Evaluation of Collector Size for the Measurement of Irrigation Depths[1]

G. A. Clark, E. Dogan, D. H. Rogers, and V. L. Martin[2]

Abstract. Fixed-plate (FP), grooved-disk, sprinkler diffusers provide distinct streams or jets of water that are not easily distorted by wind and minimize evaporative losses. However, these sprinklers provide variable, cyclic, and nonuniform application patterns of applied water that are difficult to accurately measure with collectors that have openings of 10 cm or less. In 1999, 2000, and 2002, field studies were conducted to evaluate the measurement effectiveness of a non-evaporating sprinkler irrigation catch device (IrriGage). The standard IrriGage (IrriGage) has a 10 cm diameter opening, a 20 cm long collector barrel, and an attached storage bottle for collected water. IrriGage collectors were compared to other catch devices that included a 15 cm diameter collector similar to the IrriGage and 43 cm diameter pans (PAN). All collectors were tested under three different sprinkler irrigation packages that included fixed-plate diffusers (FP) with a grooved-disk, spinning-plate diffusers (SP), and wobbling plate diffusers (WP).

In 1999, IrriGage collectors positioned within a corn canopy failed to accurately measure the irrigation depths and sprinkler patterns as compared to the larger diameter PAN collectors. In 2000, IrriGage collectors were lowered and repositioned into a grass buffer. Measured irrigation depths and CU values from IrriGages were significantly ($p < 0.05$) higher and distributed differently than associated data from PAN collectors.

In 2002, IrriGage collector evaluations under all three irrigation packages (FP, SP, and WP) indicated significantly higher irrigation depths and higher variances in collected data than the 15 cm collectors (similar to 2000 results). Measured depth differences between 10 and 15 cm diameter collectors were greatest under the FP sprinkler package. However, while rotating plate diffuser (SP and WP) measured depths with 10 cm IrriGage collectors were 4% to 7% higher than with 15 cm collectors, application patterns were mimicked. These results indicate that 10 cm IrriGage collectors should not be used to measure irrigation depths and uniformities on FP diffuser sprinkler packages. While 10 cm IrriGages may be used for sprinkler packages with rotating plate diffusers, actual irrigation depths may be slightly less than measured values.

Keywords. Uniformity, Precipitation Gauge, Rain Gauge, Irrigation Collector, Sprinklers

Introduction

Sprinkler irrigation system uniformity is an important performance characteristic (William, 1963; Branscheid and Hart, 1968; Vories and von Bernuth, 1986; Heermann et al., 1992; Evans et al., 1995; and Li and

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Kawano, 1996), and should be evaluated based on expected conditions (field conditions) that will exist in the crop field (Volker and Hart, 1968). Since crop growth and yield are dependent on available water, substantially lower uniformity might result in reduced crop yields in the areas receiving less irrigation water.

Fixed-plate (FP), grooved-disk deflector sprinkler irrigation packages have distinct jet streams with large water droplets. Spinning-plate (SP) diffuser and wobbling-plate (WP) diffuser sprinkler irrigation packages produce smaller water droplets and usually evenly distribute irrigation water to the crop fields. In addition, impact and rotating sprinkler designs also have more uniform applications due to the breakup in droplet size and patterns. However, sprayed water from those systems may be more susceptible to wind drift and evaporative losses than low drift nozzle (LDN) type sprinklers (James and Blair, 1983; Hanson and Orloff, 1996; Bilanski and Kidder, 1958).

Marek et al. (1985) indicated that collectors should display characteristics such as sharp edges to separate water droplets, should prevent splash in and out, and should minimize evaporation losses of collected water as well as from droplets on the inner surface. They evaluated the measurement performance of three different collectors: oil cans with a 10.3 cm dia. and a 14.1 cm depth, glass separatory funnels with a 9.02 cm dia., and a fuel funnel with a 4.9 cm diameter. The sprinkler irrigation package had Rainbird model 30 W-TNT series impact sprinklers with a 0.52 cm inside diameter nozzle operated with 244 kPa pressure. Results from the three different collectors were significantly different. The separatory funnels were the most accurate devices, but were expensive. While, oil cans-over estimated irrigation depth by 5%, they concluded that the fuel funnels were unacceptable collectors for uniformity measurements.

ASAE (2001) states that catch devices (collectors) used for uniformity measurements should be identical with a minimum height (h) of 12 cm, and with an opening of at least 6 cm in diameter. For data collection on center pivot systems, two or more sets of collectors parallel to one another should be used with a maximum collector spacing of 3 m between collectors for spray irrigation sprinkler packages. However, Evans et al. (1995) indicated that under field conditions, using two or more catch device rows is not practical during data collection. Further, there should be no obstructions (such as a crop canopy) between the irrigation nozzle or discharged water trajectory and the catch device. If the canopy is higher than the opening of the collection device, then a buffer distance equal to twice the distance between the opening of collector and the height of the obstruction should be cleared.

Clark et al. (2002) developed an inexpensive, non-evaporating in-field precipitation gauge (IrriGage) that might be used not only for rainfall and irrigation depth measurements, but also for evaluation of sprinkler irrigation system uniformities. The IrriGage (IrriGage) device is a 20 cm long, 10.2 cm dia. PVC pipe with a PVC cap glued to the bottom of the barrel. The gauge has a bottle attached to the bottom cap as a water reservoir. The authors concluded that these devices could be used to measure sprinkler irrigation depths with little or no evaporative loss, that they exceed the collector criteria specified in the ASAE center pivot performance test standard (ASAE, 2001), and that they are easy to make and set up in field tests. Because the IrriGages are non-evaporating, collected water amounts do not have to be read immediately following irrigation events.

Field measurements of center pivot irrigation system uniformity (data not currently reported) with 43 cm diameter pans and 10.2 cm diameter IrriGage's (IrriGage) raised some concerns about using IrriGage's on fixed-plate, grooved disk sprinkler packages. The distinct streams of water may or may not be caught by a gauge. Because the volume of water caught by the gauge is averaged over the surface area of the opening, small gauge openings may result in artificially high or low depths based upon the caught or missed streams. In addition, even with the larger catch devices, adjacently measured depths could vary from 10% to over 100%.

Therefore, the objectives of this study were to evaluate the catch accuracy of different irrigation water collectors from above-canopy, fixed-plate and rotating-plate sprinkler devices on a moving irrigation system.

MATERIALS AND METHODS

Catch Device Characteristics

This study evaluated the catch accuracy of the IrriGage (fig. 1) 10 cm diameter collection devices (Clark 2002) for both fixed-plate and rotating-plate sprinkler irrigation packages. Study sites included a linear-move sprinkler irrigation system at the Kansas State University (KSU) Sandyland Experiment Field, St. John, KS (1999 and 2000), a center-pivot system at the KSU Livestock Waste Management Learning Center in Manhattan, KS (2002A), and a linear move sprinkler system at the KSU North Central Experiment Field, Scandia, KS (2002B).

The primary objective of this work was to compare the catch accuracy of the IrriGage collectors to a larger diameter collection device. The 1999 and 2000 studies compared IrriGage collectors to large diameter (43 cm) pans (PAN; fig. 1). The 2002 study sites involved a comparison of the standard 10 cm IrriGage devices with a 15 cm diameter collector constructed very similarly to the IrriGage collectors. The PAN collectors had the shallowest depths (10 cm), slightly less than ASAE criteria (12 cm) (ASAE, 2001). However, the large diameter (d) of the PAN's resulted in a much larger hydraulic radius (R_h= A/C = d/4) than the smaller catch devices. The hydraulic radius provides a relative indication of the potential boundary dimension that could result in splash in/out errors. A large hydraulic radius indicates that the surface area for collection is large compared to the circumference of the boundary region of the collector. Thus, because the PAN's had a R_h of 10.8 cm while the IrriGage collectors had an R_h of 2.5 cm, it was believed that splash in/out would not be a substantial concern with the large diameter PAN collectors.

All sprinkler systems in this study (1999, 2000, 2002A and 2002B) had sprinklers on drops just below the system trusses, and all drops were on a 3.0 m spacing. Discharge rates from the three middle sprinkler nozzles from each treatment zone of the linear sprinkler irrigation systems (1999, 2000, and 2002B) used in this study were measured while on the sprinkler system. A PVC pipe was positioned over each sprinkler nozzle and directed the discharge water into a 20 L bucket. Discharge volumes were measured for 30 seconds, collected water was then weighed, and data were converted to discharge rate units. The middle three nozzles and pressure regulators from both FP and SP sprinkler package test zones on the center pivot irrigation system (2002A) were taken to the Biological and Agricultural Engineering, Kansas State University hydraulic laboratory for discharge rate tests. A test pressure equal to the center pivot inline pressure was used and pressure-regulated nozzle discharge rates were tested three times for one minute each. These tests were used to verify the nozzle consistency and the manufacturer reported nozzle discharge rates.

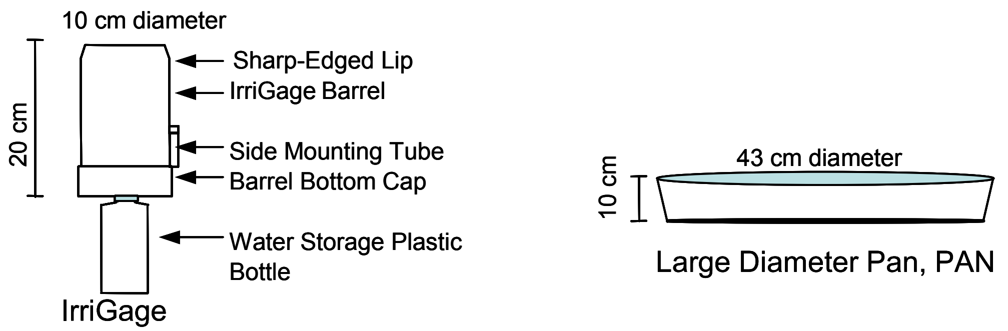

Figure 1. Characteristics of the IrriGage and PAN collectors.

1999 / 2000 Field Evaluations

The 1999 and 2000 studies were used to evaluate IrriGage collectors under three irrigation pressure and nozzle size combinations with fixed plate, grooved-disk deflectors. A linear move sprinkler irrigation system was used with four 49-m long spans that each had 16 flexible hose drops with polyethylene weights to minimize swinging. Sprinklers were positioned at 2.2 m to 2.4 m above the soil surface. The three sprinkler nozzle size/pressure combinations provided the same nozzle discharge rate, but different distribution patterns and application uniformities (Clark et al., 2003).

In 1999, twelve IrriGage collectors were placed within a corn canopy along corn rows that were 76 cm apart. The IrriGage collectors were positioned 1.2 cm above the soil surface using steel support rods. Corn plants within 1.2 m of the IrriGage collectors were removed from all sides of the IrriGage setup area to minimize any effect due to plant canopy. The corn canopy was approximately 2 m tall. Thus, at the corn tassel stage, the ratio of buffer distance to canopy height difference (from the collector opening) was 1.5 and not 2.0 as recommended by ASAE (2001). The IrriGage collectors were left in the field during the entire growing season. Water amounts from irrigation events caught with the IrriGage collectors were measured with a volumetric cylinder and then converted to depth (mm) units and used for graphical and statistical analysis.

For the irrigation testing events, PAN's were placed in a grass buffer area 10.0 to 12.0 m from the IrriGage collectors, about 6.0 m from the corn plants, and in-line with the IrriGage collectors. PAN's were positioned in the grass buffer just before irrigation events and measurements were taken immediately after the irrigation system passed over to minimize evaporative losses. Water collected by the PAN's was weighed with a balance and then converted to depth (mm) units. Those results were used as base values to compare with IrriGage collector measurements. In 1999, IrriGage collectors and PAN's were evaluated using five separate sprinkler events during the growing season.

The IrriGage collectors were also evaluated in 2000 using the same irrigation system as in 1999, but the IrriGage collectors were moved to the same grass buffer strip area where the PAN's were located . This time IrriGage collectors were mounted 60-cm high using metal support rods, located 6 m from the corn plants, and about 1 m from the PAN's. Five irrigation events were also measured in 2000.

Environmental conditions for tests in both years were obtained from a weather station located on the experiment field site. The anemometer was partially protected by a shelter belt located approximately 50 m to the south of the weather station. Reference crop evapotranspiration for that station was obtained from the Kansas State University Weather Data Library which posted modified Penman alfalfa crop ET.

2002 Field Evaluations

In 2002, standard 10 cm IrriGage collectors were compared to 15 cm collectors on two experimental field sites (2002A and 2002B) under three different sprinkler irrigation packages. In the 2002A study, collectors were evaluated at the KSU Livestock Waste Management Learning Center (WMLC), Manhattan, KS. The irrigation system was a new center pivot sprinkler irrigation system with seven, 55 m long spans. The last span of the center pivot irrigation system was used for the collector evaluations. The first nine drops of the last span were installed with a spinning plate (SP) sprinkler package. The remaining eight drops of that system had the FP sprinkler package. Both irrigation packages were operated at 103 kPa pressure. Sprinkler drops were about 1.4 m above the soil surface.

Three sets of twelve IrriGage collectors and one row of the 15 cm collectors were set up under the sprinkler packages (figure 2). Collectors within rows were 0.75-m apart All 10 cm IrriGage and 15 cm collectors were mounted on metal rods such that the openings were at a 60 cm height. Collectors were tested using three irrigation events that were each set to apply a gross depth of 19 mm of water. IrriGage collectors were set up as “Single”, “Side-by-Side”, and “Inline” (figure 2) in order to evaluate different arrangements of IrriGage collectors to accurately measure sprinkler irrigation depths and application patterns.

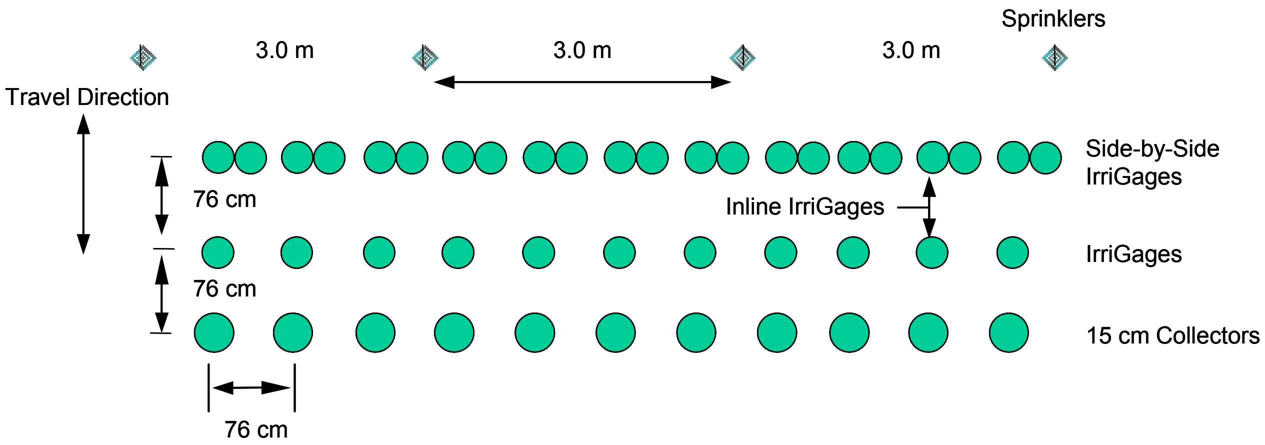

Figure 2. Set up of collection devices used in the 2002 tests.

In the 2002B study, IrriGage collectors were evaluated at the KSU North Central Experiment Field, Scandia, KS. The irrigation system was a new linear move irrigation system with five, 55-m long spans. The last two spans of the linear irrigation system were used for collector evaluations with wobbling plate (WP) sprinklers (Senninger Wobblers[3]) operated at 103 kPa pressure. Irrigation drops were 2.0 to 2.3 m above the soil surface. Collector set up was identical to the 2002A study with twelve sets of collectors that were positioned under each span. The irrigation system was set to apply 19.0 mm of water and move with a speed of 24.7 m/h. The linear irrigation system was operated twice during the same day.

Coefficient of Uniformity (CU) values were calculated for the 1999 and 2000 data sets using ASAE (2001) standard methods for center pivot and linear move irrigation systems. Irrigation depths and CU values were analyzed using ANOVA and T-Test statistical procedures and graphical analysis.

Environmental conditions for the 2002A and 2002B field tests were obtained from weather stations located an adjacent experiment field sites. Reference crop evapotranspiration for those stations were determined using the Penman-Monteith grass reference crop equation (Smith et al., 1996; Allen et al., 1998).

RESULTS AND DISCUSSION

Environmental conditions (air temperature, relative humidity, wind speed, and grass reference evapotranspiration) during catch device evaluations for all three years were hot and dry. Average daily wind speeds often exceeded the 3.6 km/h (1 m/s) testing threshold recommendation in the ASAE center pivot evaluation standard (ASAE, 2001), but never exceeded the 18 km/h (5 m/s) upper threshold recommendation. Field tests were performed in the early morning or evening hours when actual wind speeds and evaporative demands were lower.

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[3] Mention of specific products or trade names does not imply endorsement by the authors or Kansas State University

1999 Results

Average irrigation depths and corresponding CU values from each set of twelve collectors for all 5-test events under the fixed plate sprinklers operated at 42 kPa (FP42), 103 kPa (FP103), and 138 kPa (FP138) measured with IrriGage and PAN collectors are presented in table 1. Irrigation depths collected with IrriGage collectors under the FP42 sprinkler package averaged 8.3 mm, while FP103 and FP138 sprinklers had average irrigation depths of 10.3 and 10.0 mm, respectively. However, PAN collectors had significantly higher ($p < 0.05$) average irrigation depths of 13.7, 13.0, and 12.5 mm, respectively (table 1). Because the diameter of the PAN collector opening (43.0 cm) was greater than the IrriGage collectors (10.2 cm), irrigation depths from the PAN's were considered to be more accurate and representative of actual irrigation depths and patterns.

Low pressure sprinkler distribution patterns were variable but were consistent with results reported by Clark et al. (2003). The PAN collectors showed a consistent cyclic distribution pattern under the lower pressure (42 kPa) sprinklers, and a consistently uniform distribution under the higher pressure (138 kPa) sprinklers. However, IrriGage collectors recorded consistently lower amounts of water under the higher pressure sprinklers, and provided quite variable and inconsistent results under the lower pressure sprinklers. Coefficients of uniformity (CU) from IrriGage collectors for FP42, FP103, and FP138 sprinkler packages averaged 42.3, 79.1, and 80.4, respectively, while CU values from PAN's were significantly higher ($p < 0.05$) at 77.5, 90.5, and 92.5, respectively (table 1). Furthermore, standard errors from PAN's were smaller than from IrriGage collectors. Differences in both irrigation depths and CU values in 1999 were attributed in part to the height of the IrriGage collectors and possible corn canopy interference with the irrigation patterns.

Table 1. Average irrigation depths and CU values for the IrriGage and PAN collectors from the 1999 and 2000 sprinkler irrigation uniformity tests.

Year: Sprinkler Package		Average Depth (mm)			Coefficient of Uniformity (CU)		
		IrriGage	PAN	Signif.	IrriGage	PAN	Signif.
	FP42	8.3	13.7	*	42.3	77.5	*
1999	FP103	10.3	13.0	*	79.1	90.5	*
	FP138	10.0	12.5	*	80.4	92.5	*
	FP42	17.1	14.5	*	79.9	79.5	NS
2000	FP103	20.2	14.4	*	72.3	90.6	*
	FP138	16.9	13.8	*	77.1	91.3	*

Data were analyzed using ANOVA procedures. * Significantly different at 0.05 level. NS = Not significant.

2000 Results

In 2000, irrigation depths from IrriGage collectors averaged 17.1, 20.2, and 16.9 mm for the FP42, FP103, and FP138 sprinkler packages, respectively (table 1). However, PAN measured irrigation depths for the same packages were all significantly lower ($p < 0.05$) at 14.5, 14.4, and 13.8 mm, respectively. Thus, IrriGage collector depths ranged from 18% to 40% higher than the corresponding PAN collector depths. Calculated CU values from IrriGage collectors for the FP42, FP103, and FP138 sprinkler packages were 79.9, 72.3, and 77.1, respectively. PAN-based CU values were 79.5, 90.6, and 91.3 for the same sprinkler packages, respectively (table 1). While the FP103 and FP138 CU values from the IrriGage collectors were significantly lower ($p < 0.05$) than PAN-based data, associated CU values for the FP42 packages were not different.

Overall, these differences between the two collector types in both years were not expected, particularly since the IrriGage collectors had a larger opening size (10 cm) than the current ASAE standard (minimum of 5.0 cm; ASAE, 2001) for uniformity measurements from center pivot sprinkler packages. Year to year (1999 vs. 2000) differences in measured irrigation depths from low pressure fixed plate sprinklers using IrriGage collectors were attributed to: collector opening size, collector height, and possible crop canopy effect on the discharged water trajectory patterns.

2002 Results

Mean irrigation depths from all 2002 collectors and arrangements with corresponding data set variance values under the FP, SP, and WP sprinkler packages are presented in table 2. Average irrigation depths from the FP package using 15 cm and single IrriGage collectors were significantly different at 14.4 and 17.4 mm, respectively (table 2). The single row of IrriGage collectors consistently over-estimated irrigation depths by 20.8% similar to the results in 2000 under another fixed plate sprinkler package. In addition, data collected with IrriGage collectors were also significantly more variable (table 2) than with the 15 cm collector and did not mimic the individual 15 cm collector results (data not shown).

Differences in measured depths and associated variances under the rotating plate sprinkler packages (SP and WP) were consistent with one another (table 2). Measured irrigation depths from all collector arrangements under the SP and WP sprinkler packages followed similar trends with relatively close measured mean depths and low variability in the data from IrriGage and 15 cm collectors. However, single row IrriGage-based depths under SP and WP sprinklers were still significantly higher than 15-cm collector depths by 7.0% and 4.1% respectively. The associated variance in the 15 cm collector data sets from the under the SP sprinklers (0.025) and WP sprinklers (0.027) was relatively low and was significantly lower than the associated single row IrriGage variance (0.103 and 0.100) from those same two sprinkler packages. Yet, the 10 cm IrriGage collectors provided good pattern representation from individual collectors as compared to 15 cm collectors under both spinning plate and wobbling plate sprinklers (data not shown). These sprinkler packages have greater droplet breakup and smaller droplets as compared to the fixed plate sprinklers.

Coefficient of uniformity (CU) values from 10 cm IrriGage collectors were lower than corresponding CU values from the 15 cm collectors (table 6) under all three sprinkler packages. However, an analysis of variance (ANOVA) showed that CU value differences were not significant within any of the sprinkler packages from the various collector arrangements. CU values under the fixed plate sprinkler were substantially lower than those under the other sprinklers and correspond to the large variances in data associated with that sprinkler package (table 3). This typically due to the distinct jets of water that are common with those types of sprinklers. Those jets can result in application patterns with a harmonic pattern that has relatively large amplitude variations (Clark et al., 2003), which can be difficult to accurately measure with a collector that has a relatively small opening.

The addition of another set of 10 cm IrriGage collectors either as a Side-by-Side set or as another Inline set did not improve depths or variability in measured data (table 2), or CU values (table 3). Measured results were very similar to those from the single row of 10 cm IrriGage collectors. Therefore, it appears that size of an individual collector is more important than an increase in total surface area by using multiple collectors.

Table 2. Average irrigation depths and variances for the collectors evaluated under the fixed plate (FP), spinning plate (SP), and wobbling plate sprinklers in 2002.

Sprinkler Package: Collector Size / Arrangement	Mean Depth (mm)[£]	Difference from 15 cm Gage (%)	Variance (mm2)[§]	Coefficient of Variation
Fixed Plate – 2002A:				
15 cm	14.4	--	33.3	0.40
10 cm Single	17.4 ***	20.8	62.8 **	0.45
10 cm Side-by-Side	17.3 ***	20.1	58.0 **	0.44
10 cm Inline	17.5 **	21.5	78.6 ***	0.51
Spinning Plate – 2002A:				
15 cm	14.2	--	2.5	0.11
10 cm Single	15.2 *	7.0	10.3 ***	0.21
10 cm Side-by-Side	15.1 **	6.3	6.2 ***	0.17
10 cm Inline	15.4 **	8.5	5.7 ***	0.16
Wobbling Plate – 2002B:				
15 cm	19.6	--	2.7	0.08
10 cm Single	20.4 *	4.1	10.0 ***	0.16
10 cm Side-by-Side	21.1 ***	7.7	11.1 ***	0.16
10 cm Inline	21.1 ***	7.7	12.5 ***	0.17

[£] Mean depths for a specific sprinkler package were significantly different (paired t-test) from the 15 cm collector values at the 10% (*), 5% (**) or 1% (***) level of significance.

[§] Calculated variances for a specific sprinkler package were significantly different (F-test) from the 15 cm collector variances at the 10% (*), 5% (**) or 1% (***) level of significance.

Table 3. Average coefficient of uniformity (CU) values for the collectors evaluated in 2002 under the fixed, spinning and wobbling plate sprinklers.

Collector Size / Arrangement	Fixed Plate	Spinning Plate	Wobbling Plate
15 cm	66.6	94.2	90.8
10 cm Single	58.9	88.2	87.2
10 cm Side-by-Side	61.6	89.7	85.5
10 cm Inline	61.9	90.5	85.6
Significance[£]	NS	NS	NS

[£]Data were analyzed using ANOVA procedures; NS = Not significant..

SUMMARY AND CONCLUSIONS

In 1999, 2000, and 2002, field studies were conducted to evaluate the measurement effectiveness of a non-evaporating sprinkler irrigation catch device (IrriGage). In 1999 and 2000 IrriGage collectors were compared to 43 cm diameter pans (PAN). Tests in 2002 compared different arrangements of 10 cm IrriGage to15 cm diameter collectors. All collectors were tested to measure sprinkler irrigation system depths and uniformity under different sprinkler irrigation packages. Sprinkler irrigation packages tested included fixed-plate diffusers (FP) with grooved-disks, spinning-plate diffusers (SP), and wobbling plate diffusers (WP) with different nozzle and pressure combinations. FP sprinkler packages had distinct water jet streams with larger water droplets, while SP and WP sprinklers had smaller water droplets that appeared to be evenly distributed.

In 1999, IrriGage collectors positioned within a corn canopy failed to accurately measure the irrigation depths and sprinkler patterns. Even with higher irrigation pressures (103.0 to 138.0 kPa), IrriGage collectors did not reasonably measure irrigation depths or patterns as compared to PAN collectors. In 2000, even though the IrriGage collectors were lowered and repositioned into a grass buffer, measured irrigation depths and CU values were significantly ($p < 0.05$) higher than associated data from PAN collectors. In addition, irrigation application patterns from the IrriGage collectors under the FP sprinkler package with different pressure combinations did not match the PAN results.

In 2002, IrriGage collector evaluations under fixed plate (FP), spinning plate (SP), and wobbling plate (WP) irrigation packages indicated greater irrigation depths and lower CU values than 15 cm collectors, similar to 2000 results. Additionally, IrriGage collector results did not accurately measure nor mimic the FP irrigation patterns as compared to the 15 cm collectors.

The results of this work indicate that further work is needed to determine an appropriate collector size (and perhaps shape) for the measurement of irrigation depths from center pivot and linear move irrigation machines with lower pressure sprinkler packages. This is particularly needed for the fixed plate, grooved disk sprinklers that provide distinct jets of water with little pattern breakup.

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