorting the spray pattern, but close to the canopy to minimize drift and droplet evaporation. However, some farmers place devices in the canopy in an attempt to minimize water loss from wind drift and evaporation. The trend has sparked discussion relating to the best height to place sprinklers. Keep in mind that the wetted diameter of sprinkler devices will decrease when placing sprinklers closer to the ground. In addition, the diameter can greatly decrease when devices are placed in the canopy, leading to poor uniformity and more potential runoff. We discuss this topic in the next section.
- **Droplet size**—the droplet size should be small enough to avoid crusting the soil, but large enough to minimize wind drift and evaporation. Pivots that do not apply water to bare soils to germinate small seeded crops can usually utilize sprinklers that produce medium to larger droplets (i.e., drops larger than 0.04 inches) thereby minimizing wind drift and evaporative losses in the air. Droplet size is controlled by sprinkler type, spray plate, and operating pressure. Higher pressures generally produce smaller droplets.
- **Nozzle size**—the nozzle sizes need to be determined by the sprinkler design software to match the capacity of the water source and sprinkler spacing. In addition, make sure sprinklers are installed in the correct location along the lateral. A pivot can have from 50 to several hundred sprinklers requiring diligence to ensure they are installed in the correct order and at the right location. Keep in mind that smaller orifices plug easily.

IN-CANOPY VS. ABOVE-CANOPY SPRINKLERS

The best height for sprinkler devices relative to crop height has been debated for some time and has recently resurfaced. Some have decided to reposition devices at the truss rod height to back atop the pivot pipeline because of the tall corn varieties being grown today. Others have opted to place sprinklers down in the canopy to try to “save” water. Keep in mind that transpiration is very small while the canopy is wet from irrigation because evaporation is occurring from the canopy. In addition, producers can mitigate evaporation by selecting newer sprinkler devices that produce large or medium sized drops and then leave some crop residue on the soil to prevent surface sealing. Further mitigation can be achieved by keeping the wetted diameter of the sprinklers as small as possible without creating runoff. Thus, the comparison should always be between the best designed for above the canopy compare to in-canopy sprinkler packages for a given field in a specific location and water supply.

The challenges of getting good water application uniformity while preventing runoff or water moving within the field is greatly increased when sprinklers are placed in the crop canopy. The spacing needs to be close, 5 feet or less is best, but not more than 7.5 feet. Many people today are using 30-inch spacing on the outside 3 or 5 spans. The added sprinklers will increase the cost of the package and smaller orifices must be used. If any sand or debris is in the water, it should be filtered before going into the pivot with small orifices to prevent plugging.

Pivots that will irrigate both corn and shorter crops like soybeans have an added challenge when determining the sprinkler height because of the vastly different heights and canopy structure.

Advantages for In-Canopy Sprinklers

Sprinkler packages in the crop canopy have an advantage over above canopy sprinklers by reducing evaporation and wind drift losses. Factors to consider include:

- Most wind drift lands in the field, but more of the canopy is kept wet, which increases net canopy evaporation losses.
- The canopy may stay dryer during irrigation which would reduce canopy evaporation losses, but not completely dry because when sprinklers drag through the canopy they tend to spray water vertically and often get much of the canopy wet as shown in Fig. 4.
- The benefits will be smaller for locations in the Eastern High Plains (*i.e.*, east of Grand Island) because of higher humidity and smaller annual water requirements.
- The advantages will increase with the more arid environment farther west and south in the High Plains because of increased evaporative losses and larger irrigation requirements.
- The advantages will be larger for low capacity systems because

Figure 3. Example of a sprinkler dragged through a corn canopy.

they need to run more hours each year increasing the opportunity of net canopy evaporation and drift. Runoff will also be of less concern for these systems.

- The advantage will be larger if the water source provides warm water from a canal vs. cool well water.
- The economic advantage will be larger if the system capacity or a water allocation is low enough that the reduced evaporation will increase yields most years and not just reduce pumping costs.
- The advantages will be larger if the farmer desires to apply small frequent applications than for larger less frequent applications.
- In-canopy packages are most feasible on level fields where runoff due to the increased water application rate caused by canopy obstruction of water jets occurs. Runoff is much more likely on fields with significant slopes.
- Some dealers and farmers do not like up-top sprinkler placement with high iron water due to the staining of the pivot and possible issues with alignment linkage at the towers.
- No-till usually results in higher infiltration rates and reduced runoff potential.

Disadvantages for In-Canopy Sprinklers

Sprinkler packages designed to operate in the crop canopy will be disadvantaged over above-canopy sprinklers for the following reasons. Factors to consider include:

- The increased cost of closer spaced devices and longer drops
- The sprinklers will drag back in the canopy resulting in the sprinkler spraying water vertically and not horizontally as intended, resulting in wetting of most of the canopy as shown in Fig. 4. Sprinklers also become entangled in the canopy and are frequently stuck in one location for several moves of the pivot lateral. The device simply lifts each time the pivot tower moves, but the device stays at the same radial point in the field. After several tower movements the devices dislodges from the canopy and swings below the pivot lateral skipping over several feet of the row (up to six feet in some cases). The process is then repeated at the next location. Data does not exist to quantify the effect of this action on application uniformity and runoff problems, but the effect is significant and could affect crop yields or require more pumping too

Figure 4. Example of a sprinkler device entangled in the corn canopy.

fully irrigate the crop—especially on sandy soils where lateral water flow in the is less and the soils can hold less water.

- Planting in a circle will help keep the devices in the canopy, but many farmers prefer straight rows.
- Well water that is cooler than the dew point temperature of the air can lead to condensation of water from the air when droplets first travel from the sprinkler device. The droplets will warm during travel, but may experience condensation for a significant portion of the travel through the air. This increase will be small, maybe 1%, but shows that droplet evaporation is insignificant for these conditions.
- Some farmers use 30-inch spaced spray heads in bubble mode to minimize canopy wetting, but runoff needs to be closely monitored.
- Electric systems operating on load control are often shut down during the highest wind and evaporative time of the day. This point is not a disadvantage to in-canopy sprinklers, but it does lower losses for above canopy devices.
- Greatly increased runoff potential, especially in systems with higher capacity.
- The smaller wetted radius will greatly increase runoff potential on sloping fields
- Some sprinklers with moving parts can become jammed by plant material.
- The sprinklers and drop components can potentially have higher maintenance costs because they are dragging through the crop canopy, plus will get flopped around more by the wind during the off season causing them to bang together and into pivot towers.
- The devices are out of sight making it difficult to monitor problems during the season.
- The sprinklers need to wet the entire canopy for fungicide applications.
- The entire pivot should always be fenced off if cattle graze the field and having long drops increases the importance of fencing.
- In-canopy sprinklers may require more management to get the desired results.

Design Considerations for In-Canopy Sprinklers

Based our observations the success of sprinklers placed in the canopy can be improved by:

- Alternating drop tubes between the right and left side of the pivot by clipping the tubes to the truss rods to help reduce runoff potential by effectively decreasing the application rate.
- Clipping drop tubes to truss rods— this appears to help keep devices in the canopy.
- Some designers limit system capacity to 4 to 5 gpm/acre to help prevent runoff.
- Sprinkler spacing should be 40 inches or less on the outside 3 to 5 spans. Often spray heads with bubble capability are used with narrow spacing.
- Managing orifice size is an important part of designing a close spaced package. A good design will use wider spacing on the first span (90 inch to 120 inch) with sprinklers mounted at truss rod height, then 60 inch on the next span or two until an orifice size can be achieved that has little potential to plug when the spacing is narrowed to 30 inch. Other than the first span, sprinklers are often mounted at 2 or 5 feet. Many designers do not like to go smaller then a 3/32 inch nozzle to help prevent plugging.

- Use more streamlined smaller diameter sprinklers to improve movement through the canopy.
- Selecting sprinklers that vibrate, like the Orbitor—this appears to reduce entanglement and helps keep devices down in the canopy.
- Consider using extra weights and mounting them as close to the bottom of the sprinkler as possible to assist in keeping devices in the canopy.
- Sprinklers with moving pads rather than stationary spray pads seem to provide better water penetration through the canopy.
- Avoid sprinkler placement at the corn ear height where the canopy is most dense making it difficult to distribute water to adjacent rows.
- Sprinkler mounting height for short-dense crops like drilled soybeans should be high enough to keep the device above the canopy, consider a minimum of 5 ft.

SUMMARY

Sprinkler packages placed in the canopy have some potential to increase the application efficiency of center pivot and lateral move irrigation systems. However, the challenges of achieving acceptable water application uniformities and preventing local runoff that causes water to move to low areas or wheel tracks in the field are greatly increased.

Additional research needs include:

- The problems associated with the sprinklers dragging back in the canopy and then suddenly swinging several feet forward needs to be researched to determine if this creates uniformity issues that will lower yields or require additional water to meet crop needs across the majority of the field.
- The drag back problems also result in the wetting variable amounts of the canopy—probably less that with above canopy sprinklers. Bubble mode sprinklers at 30 inch spacing may help in some situations. The net canopy evaporation for these systems should be determined.
- Additional research should focus on better ways to keep the sprinklers down in the canopy.
- Ultimately, more research is needed to fully quantify the evaporation, transpiration, runoff and deep percolation for an array of fields with varying slopes and soils for current water application devices.