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Impact of Collector Size and Spacing on Center Pivot Uniformity Evaluations

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Abstract. *Field scale evaluations of center pivot sprinkler irrigation systems for water distribution uniformity have been conducted as part of the Mobile Irrigation Lab project (MIL) in Kansas for over ten years. This data base was used to demonstrate the effect on the coefficient of uniformity calculation by using subsets of the data base with increased spacing between collectors. During field evaluations, a portion of several systems were sampled using different collector sizes.*

Keywords. Center Pivot, Irrigation Uniformity, Collector Size, Collector Spacing

Impact of Collector Size and Spacing on Center Pivot Uniformity Evaluations

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ABSTRACT

Field scale evaluations of center pivot sprinkler irrigation systems for water distribution uniformity have been conducted as part of the Mobile Irrigation Lab project (MIL) in Kansas for over ten years. This data base was used to demonstrate the effect on the coefficient of uniformity calculation by using subsets of the data base with increased spacing between collectors. During field evaluations, a portion of several systems were sampled using different collector sizes.

INTRODUCTION

The ASCE On-Farm Irrigation Committee (ASCE, 1978) defines irrigation efficiency as the ratio of the volume of water which is beneficially used to the volume of water applied. Heermann and Solomon (2007) note that beneficial uses can include water used for evapotranspiration, evaporation for cooling and frost protection and water for leaching. However, they go on to note that irrigation efficiency alone does not account for the nonuniformity of an irrigation application in a given field. In the Ogallala Aquifer irrigated region of the U.S. central plains, beneficial irrigation use is primarily concerned with water used to meet crop evapotranspiration needs. The Ogallala Aquifer is experiencing declines, so irrigation water conservation is a major emphasis of water agencies and producers. Agencies are more concerned with minimizing amount of water pumped to extend the life of the aquifer while producers may be more concerned with minimizing pumpage to reduce cost. Increasing irrigation system efficiency and improving irrigation water management through irrigation scheduling are both techniques used to improve the irrigation water productivity. However, as the amount of irrigation water applied is minimized by efficiency and scheduling improvements, the uniform delivery of the water became more important, as full irrigation crop production requires that each plant has equal opportunity access to the water.

The Mobile Irrigation Lab (MIL) project was established in Kansas to promote ET based scheduling and to promote good irrigation system performance with emphasis on center pivot irrigation system uniformity (Rogers et al., 2002a, Clark et al., 2002, Rogers et al., 2002b). Center pivots are the dominate irrigation system in Kansas and are used to irrigate approximately 90 percent of the Kansas irrigated acreage base (Rogers et al., 2009). The MIL field evaluation of center pivot systems had multiple goals, including development of a streamlined testing procedure and documentation of center pivot nozzle package performance for use in extension educational programs.

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IRRIGATION UNIFORMITY

The ASABE Standard S436.1 (R2007) outlines the test procedure for determining the uniformity of water distribution for center pivot and lateral move irrigation systems and describes the collection configuration, spacing, and alignment, using two rows of collectors. The catch from a system is then analyzed using the Christiansen (1942) uniformity coefficient (CU) as modified by Heermann and Hein (1968) for center pivot systems. One of the motivations to begin field evaluations of center pivot performances was an evaluation of a new linear move nozzle package installed at a Kansas State University Research Farm (Clark et al., 2003). It was noted for fixed-plate type sprinkler packages that used the higher end of the nozzle spacing recommendations and lower end of the pressure recommendations of the manufacturer could have lower than acceptable uniformities (less than 90). At that time, the collection pans used were large diameter (430 mm) pans. These pans were difficult to handle after a test and needed to be quickly measured to minimize evaporation losses. The pans, although performing well in terms of quality of catch data, did not meet the need of the MIL project in terms of developing a less labor intensive collection system. This desire for a low cost, non-evaporating catch container resulted in the development of the IrriGage (Clark et al. 2004). The IrriGage catch diameter is 100mm. The catch water drains from the catch barrel into a collection bottle through a small hole. The MIL test procedure used a single line of collectors, spaced at approximately 80 percent of the nozzle spacing, which usually resulted in either a 122cm (4ft) or 244cm (8 ft) spacing due to the common nozzles packages in use in Kansas (Rogers et al., 2009). The catch container size exceeds the ASABE standards. Clark et al. (2006b) compared 100mm IrriGage collections (single and side by side) and 150mm IrriGage for three nozzle types (fixed-plate spray, spinning plate, and wobbling plate) to the large pan collectors. The results indicated more variability in results and differences as compared to pan readings, especially for fix plate sprays. However, all collectors used exceeded the minimum recommended ASAE S436.1 testing standard, indicating this standard may need to be reconsidered, especially for the low pressure spray devices. In a follow-up lab study, Clark et al (2006a), evaluated four collector sizes (52-mm, 101-mm, 148-mm and 198-mm diameter) using a moveable cart that was passed through six different sprinkler patterns. The results tend to indicate more variability in results for the patterns that had distinct streams of water but no collection container size had a distinct and consistent advantage.

RESULTS AND DISCUSSION

Field Evaluations – Collector Size

Four example evaluations are shown in Figures 1-8. Figure 1 shows the overall system evaluation for a center pivot equipped with rotator nozzles with a CU of 65.9 percent. In the other section 43-cm (17-inch) large black pans, 10-cm (4-inch) and 15-cm (6-inch) IrriGages were positioned. The catch analysis shows both the 10-cm and 15-cm showed more variability as compared to the black pan. The average catch depth for the IrriGages was similar with the pan amount being less. The 10-cm IrriGage had a lower CU (73.4 percent) while the 10-cm IrriGage(86.9 percent) and pan (89.2 percent) were similar.

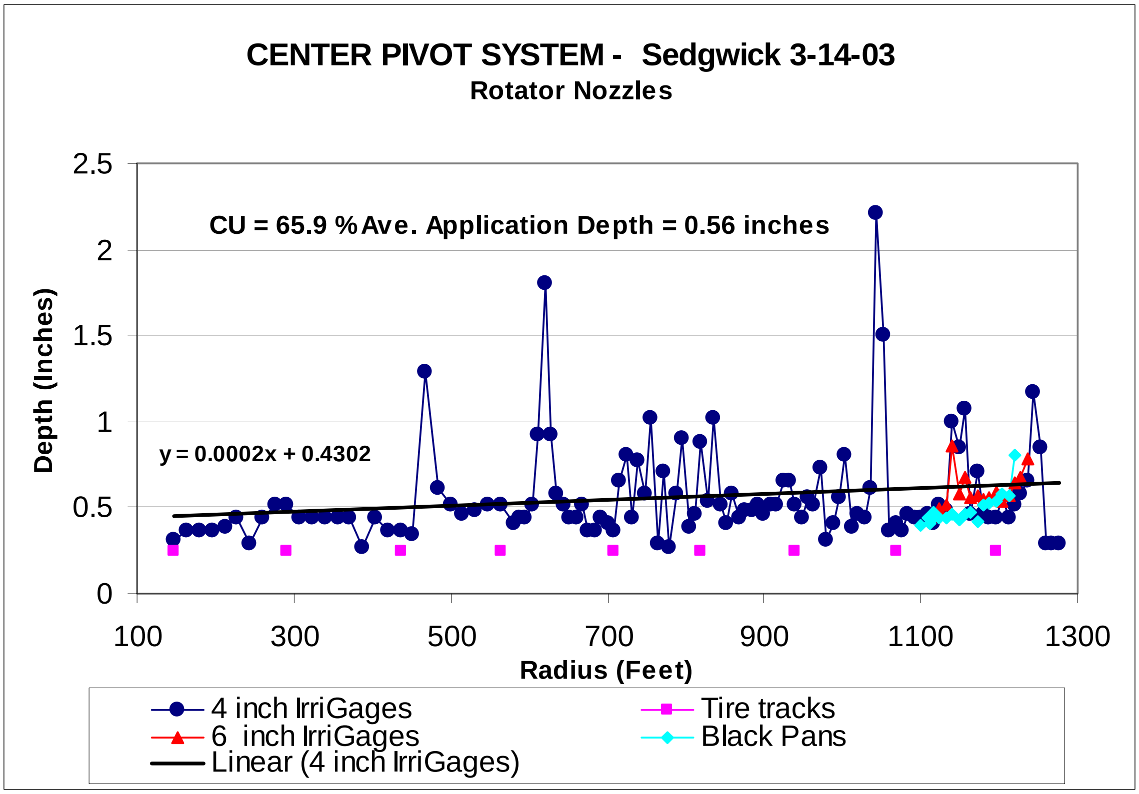

Figure 1: Center pivot uniformity analysis for a rotator nozzle package.

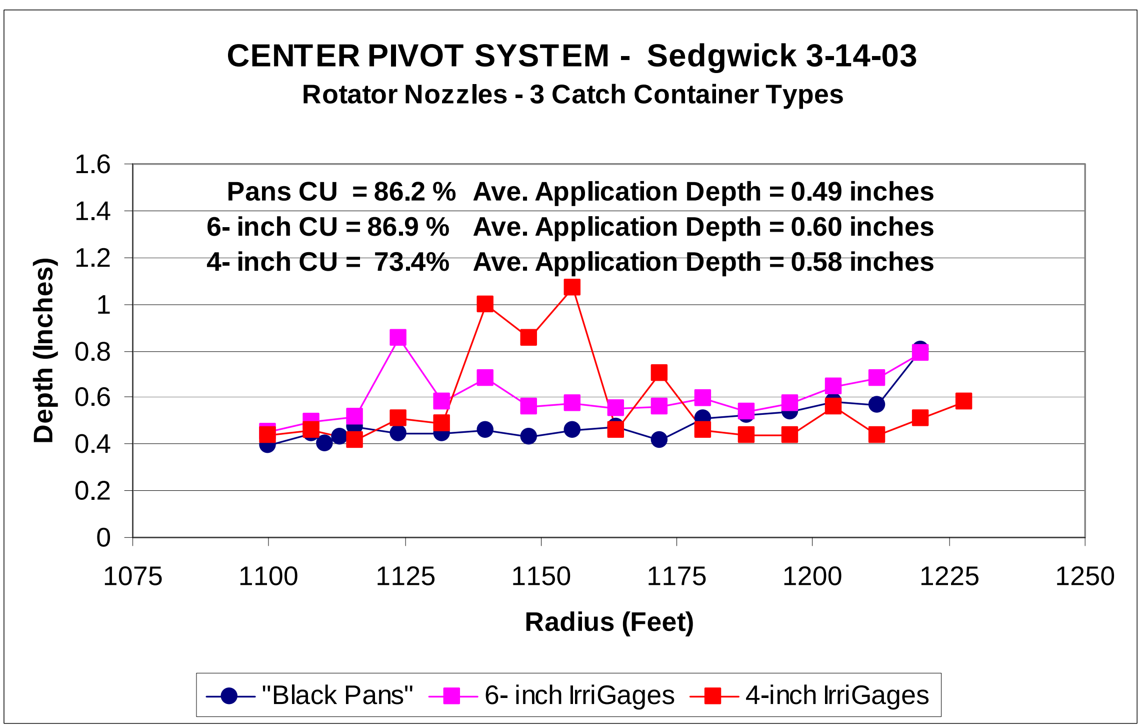

Figure 2: Comparison of three catch container sizes for a center pivot uniformity analysis.

In Figure 3, the overall uniformity of a rotator nozzle package is 87.0 percent. In Figure 4, the results from a section of that system was sampled using 10-cm and 15-cm IrriGages and rectangular shaped trough with openings of approximately 12-cm by 48-cm. One line of troughs was placed end to end across the sample section (trough1) while the other (trough2) was centered on the collection points of the IrriGages. In this case, the 15-cm IrriGage showed more variability than the 10-cm IrriGage. However, both showed more variability then either trough arrangement.

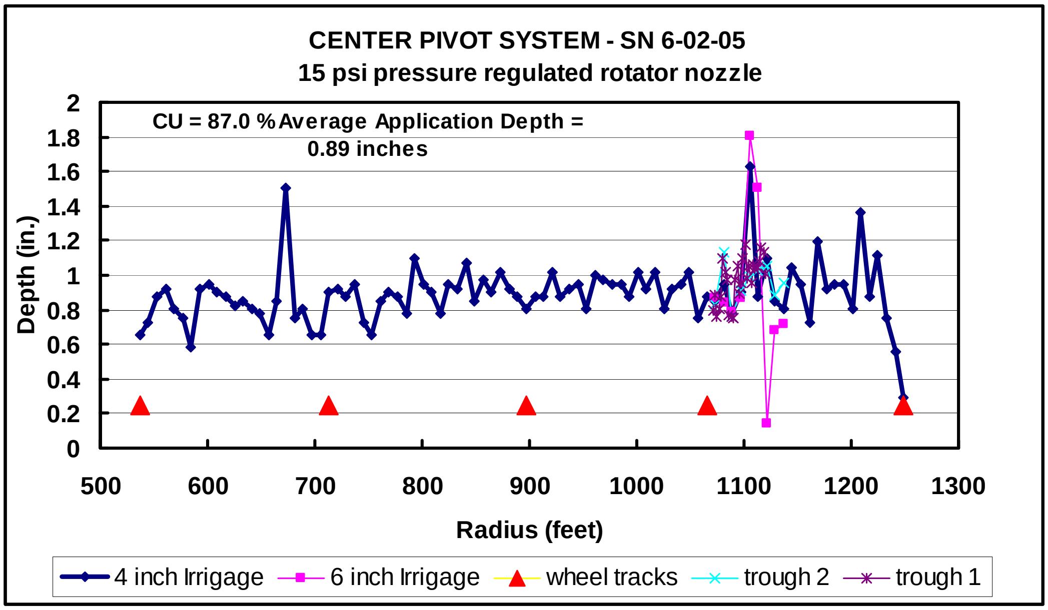

Figure 3: Center pivot uniformity analysis for a rotator nozzle package.

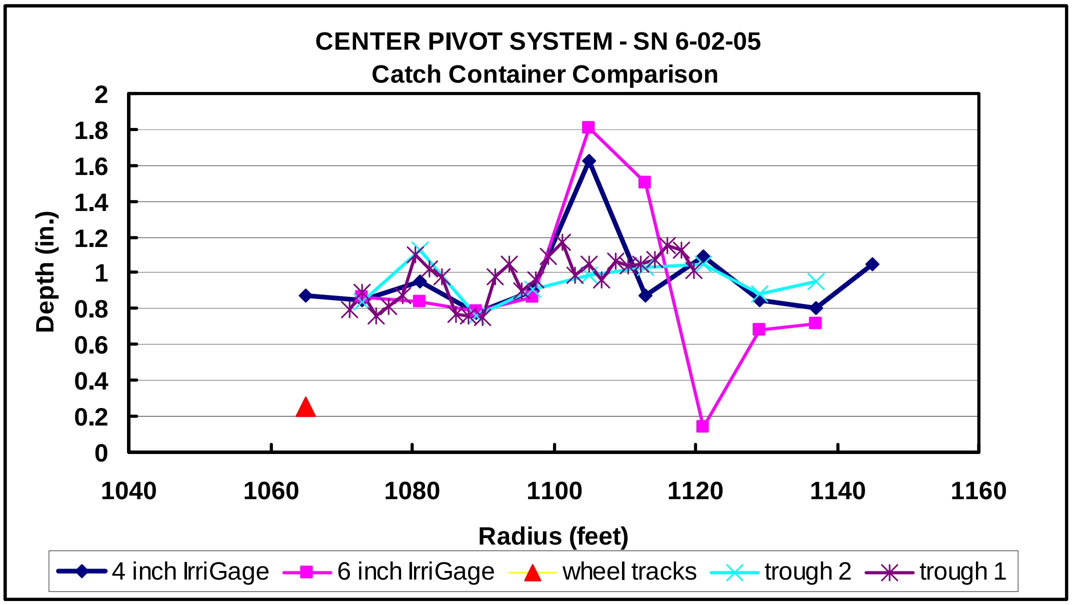

Figure 4: Comparison of four catch containers for a center pivot uniformity analysis.

In Figure 5, a pressure regulated flat spray nozzle package had a CU of 72.8 percent. In Figure 6, the CU's from a text section are shown for 10-cm and 15-cm IrriGages and two troughs as described previously. In this test section, the 15-cm IrriGage had the lowest CU (70.3 percent) as compared to the other collectors. Both trough configurations had higher CU's than did the IrriGages.

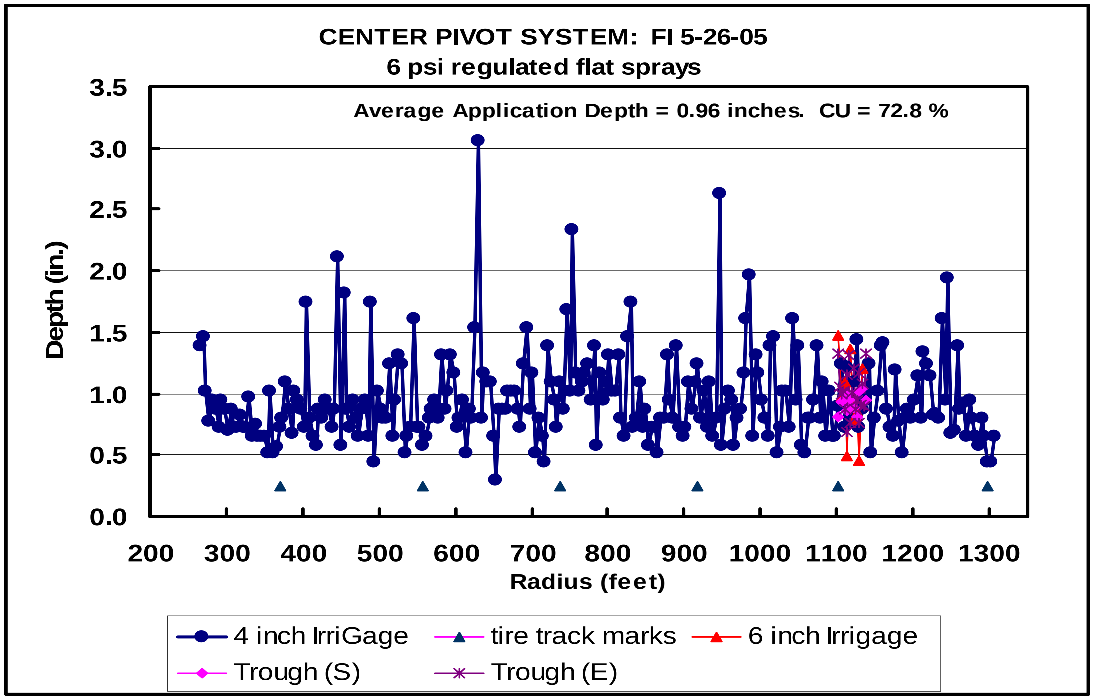

Figure 5: Center pivot uniformity analysis for a pressure regulated flat spray nozzle package.

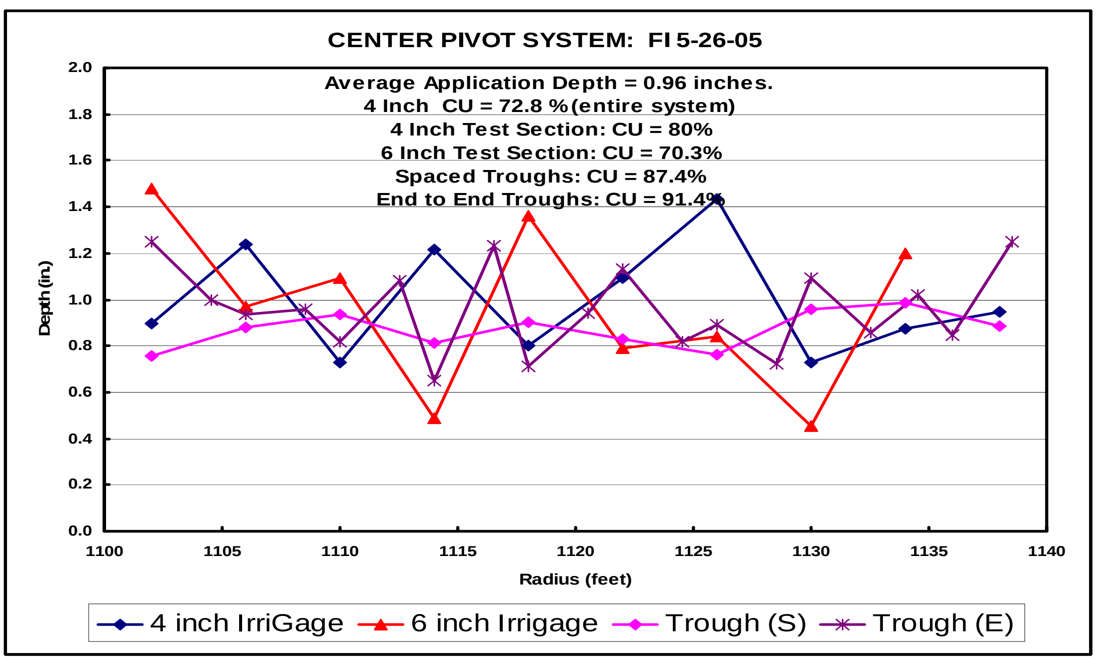

Figure 6: Comparison of four catch containers for a center pivot uniformity analysis.

Figure 7 Shows the CU evaluation (76.3 percent) of a center pivot equipped with an I-Wob nozzle package. A portion of this system was tested with both 10-cm and 15-cm IrriGages as shown in Figure 8. The results for the two container sizes show very similar patterns and calculated CU's (73.8 and 74.3 percent). The depth of catch for both containers was less than the average for the system but note in the full analysis (figure 7) that there was a change in depth of application along the pivot lateral.

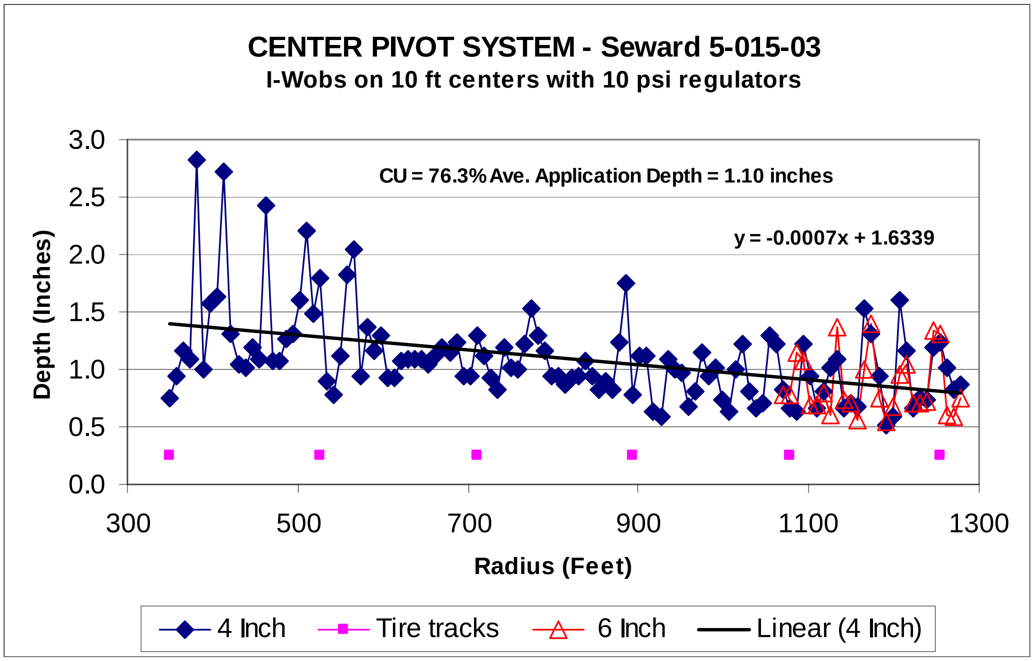

Figure 7: Center pivot uniformity analysis for an I-wob nozzle package.

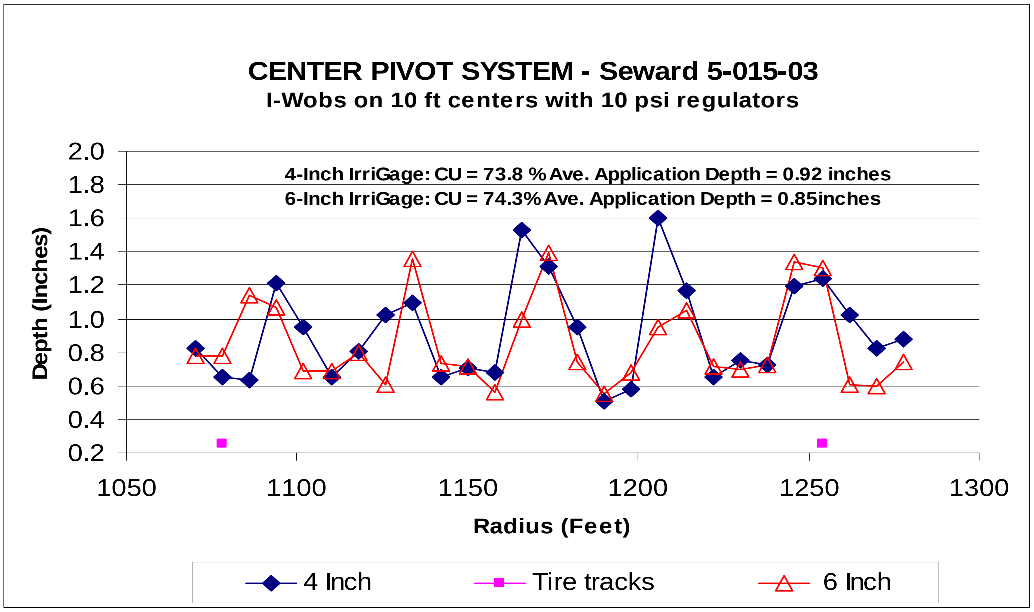

Figure 8: Comparison of two catch containers for a center pivot uniformity analysis.

Container Spacing

The spacing of the catch container is also a consideration when trying to evaluate the uniformity of a system. In one field evaluation, the container spacing for a section of the system was tested at half the spacing of the rest of the system. The field analysis for the full system is shown in Figure 9 while the results for the doubled number of containers are shown in Figure 10. The portion tested was a very uniform test section. In this instance, increasing the number of catch containers resulted in some additional variability in the catch.

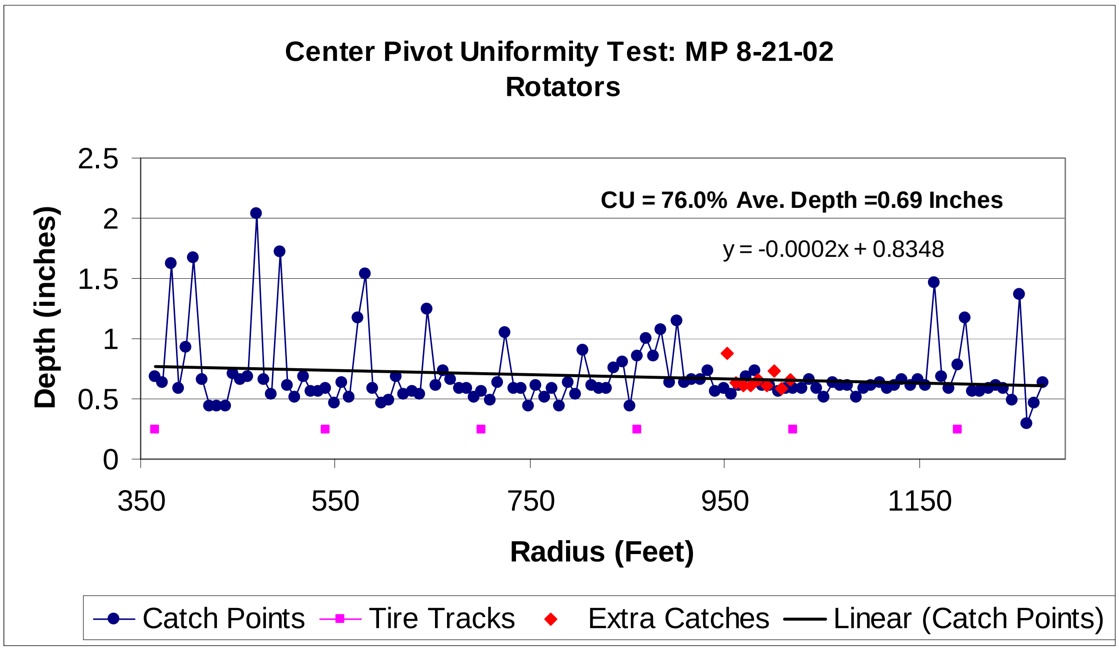

Figure 9: Center pivot uniformity analysis for a rotator nozzle package.

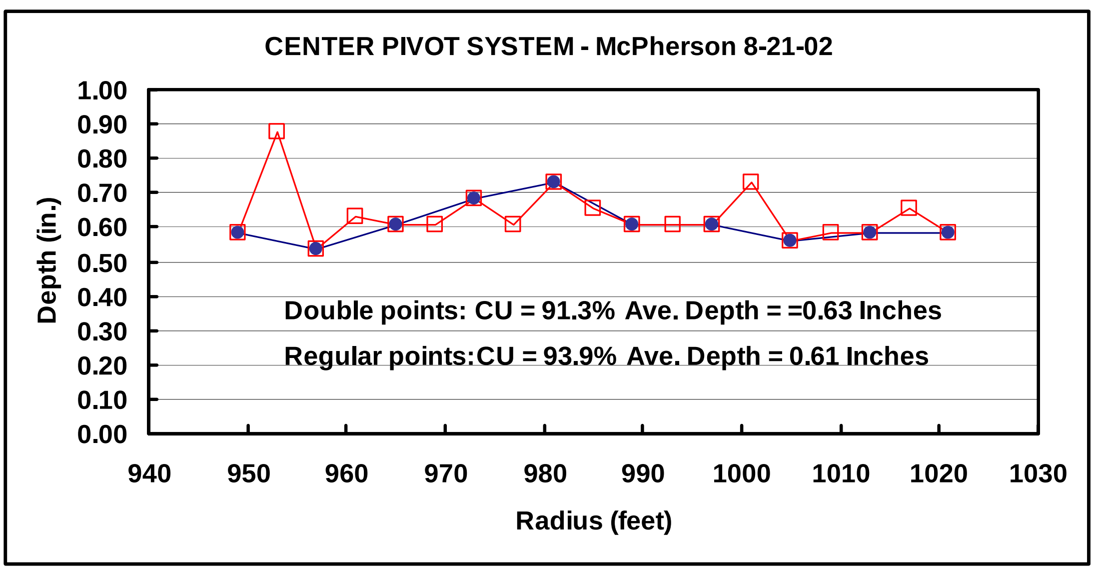

Figure 10: Comparison of two catch container spacing for a center pivot uniformity analysis.

Pragada (unpublished Master's Report, 2008) evaluated the results of 26 center pivot uniformity tests. The original tests were conducted using the general spacing of approximately 80 percent of the nozzle spacing as described previously. The data sets were divided into subsets using either 50 or 33 percent of the original data base (i.e. doubling or tripling the original spacing). The analysis indicated that the subset uniformity values were not different than the base set. In Table 1, results for a number of uniformity evaluations are shown using the full data set, one-half of the data set or one-third of the data set in the CU and regression line analysis.

Table 1: Effect of IrriGage Spacing on CU and Trendline Analysis for three nozzle types.

Type	System	Spacing	CU%	Depth (in.)	Regression Equation
Iwobs	BT 3-27-02	Full-8 ft.	81.7	0.63	y=0.0003x+0.3744
		2X-Odd	82.6	0.62	y=0.0003x+0.3579
		2X-Even	81.0	0.65	y=0.0003x+0.3922
		3X-Set 1	82.0	0.61	y=0.0003x+0.3659
		3X-Set 2	81.9	0.63	y=0.0003x+0.4328
		3X-Set 3	81.4	0.64	y=0.0004x+0.321
	PN 4-01-03	Full-8 ft.	81.9	0.71	y = -5E-06x + 0.7182
		2X-Odd	77.9	0.73	y = 0.0002x + 0.5494
		2X-Even	86.5	0.70	y = -0.0002x + 0.8873
		3X-Set 1	81.3	0.72	y = 8E-06x + 0.7172
		3X-Set 2	79.2	0.74	y = -3E-06x + 0.7419
		3X-Set 3	85.4	0.68	y = -1E-05x + 0.692
	RC 7-06-00	Full-10 ft.	72.8	0.88	y = -0.0002x + 1.0723
		2X-Odd	72.4	0.89	y = -0.0001x + 0.9781
		2X-Even	73.1	0.88	y = -0.0003x + 1.1665
		3X-Set 1	70.9	0.85	y = 0.0001x + 0.7408
		3X-Set 2	72.0	0.96	y = -0.0005x + 1.3938
		3X-Set 3	77.8	0.84	y = -0.0003x + 1.1102

Type	System	Spacing	CU%	Depth (in.)	Regression Equation
Rotators	MP 8-21-02	Full-8 ft.	76	0.69	y = -0.0002x + 0.8348
		2X-Odd	78.4	0.67	y = -0.0002x + 0.8135
		2X-Even	74.1	0.72	y = -0.0002x + 0.8564
		3X-Set 1	80.5	0.66	y = 7E-05x + 0.6012
		3X-Set 2	72.2	0.71	y = -0.0003x + 0.9392
		3X-Set 3	75.7	0.71	y = -0.0003x + 0.981
	PR 5-27-99	Full-4 ft.	84.3	0.3	y = -8E-05x + 0.3761
		2X-Odd	83.8	0.297	y = -9E-05x + 0.3803
		2X-Even	84.7	0.302	y = -7E-05x + 0.3717
		3X-Set 1	83.3	0.302	y = -7E-05x + 0.3707
		3X-Set 2	84.4	0.295	y = -7E-05x + 0.3601
		3X-Set 3	85.2	0.301	y = -0.0001x + 0.3981

	RC 98	Full-	91.9	0.81	y = -3E-05x + 0.8468
		2X-Odd	91.2	0.82	y = 5E-05x + 0.7684
		2X-Even	92.7	0.81	y = -0.0001x + 0.9305
		3X-Set 1	91	0.81	y = 0.0001x + 0.7099
		3X-Set 2	92.5	0.83	y = -7E-05x + 0.8975
		3X-Set 3	92.2	0.8	y = -0.0001x + 0.9435
	RC B01	Full - 10	72.8	0.88	y = -0.0002x + 1.0723
		2X-Odd	72.4	0.89	y = -0.0001x + 0.9781
		2X-Even	73.1	0.88	y = -0.0003x + 1.1665
		3X-Set 1	70.9	0.85	y = 0.0001x + 0.7408
		3X-Set 2	72.0	0.96	y = -0.0005x + 1.3938
		3X-Set 3	77.8	0.84	y = -0.0003x + 1.1102

Type	System	Spacing	CU%	Depth (in.)	Regression Equation
Fixed Plate Spray	FD 5-16-02	Full-8 ft.	58.2	0.65	y=-0.0005x+1.0355
		2X-Odd	56.8	0.62	y=-0.0003x+0.8814
		2X-Even	59.7	0.68	y=-0.0007x+1.1926
		3X-Set 1	60.5	0.70	y=-0.0009x+1.3559
		3X-Set 2	62.5	0.58	y=-0.0004x+0.9024
		3X-Set 3	53.1	0.67	y=-0.0002x+0.8291
	KW 6-09-99	Full-4 ft.	89.9	0.32	y = 8E-06x + 0.3147
		2X-Odd	89.7	0.33	y = 2E-05x + 0.3088
		2X-Even	89.9	0.32	y = -3E-06x + 0.3208
		3X-Set 1	90.8	0.32	y = 2E-06x + 0.3162
		3X-Set 2	89.4	0.33	y = 1E-06x + 0.3236
		3X-Set 3	89.2	0.32	y = 2E-05x + 0.304
	SN 7-18-02	Full-6 ft.	50.1	0.67	y = -0.0003x + 0.9835
		2X-Odd	44.6	0.68	y = -0.0004x + 1.0309
		2X-Even	55.5	0.66	y = -0.0003x + 0.9343
		3X-Set 1	44.7	0.62	y = -0.0005x + 1.0806
		3X-Set 2	56.2	0.75	y = -0.0001x + 0.8713
		3X-Set 3	50.7	0.64	y = -0.0004x + 0.9983
	LN 4-03003	Full-8 ft.	71.0	0.56	y = 8E-05x + 0.5036
		2X-Odd	70.6	0.57	y = 8E-05x + 0.5121
		2X-Even	71.5	0.56	y = 8E-05x + 0.4947
		3X-Set 1	71.8	0.52	y = 6E-06x + 0.5136
		3X-Set 2	70.0	0.61	y = 0.0002x + 0.4292
		3X-Set 3	71.5	0.56	y = -9E-06x + 0.5642
	ED 6-02-99	Full-4 ft.	86.6	0.54	y = -6E-06x + 0.548
		2X-Odd	87.2	0.54	y = 8E-06x + 0.5316
		2X-Even	86.0	0.54	y = -2E-05x + 0.565
		3X-Set 1	86.1	0.55	y = -6E-05x + 0.6074
		3X-Set 2	86.4	0.55	y = 8E-05x + 0.4644
		3X-Set 3	87.6	0.53	y = -4E-05x + 0.5736

Figure 11 shows the results of a center pivot uniformity test that illustrates several types of uniformity deficiencies (Rogers, et al., 2008). Section A of the pivot illustrates a portion of the sprinkler package that was performing well. This area of the pivot has a coefficient of uniformity of almost 90 percent. In section B, a leaky boot connection between two spans was caught in one container. Section C represents the area covered by the outer two spans of the system that shows an area of over watering and under watering. The difference in depth was the result of the nozzles for the two spans being switched at installation. Section D of Figure 5 demonstrates the effect of an improperly operating end gun. In this case, the end gun operation angle was improperly set and it was over spraying the nozzles of about one third of the last span and overhang of the center pivot. In this example, all of the causes of the poor uniformity could have been found with a visual inspection while the system was operating or by a comparison of the installed nozzle order to the design specifications for the system. The system modifications to correct the deficiencies would have been relatively inexpensive to correct. In this example, only one catch container captured the leak noted in area B of Figure 11. Using the spacing analysis as shown in Table 1, three of the five data sets would have missed this identifying this deficiency. The goal of performance evaluation may also be a factor in determining the desired spacing. In the case of the MIL evaluation, the close spacing (80 percent of nozzle spacing) means each nozzle should make a catch contribution to at least one container, if it is performing properly.

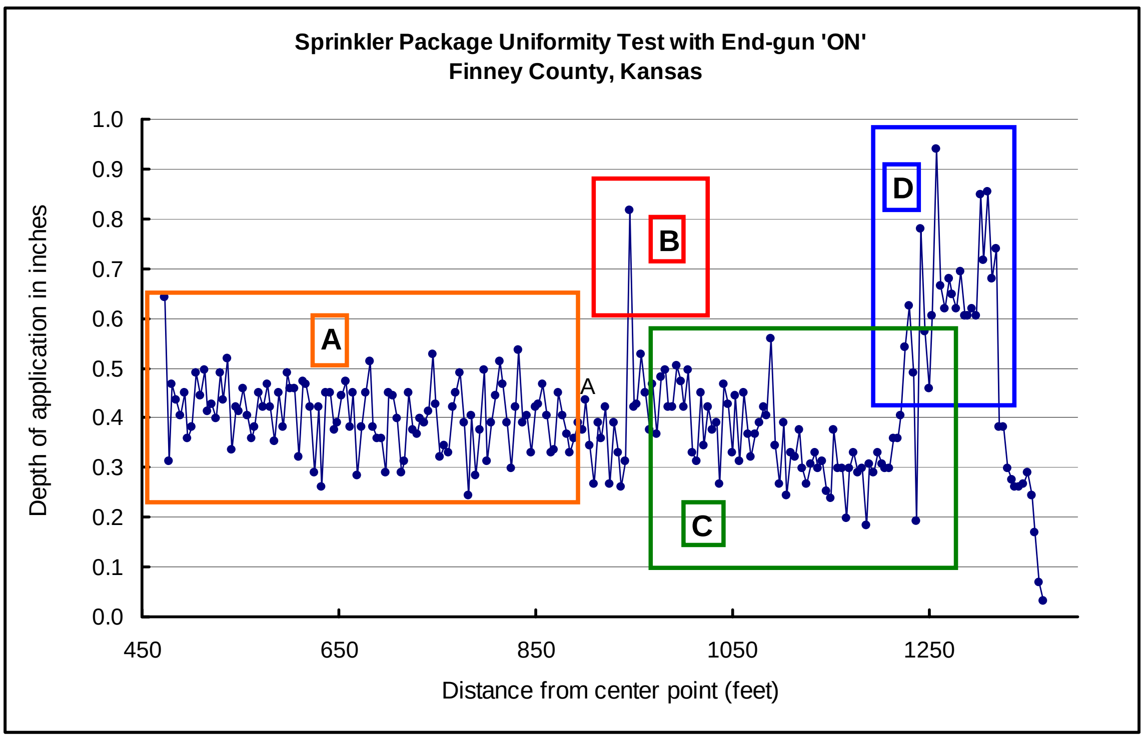

Figure 11: Center pivot uniformity analysis illustration several types of performance deficiencies.

SUMMARY

Determining the uniformity of coefficient (CU) for a center pivot appears to be relatively insensitive to the collection spacing. The spacing used may be more subject of the goal of the evaluation, such as whether to document individual nozzle deficiencies (close spacing) or determine the overall performance (wider spacing). The proper size for the container is more confounding, both literature and the test results indicate variability and inconsistencies with regards to the container size.

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