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PERFORMANCE OF CENTER PIVOT IRRIGATION SYSTEMS

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INTRODUCTION

Sprinkler irrigation systems are the largest irrigation system type in the US with about 63 per cent of the irrigated acres served; center pivot irrigation systems cover over one-half of the irrigated land in the US (USDA, 2012). Center pivot irrigation has increased to an even greater extent in some area of the country, for example, in Kansas in 2012 about 93 per cent of all irrigation was sprinkler irrigation which was mostly center pivot irrigation systems (KDA, 2012). Irrigation accounts for about one-third of all water withdrawals in the US (Maupin et al., 2014). In Kansas, irrigation water withdrawals are greater and account for about 85 per cent of freshwater withdrawals (Kenny and Hansen, 2004). Since irrigation represents a large water use and center pivot irrigation is a dominant irrigation system type, it is important that these systems be properly designed, installed and managed to accomplish high irrigation efficiency and crop water productivity. Terry Howell, recently retired director of a USDA-ARS Research Lab in Bushland, TX noted at the 1991 CPIA short course that "Sprinkler irrigation methods can be efficient even in harsh environments, such as the Texas High Plains", (Howell, et al., 1991). The late Dale Heermann and former director of a USDA-ARS Research Lab in Fort Collins, CO began his 1992 sprinkler irrigation presentation at CPIA with these cautionary words, "We often assume that if a system is working for someone else, it will work for us too. Unless all the conditions are identical this myth may cause you troubles" (Heermann, 1992). These two comments are still appropriate today, center pivot sprinkler packages, including a number of "non-sprinkler" options, can efficiently irrigate crops but only if applied and managed appropriately for the condition of use.

DESIGN CONSIDERATIONS FOR NOZZLE PACKAGES

Center pivot sprinkler irrigation systems are used on many fields with various soil and topographical conditions in many climatic zones for a wide variety of crops and cultural practice and can be equipped with many different types of nozzle types or other water distribution outlet devices that have preferred flow and pressure ranges and mounting specifications; essentially meaning there is no universally ideal sprinkler nozzle package. Nozzle package design and select is now generally handled by the irrigation dealer using information provided by the producer. Important field information includes soils and topography and water supply availability, especially the flow rate of a well but crop, cultural practices and producer preferences are factors also. These and other factors affect the selection of the nozzle type, configuration etc. for which many sources information are available Kranz et al., 2012 from CPIA and Extension bulletins such as Rogers et al., 2008 and Kranz et al., 2005.

The process of designing the sprinkler nozzle package is essentially a selection process involving a series of compromises. Most producers who irrigate would like to prevent yield limiting water stress as part of their irrigation goal. The uniformity of the water application and the irrigation efficiency of the system were often secondary goals, especially in situations of abundant water supply and low pumping costs. When center pivot systems were first being adopted in Kansas and other central plains area, many wells had discharge rates that would have been sufficient to select nozzle packages that could exceed the peak water use rate of the crop. However, irrigation capacity (determined by the system flow rate and area served) effects the application rate for a given nozzle type and placement (spacing between nozzles and mounting height) with higher application rate having higher irrigation capacity. The application rate should be less than the soil intake rate and the ability of the soil surface to hold applied water in place until the water is infiltrated. The ability to store water on the surface is related to soil type, slope and surface residue. Runoff from the field and/or water redistribution within the field is an irrigation efficiency loss. Run off loss and other irrigation loss components are illustrated in figure 1. Run off and/or water redistribution for a field should be prevented since it can represent the largest single loss of efficiency if it is occurring.

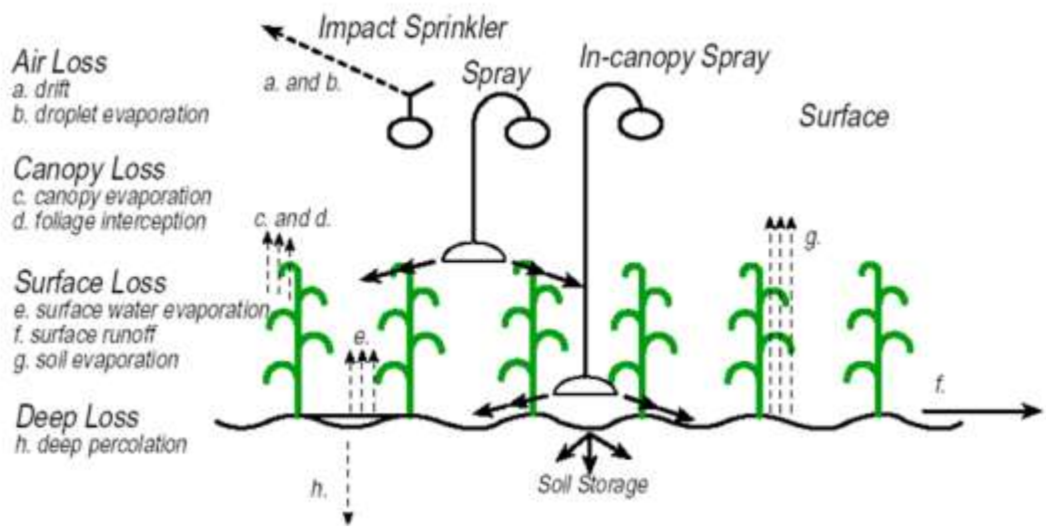

Figure 1: Illustration of where irrigation water losses can occur from KSU Extension Bulletin MF-2243, "Efficiencies and Water Losses of Irrigation Systems"

As wells yields in many areas of the Central Plains and other parts of the world decrease due to declining aquifers levels, deficit irrigation strategies become important to the design process, including trying to minimize irrigation efficiency losses due to air losses and canopy losses (figure 1). Minimization of these losses can be accomplished by using a nozzle that has a small wetted diameter and lowering the mounting height. These two actions will increase the application rate which could lead to run off. Reducing the application rate can also be accomplished by reducing the irrigation capacity which results in less ability to meet the crops needs. Run off may also be reduced for a given condition by speeding up the system but for a given seasonal irrigation amount, this increases the total number of irrigation applications and results in increased air, canopy and surface losses. Thus, large application depths can be more efficient than small application depths but only if no run off occurs and the soil has the storage capacity to hold the water in plant available root zone. The nozzle package selection is also affected by other management considerations such as whether the producer wants to use chemigation or apply irrigation in the non-growing season or during cold weather.

Once a suitable nozzle package design is completed and installed to the specification of the sprinkler package chart, the irrigation operator begins the process of managing system to maintain the integrity of the design specifications. A major specification is the input pressure and flow specifications at the pivot point but if the nozzle selection was also based on certain soil surface treatments and/or residue levels or other operational conditions, these also must be maintained in order for efficient and uniform irrigation to occur.

MANAGEMENT CONSIDERATIONS FOR NOZZLE PACKAGES

Just as routine and emergency maintenance on the pumping plant and center pivot system are essential to longevity and functionality of the equipment, so should maintenance of the nozzle package. While a missing nozzle or completely clogged nozzle can be visually detected, other flow variations between nozzles may not be as obvious.

After the system is installed and correct nozzle placement is verified, the design operating pressure and flow must be supplied to the package for it to perform properly. If properly designed and operated, the water application depth should be delivered with high uniformity across the field. Perfect uniformity is not possible since at each outlet a specific flow rate is required but only a fixed number of nozzle sizes are available. For example, Table 1 shows a portion of a sprinkler package design chart. Notice at each location, the chart shows the required flow rate and the delivered flow rate for each position. The delivered flow rate is sometimes higher or lower than required since manufacturers make nozzle diameters in fixed intervals. The spacing between the nozzle outlets are also sometimes disrupted by the tower structure of the center pivot. This is illustrated by outlet 100 of table 1 when the spacing differs from the previously used value.

Table 1: A Portion of Sprinkler package design printout (Kranz et al., 2012)

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

As noted, visually inspecting for flow variations on an operating system is difficult but best accomplished when sunlight angles are low (sunrise and sunset). The patterns between nozzles should appear similar and if a variation is detected, that area should be inspected more closely.

Closer inspection can involve comparing the installed nozzle diameter to the design nozzle diameter to make certain the correct diameter is in place. If water distribution patterns seen dissimilar at a number of locations, the nozzles may be worn and could be checked by inserting a drill bit of the same diameter size as the design diameter. It should be a snug fit. This could be an issue with water supplies containing sand.

The deflection pads can also be affected by sand and other water quality issues, especially certain salts or minerals that can become encrusted on the pads and cause the deflection pattern to be drastically altered. To a lesser degree, the producer also needs to be aware that certain chemicals and/or chemical combinations could impact the nozzle.

Another component of many nozzles packages are pressure regulators. These also must be operating correctly in order for the nozzle to deliver the correct flow. A study of pressure regulators collected from Kansas fields for older systems indicated good longevity for the sites sampled at the outlet positions sampled on the systems. However, one complete system package was tested and many of the pressure regulators for the first two spans were not functioning properly (Rogers et al., 2010). Since most clogging problems occur due to the small diameter nozzles at this location on the system, it was thought freeze damage to the regulators might have occurred over time.

The combined flow of the individual nozzles is dependent on the proper operating pressure and flow rate at the pivot point. These should be monitored with a pressure gauge and flow meter. The input pressure and flow rate should match the design specification. The sprinkler package cannot operate properly and provide uniform water application if these values are not correct.

The uniformity of application for many sprinkler packages can be evaluated using a catch can test. To be a viable test, certain test conditions must be met, one of which is that there should be at least three feet of clearance between the top of the catch container and the nozzle. In Kansas, many systems have low to the ground drop nozzles (Rogers et al., 2009) and therefore cannot be tested with catch cans. However as part of the Mobile Irrigation Lab program (Rogers et al., 2003, 2006), a streamlined testing procedure was developed and used to evaluate a number of systems to document center pivot uniformity performance. Figure 2 shows the results of an evaluation with different sections of the evaluation designated with letters. Section A designates the portion of the evaluation which had a coefficient of uniformity of about 90 per cent which is acceptable. Section B represents the area that was catching water from a leaky boot connection between two spans. Section C represents the outer area two spans of the system. Notice a gradual decline in application depth in this section, which was due to improper nozzle installation. The nozzles from the two spans were switched during installation. Section D represents the effect of an improperly operating end gun. In this case the end gun operation angle was incorrect and the end gun was over spraying about one-third of the last span and the overhang section of the pivot system. These three problem areas could have been identified with a comparison of the installed nozzle sequence to the design package specification and visual inspection during operation.

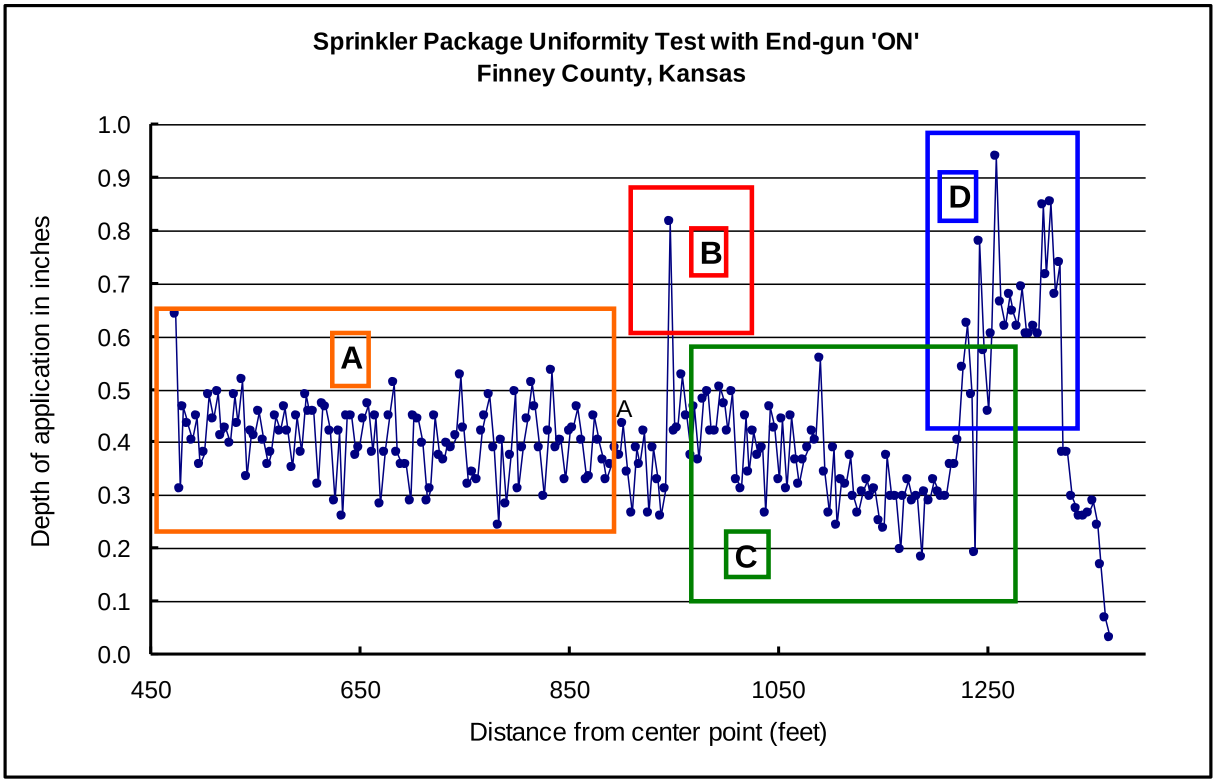

Figure 2. Uniformity test results for a Mobile Irrigation Lab uniformity evaluation (Rogers et al., 2008)

Figure 3 shows the results of another uniformity evaluation conducted in Kansas. The coefficient of uniformity for this system was 84, largely due to the low catch values at the end of the last span and overhang in the area marked with the dashed lines. The producer had noticed low production around the edge of the field but was attributing this to edge effects. The issue was improper installation which included a missing drop nozzle (not installed) and under sized nozzles on either side of the missing nozzle location. Since this location was near the end of the system, the area affected represented approximately 9.2 acres. The application depth in this area was about one-half of the target depth, so over the course of the season, this area might have received 6 inches less water. Assuming only a marginal yield response to water by corn of 10 bushels per inch, the yield loss would be estimated to be at least 60 bushels per acre or over 550 bushels for the affected area. This nozzle package repair would be a minimal expense as compared to the loss of annual crop production. This nozzle package deficiency could have been detected with a comparison of installed nozzles to the design nozzle package.

MANAGEMENT CONSIDERATIONS – IRRIGATION SCHEDULING

The overall irrigation requirement for a field is effected by more than just the irrigation efficiency of the irrigation system. Other factors are the effect of the tillage or cultural practice on off season capture and storage of precipitation and soil water losses to evaporation within the growing season

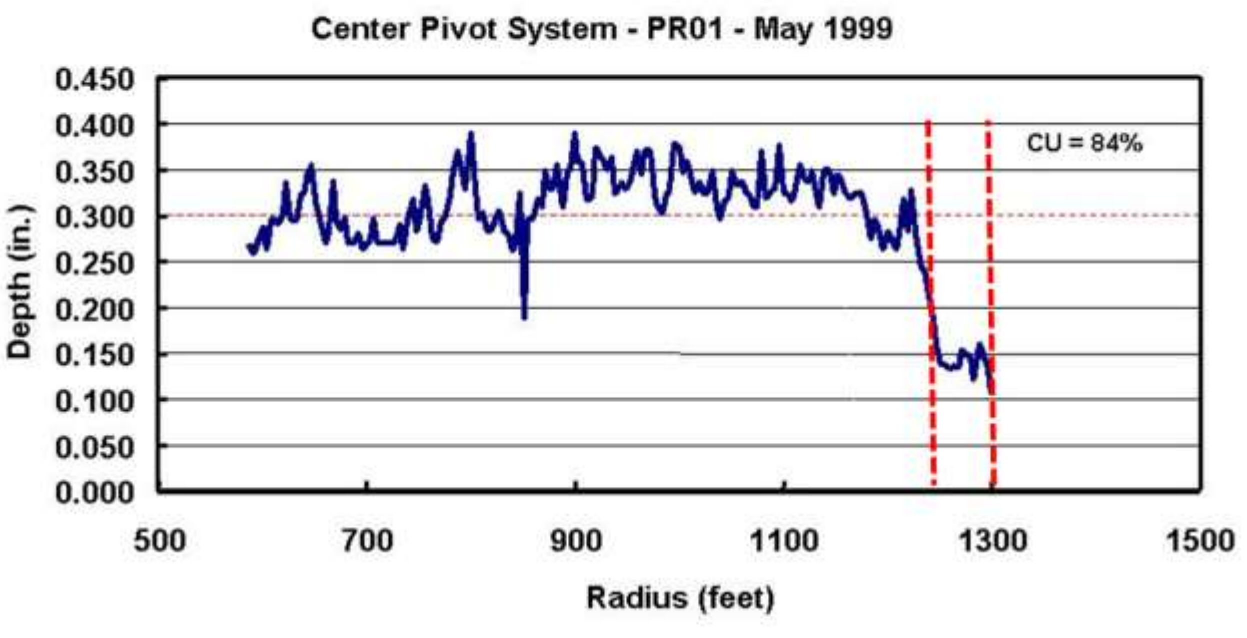

Figure 3. Unformity test results for a Mobile Irrigation Lav uniformity evaluation. (Rogers , unpublished data)

and deep percolation of water below the root zone. These factors would not be directly associated with the sprinkler package but are important to managing the overall water budget of an irrigated field. The effects on the water budget of these factors have been discussed in previous meetings and will be discussed in other sessions at this meeting. However, irrigation scheduling is at least indirectly linked to irrigation efficiency as a single irrigation event that is in excess to the crop needs can offset the entire gain of improving the irrigation efficiency of a system with a sprinkler package up grade. For example, if the gross irrigation application to a field was 10 inches and it was applied at 85 % efficiency, the net irrigation applied is 8.5 inches. If the system efficiency could be improved to 90 %, then the net irrigation application is 9.0 inches, a net gain of 0.5 inches that could either be saved (not used) or applied to gain crop productivity if the system was deficit irrigation mode. However if the crop needs were being met and a single extra irrigation event occurred, assuming a 1.0 inch application amount, the extra irrigation event was greater than all the potential savings from increasing irrigation efficiency.

Irrigation scheduling is a tool to help prevent over application of irrigation water. Although no scheduling method will be perfect in light of unpredictable rainfall events for the central plains region and other areas of the world, it is an important tool to help effectively utilize the high uniformity and application efficiency potential of the nozzle packages. Irrigation scheduling can be accomplished using climatic or crop evapotranspiration based scheduling tools, soil water content based scheduling tools, or a complimentary combination of these type of methods and plant health based methods that are being developed and discussed at this conference.

CONCLUSIONS

The nozzle package of a center pivot irrigation system can apply water in a uniform and efficient manner but only if it is properly matched to the conditions of the field and crop, installed to the design specifications, and operated at the design specifications which include proper pressure and water flow and could include other field conditions, such as a certain level of crop residue to prevent soil surface water movement. Proper maintainance of sprinkler packages include checking of the nozzles to ensure the proper size is at the proper location and that all nozzles are operating without obstuction and distrubing the water in a similar water distribution pattern for the individual nozzles. The package needs to be operated at the design pressure and flow rate specifications which can be monitored with pivot point pressure gauges and water meters.

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