Effect of collector size on center pivot water depth catch

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Abstract: *The ASABE standard on uniformity testing of a center pivot system contains specifications on the collector size to measure the applied water depth. The standard was developed before many of the current sprinkler application devices were developed. A study comparing the catch depths of five collector sizes for three types of sprinkler application devices: spinning plate, fixed plate, and wobbling plate sprinkler systems using four 5x5 Latin squares. Each collector's water depth was measured and statistically analyzed. Two analysis of variance (ANOVA) tests of the collector size effect were reported. Past experimental results were also compared to this experiment's results.*

Keywords: Center pivot irrigation, uniformity, sprinkler packages collector size

Introduction

Center pivot irrigation systems are used to irrigation over 90 percent of the irrigated land in Kansas (Rogers and Aguilar, 2017) and over 50 percent in the US (USDA, 2013). A variety of reasons related to the adaptability of the systems to a wide variety of field conditions, crops, cropping systems, labor, water supplies and ultimately favorable economics, along with the capability of efficiently and uniformly applying water, have contributed to the conversion to center pivot irrigation systems from surface irrigation systems or the expansion of irrigation into previously unirrigated cropland areas.

Quantification of the uniformity of water application by sprinkler systems was pioneered by Christiansen (1942) which was before the invention of center pivot sprinkler irrigation systems. The adaption of Christiansen's coefficient of uniformity (CU) concept to center pivot systems was accomplished by weighting of the individual application depths along the center pivot lateral relative to the area served at that location (Heermann and Hein, 1968). This adaptation of the

CU equation is the basis for the ASABE standard, *Test Procedure for Determining the Uniformity of Water Distribution of Center Pivot and Lateral Move Irrigation Machines Equipped with Spray or Sprinkler Nozzles,* for quantifying the water application uniformity for center pivot irrigation systems (ASAE S436.1, 2007).

In addition to ASAE S436.1, ASAE S398.1 (2007), *Procedure for Sprinkler Testing and Performance Reporting,* is a standard to quantify the performance of individual sprinkler devices. This standard does not specify the collector size, only that they should be identical and no water can splash in or out. ASAE S436.1 expands the specification to include that height of the collector and the minimum entrance diameter which is to be no less than 60 mm.

Schneider (2000) noted that the use of collectors is the common method of measuring irrigation application depths but cautioned against using small catch cans for use on uniformity studies of spray irrigation systems. Marek and Howell (1987) compared the catches of seven different collectors to a separatory funnel gage used in their previous research and found that the larger diameter collectors had less variability than smaller diameter collectors. They indicated a diameter of 75 mm was needed to measure with +/- 2 percent of the separatory funnel gage.

Clark et al. (2006a) used 100 mm Irrigages (Clark et al., 2004) to measure the application uniformity of three low pressure center pivot nozzle devices and compared the results to a 430 mm pan collector and found the under reported the application depths as compared to the pans. The test was repeated the following year for the same system but a different location within the field, this time the Irrigages collected higher application depths than the pans, leading to the conclusion that the diameter size of the Irrigage used was too small for the low pressure application devices of the irrigation system. Clark et al. (2006b) conducted a lab study to determine the minimum collector diameter for spray systems using diameters from 52 to 780 mm and compared the results to collectors with a 198 by 211 mm opening. The results from the collections from six different spray devices were highly variable, again leading to a conclusion that consistently measuring water application depths is a challenging task.

The goal of this study was to evaluate the accuracy and variability of irrigation water application depths of various collector diameter sizes for three types of water application devices; fixed plate, spinning plate and wobbling plate sprinkler devices. Five collector devices with unique diameters were positioned under center pivot irrigation systems in a 5 x 5 Latin square arrangement to measure the application depth and through the statistical analysis seek to identify the ideal collector size for the three application device types.

Procedures

Field evaluations were conducted at three farms near Garden City, KS, each equipped with one of the target application devices. Site 1 was equipped with spinning plate devices, represented by Nelson A300 Accelerator with Nelson 69 kPa pressure regulators that were positioned approximated 1.5 m above ground surface. At the test zone, the nozzle sizes were two Nelson #28 (5.56 mm; 28/128 in.), and a #29 (5.75 mm; 29/128 in.) with a spacing of 3.05 m. Site 2 was equipped with fixed plate devices, represented by Senninger LDN sprays with D3000 blue plated and #29 (11.5 mm; 29/64 in.) nozzle sizes with Senninger 104 kPa pressure regulators that were positioned approximately 1.8 m above ground surface and spaced at 1.5 m. Site 3 was equipped with wobbling plate devices, represented by Senniger I-Wobs with LA9 pads and 6.55 mm (33/128th in.) nozzles and Senninger 83 kPa pressure regulators that were positioned approximately 2.3 m above ground and at a 2.3 m spacing.

Twenty collectors for each of the five diameters were constructed which were 5.5 cm, 10 cm, 14.8 cm, 20 cm, and 27.4 cm, referenced as C2, C4, C6, C8, and C10, respectfully. All collectors had a height of 20.3 cm and beveled to create a sharp-edge inner lip. Additional construction details are available in Wiens, (2010).

SAS 9.2 was used to generate the design of the collector arrangement in the field. Four Latin square replicates were used for each sprinkler test. Figures 1 and 2 show the details of the generalized test location within the field and example collector position within the Latin square.

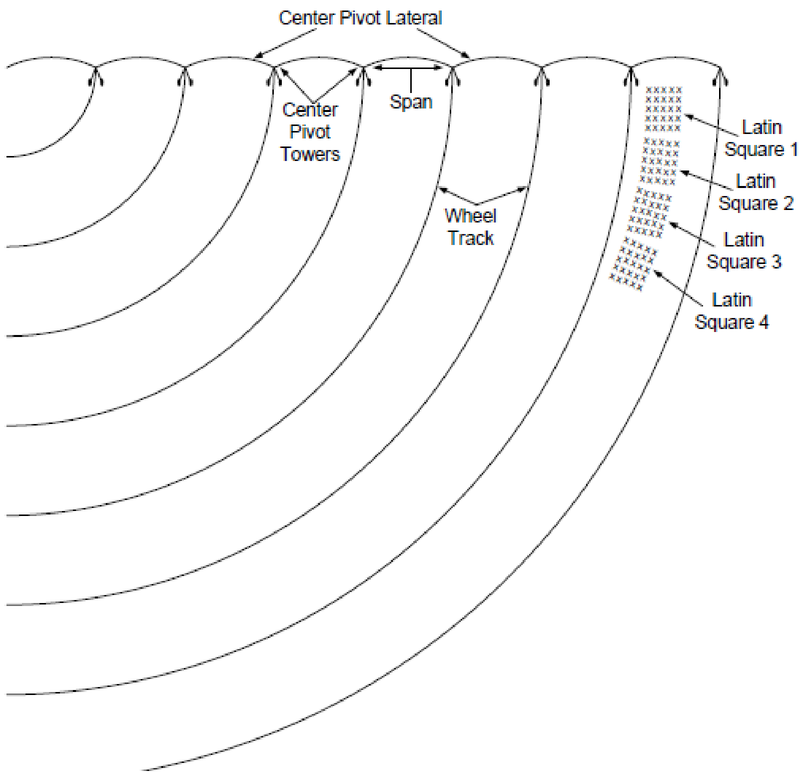

Figure 1. Center pivot irrigation system and location of Latin square field site (Wiens, 2010).

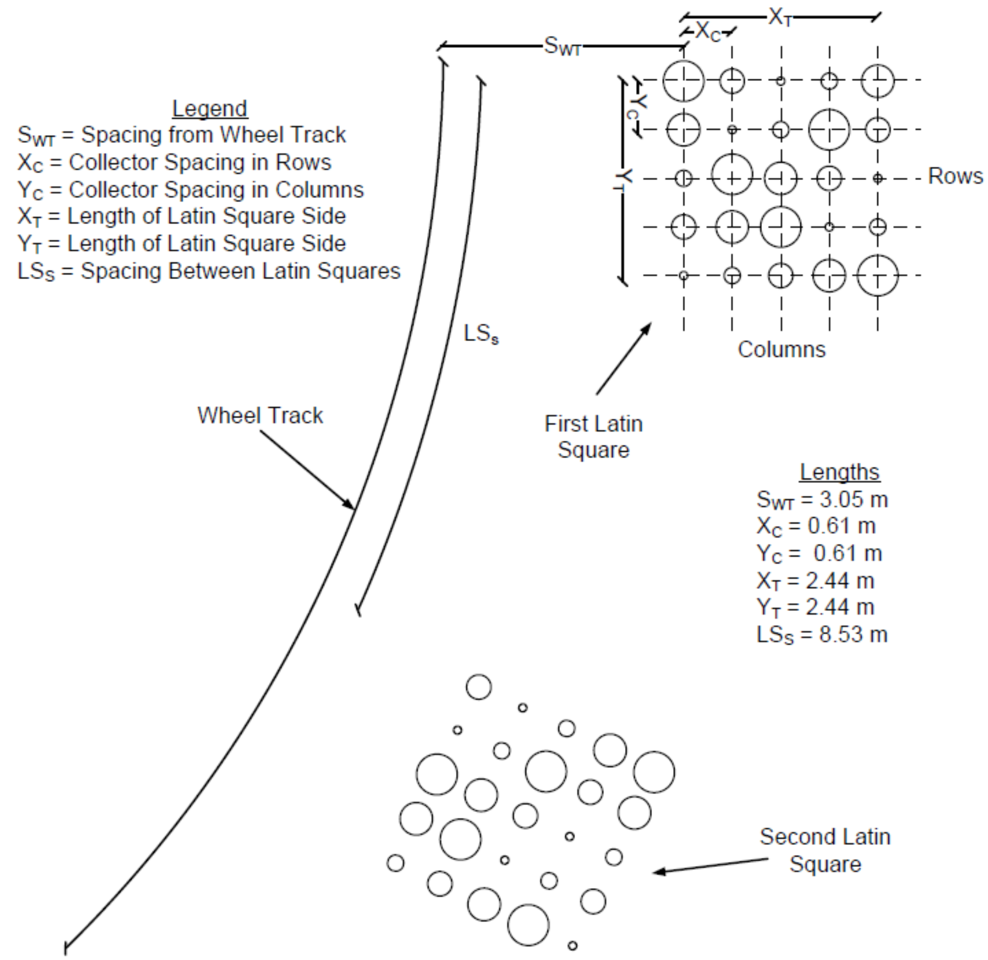

Figure 2. Two Latin squares with the collector spacing, columns, and rows labeled (Wiens, 2010).

Evaporation losses were minimized by measuring the collected volumes as soon as the collectors stopped receiving water from the irrigation event and measured using a graduated cylinder. This volume was converted to an application depth by dividing the volume by the collector surface area.

The SAS 9.2 “Proc Means” command was used to determine the means and standard deviations of the depth measurements for the different collectors, columns and squares. An analysis of variance (ANOVA) of the depths was created using the “Proc Mixed “command for the collector sizes, since this accounted for both fixed (collector size, column and row) and random (Latin square) effect factors in the model. If the ANOVA showed there was a significant effect of collector size on depth, then the collector size measurements were compared.

A second ANOVA was conducted to examine the variability of measured depth of each collector size. The significance of the column effect on measure depth was determined for each test. If there was significance, then the measured depths were adjusted to eliminate the column effect. After adjustments, the standard deviation of the measured depth data was calculated and used to develop an ANOVA of whether collector size had an effect on the variability of the measured depths. If size was significant, then a comparison between collector sizes was made.

In addition, the 95 percent confidence interval was created for each collector size and used to estimate accuracy of a depth measurement for a given number of collectors. These results are unique to the tested systems and should not be generalized to other systems.

Results and Discussion

Various diameter sized catch can depth of application catches for three different types of center pivot irrigation sprinkler packages were analyzed to study the effect of collector size on the measured water depth. The three types of sprinklers packages tested were fixed plate spray (FP), spinning plate (SP), and wobbling plate (WP) sprinklers as described previously. The tests were conducted under acceptable weather conditions and the average application depths meet the minimum depth specified by ASABE S436.1 standard for uniformity of center pivot irrigation systems. The means and standard deviations for the combination of all catches for each system test are shown in Table 1. The applied depth was determined by averaging the measured depth of the catches across all diameter sizes. The FP average applied depth was much larger than SP and WP values, making the standard deviation of FP large but still with a comparable amount of variability due to the higher average applied depth. The coefficients of variability (CV) for the systems were similar with FP being the highest.

Table 1. Means and standard deviation of each sprinkler system combined across collector diameter sizes (Wiens, 2010).

System	Applied Depth (cm)	Nominal Depth (cm)	Lower 95% Mean Confidence Level	Upper 95% Mean Confidence Level	St. Dev. (cm)	CV
Spinning Plate	1.49	1.52	1.46	1.51	0.108	0.07
Fixed Plate	5.11	5.08	5.01	5.21	0.510	0.10
Wobbling Plate	2.27	2.54	2.23	2.31	0.208	0.09

Spinning plate (SP) results are shown in Table 2. The difference between container catches was not statistically different. The largest measurement difference between containers was only 0.05 cm. The standard deviations (SD) of the measurements were similar except for C6 which had a SD of approximately one-half the other containers.

The position of the catch container in each column (see fig 2) were statistically different (Table 2). This is likely due to the position of each column relative to the application depth applied at that position from the combined depth of water from the overlap of the sprinkler device pattern. There were also differences in the water application depth of each square of collectors (Table 2) with a decreasing amount of depth with each successive square. The reason for this change in depth measurement is unclear as the variability of the measurements within the squares was consistent across all squares.

Table 2. Proc Means results for the spinning plate sprinkler (Wiens, 2010).

Treatment	Mean (cm)	Grouping*	St. Dev. (cm)	CV
C2	1.51	A	0.127	0.08
C4	1.48	A	0.108	0.07
C6	1.51	A	0.0598	0.04
C8	1.47	A	0.115	0.08
C10	1.46	A	0.121	0.08
Column	Mean (cm)	Grouping*	St. Dev. (cm)	CV
1 (Inner)	1.45	A	0.0861	0.06
2	1.47	AB	0.0983	0.07
3	1.42	A	0.0850	0.06
4	1.53	BC	0.145	0.09
5 (Outer)	1.55	C	0.0537	0.03
Square	Mean (cm)	Grouping*	St. Dev. (cm)	CV
1	1.54	A	0.101	0.07
2	1.52	AB	0.107	0.07
3	1.47	B	0.0864	0.06
4	1.41	C	0.0925	0.07

* Treatments with the same letter are not different at the 95 percent significance level.

Fixed plate (FP) results are shown in Table 3. There was statistical difference between container catches with C10 having the lowest catch. The CV between containers was similar.

Statistical differences also occur for columns and squares. In general, inner columns catches were less then outer catches as discussed for SP catches. The squares were also statistically different, which would be unexpected.

Wobbling plate (WP) results are shown in Table 4. There were statistical differences between the container sizes with C6 having the lowest catch. The CV of C2 was higher than for the other collectors, which means less confidence in the accuracy of measurement for that collector size as compared to the other options. Higher CV was thought more likely to occur for the FP tests.

Statistical differences also occur for columns and squares. In general, inner columns catches were less then outer catches as discussed for SP catches. The squares were also statistically different, which would be unexpected.

The results of the proc mixed test of measured depths are shown in Table 5. There was statistical significance for each of the sprinkler types with regards to column location as discussed previously. Unexpectedly, the FP collectors had a significant effect due to row location and collector size.. Collector size was not a factor for SP and WP sprinklers in this test.

Table 3. Proc Means results for the fixed plate sprinkler (Wiens, 2010).

Treatment	Mean (cm)	Grouping*	St. Dev. (cm)	CV
C2	5.23	A	0.539	0.10
C4	5.04	AB	0.476	0.09
C6	5.19	A	0.549	0.11
C8	5.22	A	0.486	0.09
C10	4.85	B	0.435	0.09
Column	**Mean (cm)**	**Grouping***	**St. Dev. (cm)**	**CV**
1 (Inner)	4.91	AB	0.340	0.07
2	4.77	A	0.362	0.08
3	5.12	BC	0.486	0.10
4	5.26	CD	0.537	0.10
5 (Outer)	5.48	D	0.501	0.09
Square	**Mean (cm)**	**Grouping***	**St. Dev. (cm)**	**CV**
1	5.45	A	0.541	0.10
2	5.37	A	0.410	0.08
3	4.78	B	0.357	0.07
4	4.82	B	0.311	0.06

* Treatments with the same letter are not different at the 95 percent significance level

Table 4. Proc Means results for the wobbling plate sprinkler (Wiens, 2010).

Treatment	Mean (cm)	Grouping*	St. Dev. (cm)	CV
C2	2.30	AB	0.340	0.15
C4	2.23	A	0.136	0.06
C6	2.35	B	0.214	0.09
C8	2.26	AB	0.134	0.06
C10	2.22	A	0.122	0.06
Column	**Mean (cm)**	**Grouping***	**St. Dev. (cm)**	**CV**
1 (Inner)	2.20	AB	0.365	0.17
2	2.18	A	0.105	0.05
3	2.35	C	0.0687	0.03
4	2.32	BC	0.112	0.05
5 (Outer)	2.31	BC	0.197	0.09
Square	**Mean (cm)**	**Grouping***	**St. Dev. (cm)**	**CV**
1	2.33	A	0.136	0.06
2	2.21	B	0.139	0.06
3	2.39	A	0.300	0.13
4	2.16	B	0.130	0.06

* Treatments with the same letter are not different at the 95 percent significance level.

Table 5. Proc Mixed results for the collector size effect on measured depth for the spinning plate, fixed plate and wobbling plate systems (Wiens, 2010).

Sprinkler Type	Source	Degrees of Freedom	F Value	p-Value	Significance
Spinning Plate	Row	84	1.12	0.3528	NS
	Column	84	8.87	<0.0001	***
	Collector Size	84	1.47	0.2187	NS
Fixed Plate	Row	84	2.62	0.0405	**
	Column	84	18.66	<0.0001	***
	Collector Size	84	6.17	0.0002	***
Wobbling Plate	Row	84	0.34	0.8518	NS
	Column	84	3.63	0.0089	***
	Collector Size	84	1.79	0.1386	NS

* NS indicates collectors are not significantly different, * indicates collectors different at 90 percent significance, ** indicates collectors different at 95 percent significance, and *** indicates collectors different at 99 percent significance.

Table 6 shows the proc mixed test results for the comparison of measured depths for FP since it was the only sprinkler type that showed collector size had a significant effect (from Tables 3-5) on measured depth. C10 had the lowest mean depth and was different than all the other containers. C2 and C4 were also different. It is interesting to note there was not a strong trend of increasing or decreasing depth measurement relative to collector size.

Since the actual water application depth is not known, the ideal collector size cannot be determined from this study. Previously noted C10, the largest collector size had the lowest measured depth result. While large collector diameter is associated with increased accuracy, acceptance of the C10 average depth as the closet to the true actual applied depth, would ignore the that combined estimate from C2, C6 and C8 (sixty observations that were very consistent) which was much higher.

The final statistical test was the proc mix test on the level of variability (SD) of the measured depth for the various collector size for each of the sprinkler type. In this test, the test model adjusted the raw data to eliminate the column effect. The results, shown in Table 7, show only SP had significant differences in the variability of the measured depths. Therefore SP's SD values were proc mix tested for significance. The results are shown in Table 8, for 99 and 90 percent confidence levels. At 99%, C6 had lower variability than C2 or C10. At 90%, C2 had lower variability than C4, C6 was different than C8, and C6 different than C10.

Table 6. Proc Mixed comparison test of the measured depths for the fixed plate sprinkler (Wiens, 2010).

Treatment	Mean (cm)	95% Significance Grouping
C2	5.23	A
C4	5.04	B
C6	5.19	AB
C8	5.22	AB
C10	4.85	C

* Treatments with the same letter are not significantly different at the 95 percent level.

Table 7. Proc Mixed test of the collector size effect on variability of measure depth (Wiens, 2010).

Sprinkler Type	Degrees of Freedom	F Value	p-Value	Significance
Spinning Plate	12	3.43	0.0432	**
Fixed Plate	12	0.10	0.9817	NS
Wobbling Plate	12	1.09	0.4061	NS

* NS indicates collectors are not significantly different, * indicates collectors different at 90 percent significance, ** indicates collectors different at 95 percent significance, and *** indicates collectors different at 99 percent significance.

Table 8. Proc Mixed comparison test of the measured depth variability for the spinning plate system (Wiens, 2010).

Collector Size	Estimated Standard Deviation	99% Significance Grouping	90% Significance Grouping
C2	0.100	A	A
C4	0.0687	AB	BC
C6	0.0477	B	B
C8	0.0785	AB	AC
C10	0.0997	A	A

* Treatments with the same letter are not significantly different at the noted significance level.

Conclusion

Measured depth and variability of measured application depth of three distinct sprinkler application devices were compared for six difference catch can collector using a replicated Latin square study design. The collector sizes were C2, C4, C6, C8, and C10 collectors with diameters of 5.5 cm (2.19 in.), 10.0 cm (3.92 in.), 14.75 cm (5.81 in.), 20.0 cm (7.87 in).

The C6 collector measured the largest water depths for the SP and the WP systems, while the C2 collector measured the greatest depth measurements for the FP system. The C10 collector measured the lowest water depth for all three sprinkler systems. The larger collector sizes measured the same variability of measured depths as the smaller collector sizes for the SP and

FP systems. There was a trend of decreasing measured depth variability as the collector size increased for the WP system, although C4, C8, and C10 collectors had similar levels of measurement variability. The larger collector sizes were expected to record lower measured depth variability for the fixed plate system but the variability was consistent across all collector sizes.

Previous studies had indicated difficulty in accurately measuring the application depth of FP systems using collectors with small diameter with less difficulty of other sprinkler types. An ANOVA analysis of the measured depths showed that the latter expectation was upheld as collector size was not a significant factor in determining the mean water depth for SP and WP systems. However, for the FP system, there was significance at the 95 percent level.

The comparison test of the collector sizes for the FP system indicated that the C2 and C4 collectors measured significantly different depths and the C10 collector was significantly different from all other collectors.

The variability of the measured depths indicated significant differences for the SP system but not for FP and WP systems. It was expected that SP and WP type sprinklers would be similar and the FP more variable. The C6 collector had lower depth measurement variability (90 percent significance) than the C2, C8, and C10 collectors and the C4 collector had measured variability that was significantly lower than the variability of C2 and C10 measured depths.

If the ideal collector size selection was based on minimum variability of depth measurements, then either C6 or C4 collectors could be used. The measurement variability of C6 was numerically lower than the C4 but not significantly different statistically. Though not significant, C4, C8, and C10 had the lowest variability of measured depths for the WP system. A surprising outcome for this study, all collector sizes measured similar levels of variability of depth measurements for the FP system.

Acknowledgement

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