Proceedings of the 24th Annual Central Plains Irrigation Conference, Colby, Kansas, February 21-22, 2012
Available from CPIA, 760 N. Thompson, Colby, Kansas

CENTER PIVOT SPRINKLER NOZZLE REPLACEMENT AND MAINTENANCE

William Kranz
UNL Irrigation Specialist
Concord, NE
Voice: 402-584-3857 wkranz1@unl.edu

Ray Glaser
Senninger Irrigation
Voice: 308-381-8558
rglaser@senninger.biz

Gene Ross
Nelson Irrigation
Voice: 402-727-0378
Gene.Ross@nelsonirrigation.com

Danny Rogers
KSU Extension Ag Engineer
Manhattan, KS
Voice: 785-532-5813
drogers@ksu.edu

INTRODUCTION

Couched between the installation of a new center pivot and total system failure are a number of maintenance issues that can have a significant impact on economic returns. The original purpose of this paper was to highlight estimates of the expected life of a sprinkler package. However, during the course of our review of the available information it became clear that estimates vary greatly and in the end may not be very useful in ensuring that water application uniformity is maintained over the life of the sprinkler. This discussion will concentrate on a more important issue that is too often placed in the category of 'If it ain't broke don't fix it'. Sprinkler package selection is a major topic when making the original purchase of the center pivot, but it is just the first decision related to managing the center pivot year-in, year-out. To be effective, the sprinklers must continue to run properly which means that when wear and tear causes the sprinkler to malfunction, repair or replacement is necessary.

SPRINKLER DISCHARGE

The design sprinkler flow rate out of each sprinkler orifice is based on the water pressure supplied to the sprinkler inlet as illustrated in Figure 1. Overall, the discharge delivered by a sprinkler also depends on the system capacity, the distance from the pivot point to a specific sprinkler, and the spacing between sprinklers at that location on the lateral. The goal of the sprinkler package selection or design process is select nozzles that would apply water with over 90% application uniformity.

The nozzle diameter has a big influence on the discharge from the nozzle since the discharge depends on the square of the nozzle diameter. For example, at a pressure of 40 psi the discharge for the $^{1}/_{8}$-inch nozzle is 2.8 gpm and discharge for a ¼-inch nozzle is 11.2 gpm. Therefore, doubling the nozzle diameter quadruples the discharge. Depending on the construction material of the nozzle and the quality of water being pumped, the nozzle opening could change. If the nozzle opening increases due to wear, the actual flow rate may be vastly different than the original design.

The effect of pressure is less significant than the nozzle diameter; since, in this case, the discharge varies as the square root of the pressure. For example, the discharge from the ¼-inch nozzle at 20 psi is 7.96 gpm while at 40 psi the discharge is about 11.2 gpm, an increase of 40% in the discharge rate. Normal wear on a pump impeller will result in a decrease in both flow rate and output pressure. Several years after the original installation, each nozzle will likely be supplied with less pressure and flow rate unless pressure regulators were installed and sufficient pressure is available to keep the regulators activated. Without pressure regulators, when nozzles become worn, field topography plays a major role in the flow rate delivered by each sprinkler. Thus uniformity depends on where in the field you look.

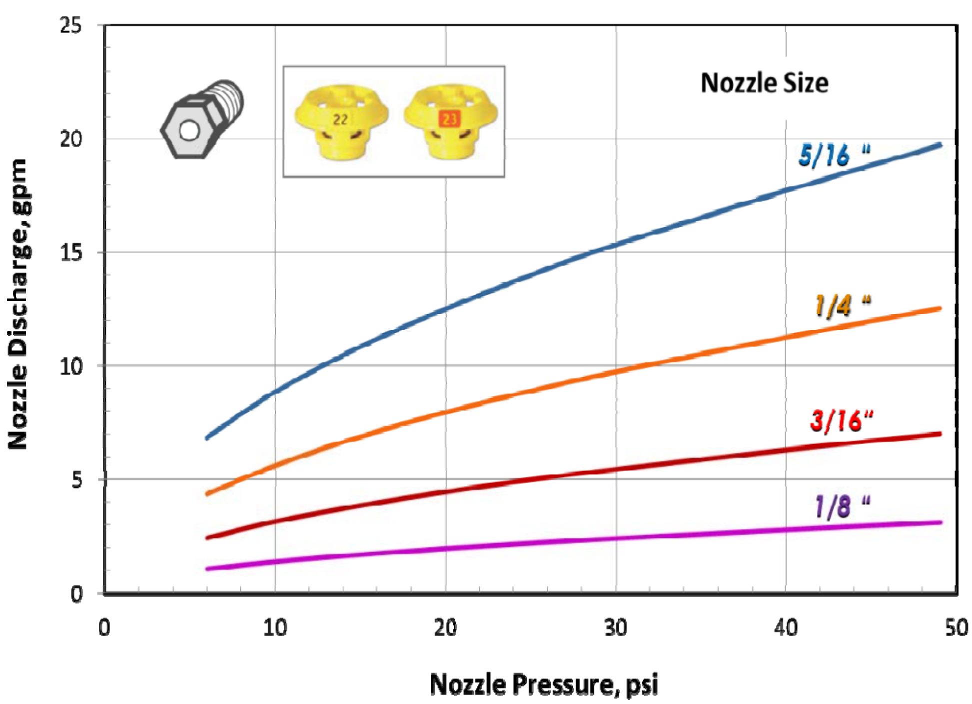

Figure 1. Performance of nozzles used in sprinkler devices

In the absence of the original sprinkler package printout, the approximate flow rate required from each sprinkler can be determined by collecting some information about the overall sprinkler operation. Figure 2 depicts a center pivot lateral showing the spacing between the sprinklers along the lateral and how to measure the distance from the pivot point to a sprinkler at some specific distance from the pivot point. The only other factor needed is the system capacity which is determined by dividing the total flow rate by the number of irrigated acres.

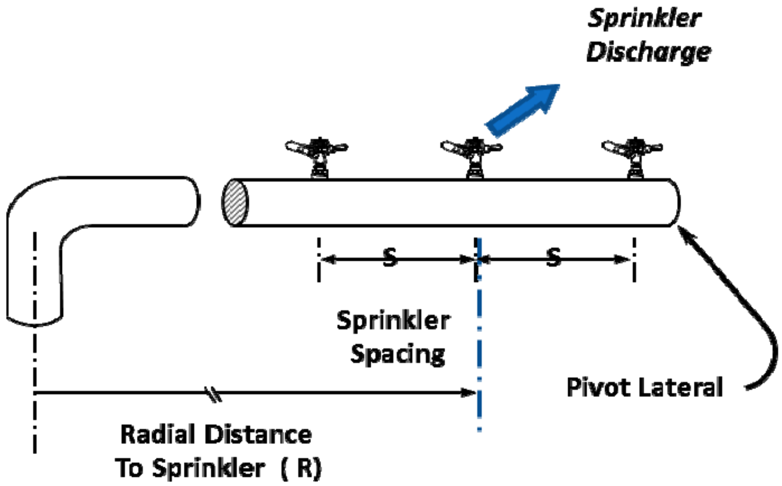

Figure 2. Information used to determine discharge required for a sprinkler along the center pivot lateral.

The following equation describes how to compute the required discharge from a sprinkler:

$$q_s = \frac{C_g \; R \; S}{6933}$$

where:

q_s is the discharge from a sprinkler (gpm),
C_g is the system capacity (gpm/acre),
R is the distance from the pivot point (feet),
S is the spacing between sprinklers along the lateral (feet), and
6933 is a conversion constant

For example, if a sprinkler is located 1000 feet from the pivot, the local spacing of sprinklers along the lateral is 9 feet and the system capacity is 6 gpm/acre, the required sprinkler discharge is:

$$q_s = \frac{6\,gpm / acre \times 1000 \;\; feet \times 9 \;\; feet}{6933} = 7.8 \;\; gpm$$

The required nozzle size can be determined after computing the sprinkler discharge. To select the correct nozzle, the pressure available to the sprinkler must be determined. If pressure regulators are used, the available pressure is usually the pressure rating of the regulator. However, if regulators are not used then the pressure in the sprinkler lateral at the designated location must be determined based on pressure at the pivot point, pipeline friction loss and elevation difference between the pivot point and the position in question.

Though the goal is to apply water in a completely uniform manner, there is virtually no way to accomplish this even with a new system. Due to a limitation in available nozzle diameters, some nonuniformity of water application will occur in the design process. Table 1 presents information taken from a sprinkler design printout for a center pivot in Nebraska and depicts the point quite well. Note that the printout calls for 13.5 gpm at position 94, 912.5 feet from the pivot point (Row 5, Column 7) and the actual flow rate delivered is 13.9 gpm (Row 5, Column 8). This means that the water application depth will be slightly greater than desired at that location. This is because the nozzle diameters increase in 1/128" increments and the sprinkler package design requires a more precisely sized nozzle.

Similar things happen at each tower. Center pivot mainline pipe lengths and distance reserved for each tower can cause sprinkler spacing to change as noted for Position 100 in Table 1. Here the first sprinkler in the next span is located 23 feet from the previous sprinkler (23 feet vs. 19 feet). In this case there will be some nonuniformity that results due to constraints on sprinkler placement resulting from the pivot structure manufacturing specifications.

Table 1. Sprinkler package design printout for a center pivot in Nebraska.

Outlet		**Sprinkler**				**Flow Rate, gpm**		**Pressure**
No.	Loc.	No.	Sep.	Model	Nozzle	Req.	Del.	PSI
86	836.5	39	19	5006H2	RN-#14 x #14	12.4	12.4	61.5
88	855.5	40	19	5006H2	RN-#14 x #14	12.6	12.3	61.4
90	874.5	41	19	5006H2	RN-#15 x #14	13.1	13.1	61.3
92	893.5	42	19	5006H2	RN-#15 x #14	13.2	13.1	61.3
94	912.5	43	19	5006H2	RN-#15 x #15	13.5	13.9	61.2
96	931.5	44	19	5006H2	RN-#15 x #14	13.3	13.1	61.1
98	950.5	45	19	5006H2	RN-#17 x #16	15.7	16.0	61.0
100	973.5	46	23	5006H2	RN-#16 x #16	15.5	15.2	60.9

From a technical point of view, water application uniformity of a center pivot is determined by doing a catch-can test. Catch cans are placed in a ray outward from near the pivot point out to where the last sprinkler applies water. The cans are normally equally spaced at 10-15 foot intervals. Determination of the application uniformity is done by entering the catch amounts for each catch can into an equation that assigns each catch to a representative area of the field. Thus, catch cans near the distal end of the system are weighted more than catch cans near the pivot point. This process is both complicated and tedious to complete. Complications include the influence of the type, size, and spacing of catch cans, and climatic conditions like wind speed and air temperature. These factors most often render the test to one of identifying major water application issues such as improper operation of the sprinkler, missing low pressure drains, leaky tower boots, or improper endgun operation. Most of these same issues can be identified by a much more simple approach which will be outlined in the information provided below.

What are the problems associated with center pivot sprinkler operation?
The most obvious answer to this question is that over time various parts of the sprinkler can become worn to the point where it no longer distributes water over the same wetted area in a uniform manner. However, in some cases the original installation can be the issue. Figure 3 presents results from a catch-can test conducted in Kansas (Rogers, 2008).

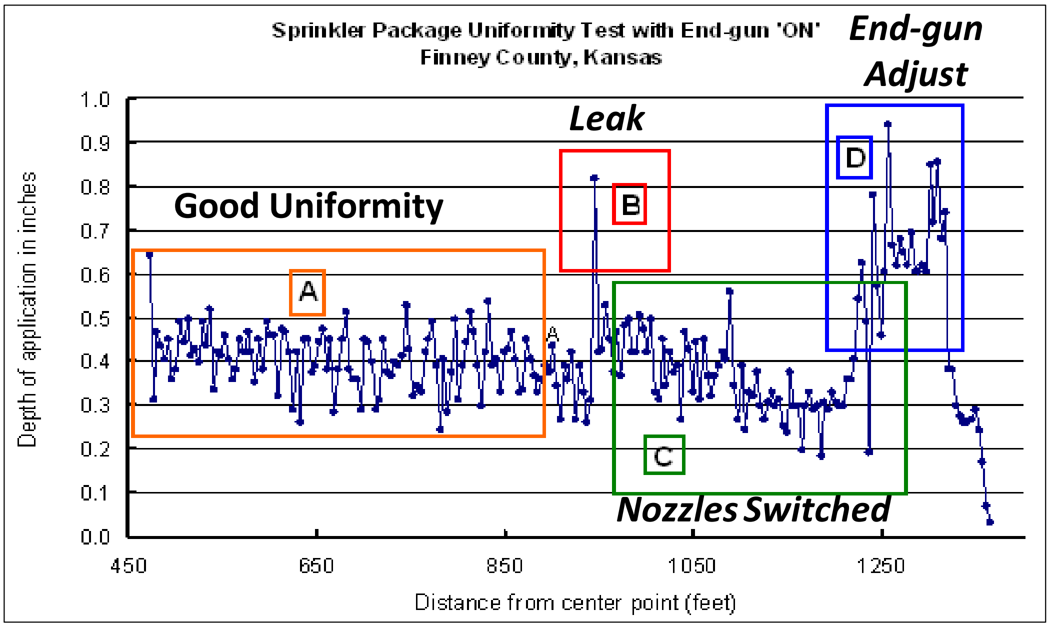

Figure 3. Results of a catch-can test of uniformity for a center pivot in Kansas.

The first 900 feet of this system has few application uniformity issues that are abnormal. Beginning at about 900 feet the catch-can test had several cans with elevated catch amounts. Upon inspection it was determined that the problem was a leak in a tower boot. This leak could have been identified by walking along the system while it was operating. Section C of the system provided some questions that could not be answered by simply walking along the system. However, when comparing the sprinkler package printout to the sprinklers installed it was determined that the sprinklers on two spans were installed in reverse order. The final item identify by the can test is depicted in Section D of the image. In this case, the end gun was set to irrigate a portion of the field located under the pipeline portion of the system. Thus, the field area starting at about 1200 feet was irrigated by the mainline sprinklers and the end gun when the original design was based solely on irrigation by the mainline sprinklers.

The water source can lead to two additional complications. If the water supply is a delivery canal or stream, suspended solids including moss, sand, decaying plant materials, and other solids can pass through the pump and be delivered to the center pivot where these materials can partially or completely plug the nozzle or pressure regulator. This issue can occur anywhere on the system but is often confined to the first couple of spans where nozzle openings are too small to pass the solids contained in the water.

The second water source factor deals with another water quality issue. Water pumped from surface water sources and from some irrigation wells can contain relatively large amounts of sand. When the water-borne sand contacts a stationary deflection pad it tends to wear the grooves out and over time can wear completely through the pad. Generally speaking moving deflection pads are less prone to this issue. In some cases, water containing excessive amounts of calcium and magnesium salts can cause the grooves in a stationary pad to become incrusted with calcium to the point where the grooves have little capacity to distribute water as they were originally designed to do.

Another possibility when the application water contains sand is that the sprinkler diameter may increase in diameter. One way to check to see if the nozzle diameter is greater than the manufactured size is to purchase a set of drill bits in 1/128" increments and based on the size of the nozzle (as shown in Figure 1) insert the correct sized drill bit into the nozzle opening. The drill bit should fit into the opening, but it should be snug so that the drill bit will not move side-to-side very easily. If the drill bit does move side-to-side easily, the nozzle is worn and should be replaced. In some cases, the only thing that needs to be replaced is the nozzle, the rest of the sprinkler and pressure regulator may be just fine.

With the constant introduction of new pesticides, insecticides and fertilizers over the last 25-30 years, end users should be aware that it may be a possible for these products or in combination with other ingredients could lead to deterioration or premature wear to sprinkler products. This sort of deterioration or wear is usually not easy to detect. Potential sites are generally associated with vegetable crop production where fungicides and insecticides are applied several times during the growing season.

The final item that we will discuss is damage to sprinklers caused by impact against the center pivot infrastructure. Sprinklers installed on long flexible drop tubes can be damaged when the wind is blowing at a sufficient enough velocity to cause the drop tubes to swing side-to-side. If the sprinkler impacts the truss rods, tower structure, or pipeline the sprinkler may be cracked or a piece of the sprinkler may be broken off. Sprinklers may also be damaged if the system is exposed to large wind-driven hail. When these kinds of damage occur, it may not be easy to diagnose but over time broken sprinklers will not distribute water according to the original design.

It is always good to conduct the inspection just before sunrise and sunset as the angle of light from the sun makes it easier to identify water application problems. Each sprinkler should be operating and look very similar to the sprinkler next to it. If not, the regulator or nozzle opening could be partially plugged. Each of the issues described above could have been identified by a simple five part inspection which is best done in the spring before the crop canopy is present.

1) Verify that the system is supplied by the correct flow rate and operating pressure,
2) Compare the sprinklers sizes installed to the sprinkler design printout,
3) Verify that the last sprinkler is supplied with correct operating pressure when the end gun is on and the last tower is at its highest point.
4) Verify that the end gun is set to run according to the design sheets, and
5) Verify that the sprinkler is not cracked or broken and that the deflection pads are not worn excessively.

Why is water application uniformity important?

The original sprinkler package design will normally have a water application uniformity above 90% when operated under nowind conditions. Reduced water application uniformity means that some areas of the field are not receiving the correct amount of water. If any of the issues discussed above are present the nonuniformity can occur each time water is applied and the accumulative impact is that grain or forage yield can be less than expected. Often times small problems that impact only a few sprinklers may not be noticeable in yield maps while others can easily be seen from the air. Nonuniform water application can cause significant economic losses when corn is at $6/bu.

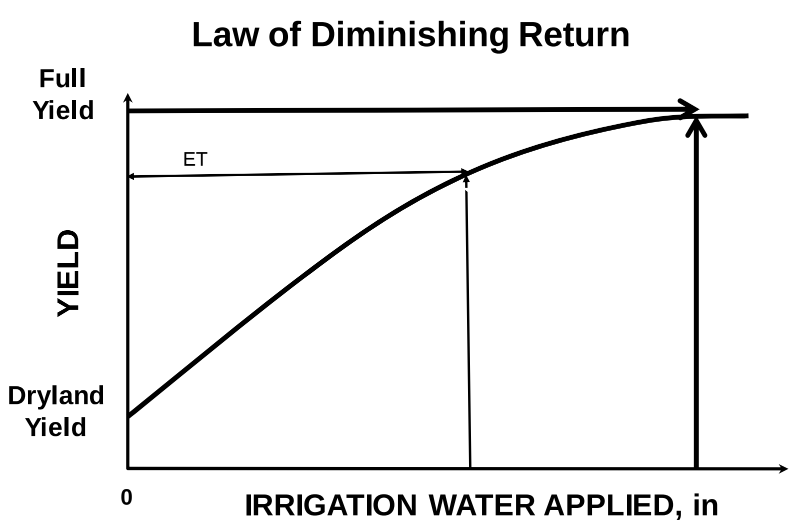

Figure 4. Graphical depiction of the Law of Diminishing Returns with respect to irrigation water application.

Grain and forage yield are dependent on irrigation water application uniformity due to the law of diminishing returns. Poor uniformity can lead to unnecessary water applications Figure 4 shows a grain yield response to irrigation water curve. Note that inside the small boxlike area, yield increases at a fairly constant rate. Recent yield trials would suggest the slope of the line in that segment would be approximately 15-16 bushels per inch of water. However, additional movement to the right on the curve shows that the slope of the curve decreases until on the far right it is flat. Research also suggests that while the plant may survive additional water application, excess water application would merely leach soluble nutrients out of the root zone and yields would begin to decline for each additional inch. This curve is a classic example of crop productivity known as the Law of Diminishing Returns.

One extreme example of nonuniform water application was exposed in Nebraska when aerial photographs indicated distinct rings in some center pivot fields in the western part of the state. The main issue was one of sprinkler spacing and to a lesser extent sprinkler positioning. Sampling of several of these fields identified the season-long impact of nonuniform water application. Hand harvest of each corn row between two sprinklers was conducted where the center pivot was oriented perpendicular to the crop row direction. Figure 5 shows the corn grain yield in bushels per acre for each row. Note that with a spacing of about 17.5 feet, grain yield varied from over 220 bu/ac to180 bu/ac. The economic impact of this outcome is obvious and with today's corn prices; installing at least one more sprinkler between the existing sprinklers was justified.

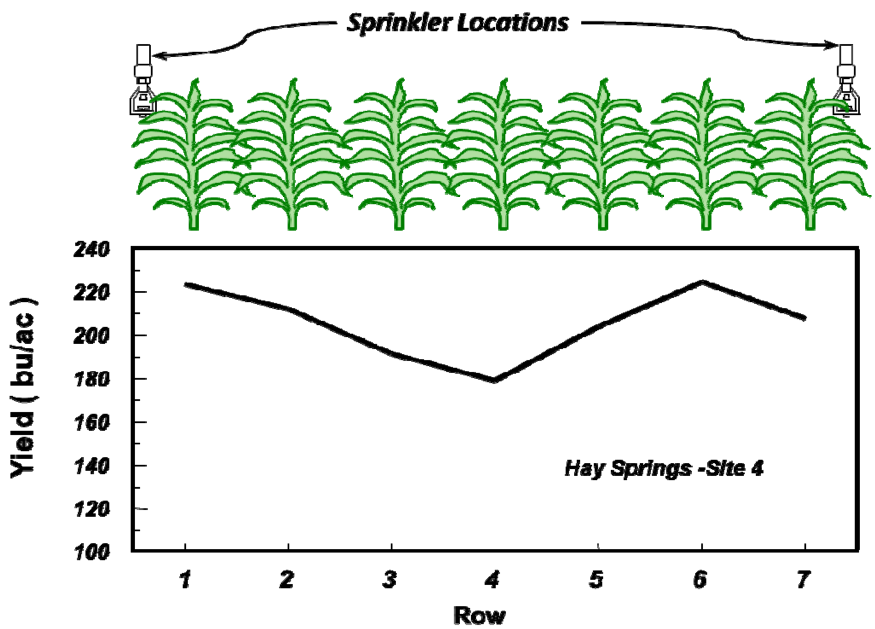

Figure 1. Variation of grain yield for individual corn rows where sprinkler spacing was too wide.

Figure 5 also depicts the situation that would occur if only one sprinkler of a center pivot were plugged or malfunctioning. Assume that there is a sprinkler located between the ones in Figure 5 but it is not functioning. Many of the potential problems discussed earlier in this paper could be included in this discussion. Looking at the graph the main impact of the wide sprinkler spacing is exhibited in rows 2-5 or a 7.5 foot wide strip. Extend a 7.5 foot wide strip along a full revolution and the importance depends on where on the lateral the sprinkler is located. A 7.5 foot wide strip located between 300 and 307.5 feet from the pivot point would represent only1/3 of an acre while the same sized strip located from1250 to 1257.5 feet from the pivot point would represent 1.4 acres. Either way there will be an impact of the malfunction of a single sprinkler on economic returns. Damage to or plugging of a sprinkler could happen during the first season of operation or not until the system has been in operation for 20 years. So delaying replacement of the sprinkler or waiting until the sprinkler package has been in operation for 10,000 hours will allow the problem to impact crop production for the entire period. Thus, one must fix this problem immediately.

The impact of wide sprinkler spacing would be exacerbated if the sprinklers were placed closer to the soil surface. Research conducted at Colby, KS and Alliance, NE clearly indicates that the corn canopy is quite adept at intercepting the water application pattern of most any sprinkler when positioned within the canopy. That work confirms that the water application pattern is narrowed to less than 7.5 feet when the sprinklers are operated in the corn crop canopy. Placing sprinklers at 6 feet from the soil surface would require a sprinkler spacing of 5 feet to ensure uniform water application.

SUMMARY

Selecting a sprinkler package is an important decision when purchasing a center pivot irrigation system. The original design seeks to deliver water with an application uniformity of over 90% unless the owner alters the sprinkler selection criteria due to the cost of the installation. Once installed, it is more important to ensure that each sprinkler continues to operate as it was designed. Field topography and pumping plant performance can have major impacts on the performance of a sprinkler package. Sprinklers may be damaged by a myriad of issues at any time after the original installation. Failure to replace damaged sprinklers or remove materials that may plug nozzle openings allow the water application to be affected in a negative manner for extended periods of time. Keeping good records on pumping plant performance and performing a simple sprinkler system check on a regular basis will help ensure that the system is operating efficiently regardless if it has been in operation for 100 or 10,000 hours.

REFERENCE

Rogers, Danny H., Maybub Alam, and L. Kent Shaw. 2008. Considerations for nozzle package selection for center pivots. KSU Irrigation Management Series No. L908. KSU Extension. pp. 8.