EVALUATION OF IRRIGAGE COLLECTORS TO MEASURE IRRIGATION DEPTHS FROM LOW PRESSURE SPRINKLERS

G. A. Clark, E. Dogan, D. H. Rogers, V. L. Martin

ABSTRACT. *Coarse-grooved, fixed-plate sprinkler deflector pads 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 small openings. In 1999, 2000, and 2002, field studies were conducted to compare the measurement effectiveness of a non-evaporating sprinkler irrigation catch device (IrriGage) with larger collectors. The standard IrriGage has a 100-mm diameter opening, a 200-mm long collector barrel, and an attached storage bottle for collected water. These characteristics exceed current ASAE standard (ASAE S436.1) recommendations for sprinkler collectors. IrriGage collectors were compared to other catch devices that included 430-mm diameter pans (PAN) in 1999 and 2000, and a single row of 150-mm diameter collectors (150-S) similar to the IrriGage in 2002. IrriGage collectors were tested under three different sprinkler irrigation packages that included fixed-plate deflector pads with coarse grooves, spinning plates, and wobbling plates.*

In 1999, IrriGage collectors positioned with openings at a 1.2-m height within a corn canopy measured lower irrigation depths and different sprinkler patterns as compared to the larger diameter PAN collectors that were positioned in an adjacent grass buffer. In 2000, the 100-S collectors were lowered to a 600-mm height and repositioned into the grass buffer with the PAN collectors. The resultant measured irrigation depths and data variability for the IrriGage collectors were significantly greater and distributed differently than associated data from the PAN collectors.

In 2002, a single row arrangement of IrriGage collectors (100-S) under the fixed plate sprinkler package had significantly greater irrigation depths (14% to 25%) and greater variances in collected data than the 150-S collectors (similar to 2000 results). However, while measured depths under spinning and wobbling plate sprinklers with 100-S collectors were 2% to 9% greater than measured depths with 150-S collector, differences were generally not significant. Furthermore, individual collector data between 100-S and 150-S collectors under the spinning and wobbling plate sprinklers tracked very well. Additional tests included multiple collector tests using inline (100-IL) and side-by-side (100-SS) arrangements of the 100-mm IrriGage collectors. Results from these tests showed that the 100-IL and 100-SS arrangements did not improve catch accuracy when compared to the individual 150-S collectors.

The current ASAE standard (ASAE S436.1) for collector size criteria requires a minimum entrance diameter of just 60 mm. Based upon the field results of this work, the current standard collector size criteria are not appropriate for the low pressure, fixed plate, coarse-grooved sprinklers that provide distinct streams of water with little pattern breakup. Additional research 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.

Keywords. *Uniformity, Precipitation gauge, Rain gauge, Irrigation collector, Sprinklers.*

Sprinkler application uniformity is an important performance characteristic of sprinkler irrigation systems (William, 1963; Branscheid and Hart, 1968; Vories and von Bernuth, 1986; Heermann et al., 1992; Evans et al., 1995; Li and Kawano, 1996), and should be evaluated based on expected conditions (field conditions) that will exist in the crop field (Branscheid 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.

Coarse-grooved, fixed plate deflector pad sprinkler irrigation packages have distinct jet streams with large water droplets. Spinning-plate and wobbling-plate sprinkler irrigation packages produce smaller water droplets and more evenly distributed patterns. Impact and moving-plate sprinkler designs have more uniform application patterns due to droplet breakup and nozzle and/or deflector plate movement. However, sprayed water from those systems may be more susceptible to wind drift and evaporative losses than low drift nozzle (LDN) type sprinklers (Bilanski and Kidder, 1958; James and Blair, 1984; Hanson and Orloff, 1996).

Heermann et al. (1999) studied the effect of low-pressure sprinkler drop spacing on irrigation uniformity and concluded that the spacing of low-pressure sprinklers is more important than the pattern or shape of the low-pressure sprinkler package. To maintain a high coefficient of unifor-

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mity, the distance between irrigation drops should be no more than the throw radius of the irrigation package. Clark et al. (2003) reported that with some LDN packages, that the spacing should be no greater than 40% to 50% of the radius of throw in order to maintain CU values greater than 90. Field tests help with the assessment of these recommendations.

Kohl (1972) indicated that while various collectors had been used in research to measure applied irrigation amounts, little was known about the accuracy of those collectors. He conducted research to compare collected irrigation depth with 1-qt (~1.0-L) oil cans, oil cans with paraffin, and 76.2-mm diameter sharp edged rain gauges. He concluded that a good collector should have the following design criteria so that evaporation loss would be minimal: collectors should have a small inner surface where water drops adhere and evaporate; the device opening should be designed to minimize evaporation; collectors should be painted white so that sensible heat transfer to the inner surface would be minimized; and devices should be easy to carry around and be easy to read. Seginer and Kostrinsky (1975) indicated that evaporation, wind drift, and splash out of collectors can cause water loss between sprinkler heads and irrigation water collectors and needs to be considered during uniformity tests. Many other types and sizes of catch devices were used to measure irrigation application depths including quart cans (Nir et al., 1980), plastic pans, fuel funnels (Clark and Finley, 1975), commonly used oil cans (Heermann and Kohl, 1980), and coffee cans on stakes (Vlotman and Fangmeier, 1983). A standardized water application collector would make it easier to compare research from different sources.

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 103-mm diameter and a 141-mm depth, glass separatory funnels with a 90.2-mm diameter, and a fuel funnel with a 49-mm diameter. The sprinkler irrigation package had Rainbird model 30 W-TNT series impact sprinklers with a 5.2-mm 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 120 mm and an opening of at least 60 mm 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 entrance of the collection device, then a buffer distance equal to twice the distance between the entrance of the collector and the height of the obstruction should be cleared.

Clark et al. (2004) developed an inexpensive, non-evaporating in-field precipitation gauge (IrriGage) for rainfall and irrigation depth measurements, but also for evaluation of sprinkler irrigation system uniformities. The IrriGage (Clark et al., 2004) is a 200-mm long, 100-mm diameter PVC pipe with a PVC cap glued to the bottom of the barrel. The IrriGage has a bottle attached to the bottom cap to serve as a water reservoir. The authors concluded that these collectors 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 Standards*, 2001), and that they are easy to make and set up in field tests. Because the IrriGage is non-evaporating, collected water amounts do not have to be read immediately following irrigation events.

Observations during center pivot irrigation system uniformity tests with 430-mm diameter pans (Clark et al., 2003) raised some concerns about using the IrriGage with coarse-grooved, fixed plate sprinkler packages. The distinct streams of water may or may not be caught by a gauge with a smaller diameter. 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 collectors, adjacently measured depths could vary from 50% to over 150% of the mean of measured depths (Clark et al., 2003).

While the ASAE Standard (S436.1, 2001) for measuring the uniformity of water application from center pivot and lateral move irrigation machines has been in place for some time, few data exist that evaluate the collector size requirements with low pressure, fixed plate sprinklers. Reported collector size evaluation data have been associated with higher-pressure impact sprinklers that tend to have greater droplet breakup. The objective of this study was to evaluate field measured data associated with the catch accuracy of the 100-mm diameter IrriGage collectors for measuring irrigation depth and uniformities of application from low-pressure, above-canopy, fixed plate and moving plate sprinkler devices on a moving irrigation system.

Materials and Methods

Catch Device Characteristics

This study evaluated the catch accuracy of the 100-mm diameter, IrriGage collectors (fig. 1; Clark et al., 2004) for fixed plate, spinning plate, and wobbling plate sprinkler irrigation packages. Study sites included a linear-move sprinkler irrigation system at the Kansas State University (KSU) Sandyland Experiment Field, St. John, Kansas (1999 and 2000), a center-pivot system at the KSU Livestock Waste Management Learning Center in Manhattan, Kansas (2002), and a linear move sprinkler system at the KSU North Central Experiment Field, Scandia, Kansas (2002).

The 1999 and 2000 studies compared single IrriGage collectors (100-S) to large diameter (430 mm) pans (PAN; fig. 1). The PAN collectors had rounded edges (10 mm wide) and shallow depths (100 mm), slightly less than ASAE criteria of 120 mm (*ASAE Standards*, 2001). However, the diameter (d) of the PANs was much larger than the IrriGages and the minimum recommended diameter of 60 mm (*ASAE Standards*, 2001). This resulted in a much larger hydraulic

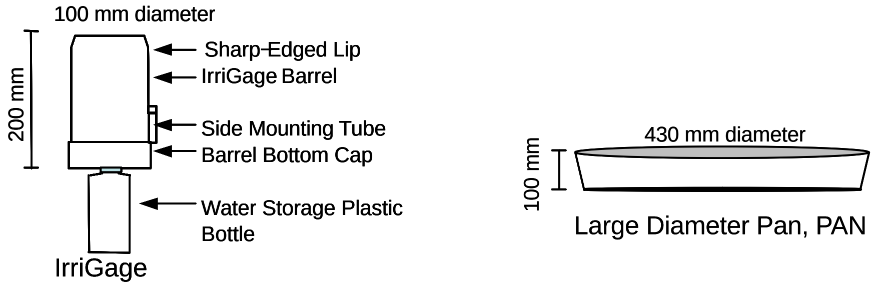

Figure 1. Characteristics of the 100-mm IrriGage and PAN collectors.

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. The PANs had a R_h of 108 mm while the R_h values for the IrriGage collectors and 60-mm ASAE minimum diameter criteria were 25 and 15 mm, respectively. Thus, it was believed that splash in/out would not be a substantial concern with the large diameter PAN collectors. The 2002 study sites involved a comparison of the standard 100-mm IrriGages in single (100-S), side-by-side (100-SS), and inline (100-IL) arrangements with a single row arrangement of 150-mm diameter collectors (150-S). The 150-mm diameter collectors were constructed similar to the IrriGage collectors (fig. 1). The 100-mm diameter PVC pipe barrel and associated bottom cap were replaced with a 150-mm diameter, 200-mm long PVC pipe barrel and appropriately sized bottom cap. All other components were the same.

All irrigation systems in this study (1999, 2000, and both 2002 studies) had sprinklers on drops just below the system trusses, and all drops were on a spacing of 3.0 m. Discharge rates from the three middle sprinkler nozzles from each treatment zone of the linear sprinkler irrigation systems (1999, 2000, and 2002-Scandia) 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 collected for 30 s, weighed, and data were converted to discharge rate units. The middle three nozzles and pressure regulators from both fixed plate and spinning plate sprinkler package test zones on the center pivot irrigation system (Manhattan - 2002) 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 replicated three times for 1 min each. These tests were used to verify the nozzle consistency and the manufacturer reported nozzle discharge rates.

1999/2000 Field Evaluations

The 1999 and 2000 studies were conducted using three irrigation pressure and nozzle size combinations with coarse-grooved, fixed plate deflector pads (Senninger LDN sprinklers, Clermont, Fla.). The linear move sprinkler irrigation system had four 49-m long spans that each had 16 flexible hose drops with polyethylene weights to minimize swinging from wind. Sprinklers were positioned at 2.2 to 2.4 m above the soil surface. Characteristics of the irrigation package used in 1999 and 2000 are presented in table 1. 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 760 mm apart (fig. 2, top). The IrriGage collectors were positioned such that the openings were 1.2 m above the soil surface using steel support rods. Thus, collector openings were 1.0 to 1.2 m below the sprinkler nozzles as recommended by *ASAE Standards* (2001). Corn plants within 1.2 m of the IrriGage collectors were removed to minimize any effect due to plant canopy. The corn canopy was approximately 2 m tall at the corn tassle stage; thus, the ratio of buffer distance to canopy height difference (from the collector opening) was 1.5 and not 2.0 as recommended by *ASAE Standards* (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, then converted to depth (mm) units, and used for statistical and graphical analysis.

For the irrigation testing events, PANs 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 linear system direction of travel and the IrriGage collectors (fig. 2, top). PANs 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 PANs was weighed with a top loading, mechanical balance and then converted to depth (mm) units. A balance was used to speed up the measurement process (all 12 PANs were measured within a 30-min period) and to eliminate risk of water loss by

Table 1. Operating pressure, nozzle orifice size, and flow rates for the sprinkler packages used in this study.[a]

Year	Sprinkler Package	Pressure Regulation (kPa)	Orifice Size (mm)	Flow Rates ($L\ s^{-1}$) Manufacturer	Field	Lab
1999/2000	FP	41	6.4	0.28	0.32	0.31
		103	5.2	0.28	0.31	0.33
		138	4.8	0.28	0.28	0.31
2002	FP	103	5.2	0.29	----	0.29
	SP	103	5.2	0.29	----	0.29
	WP	103	6.0	0.38	0.39	----

[a] Flow rates are shown as listed by the manufacturer, average field measured values, and average lab measured values.

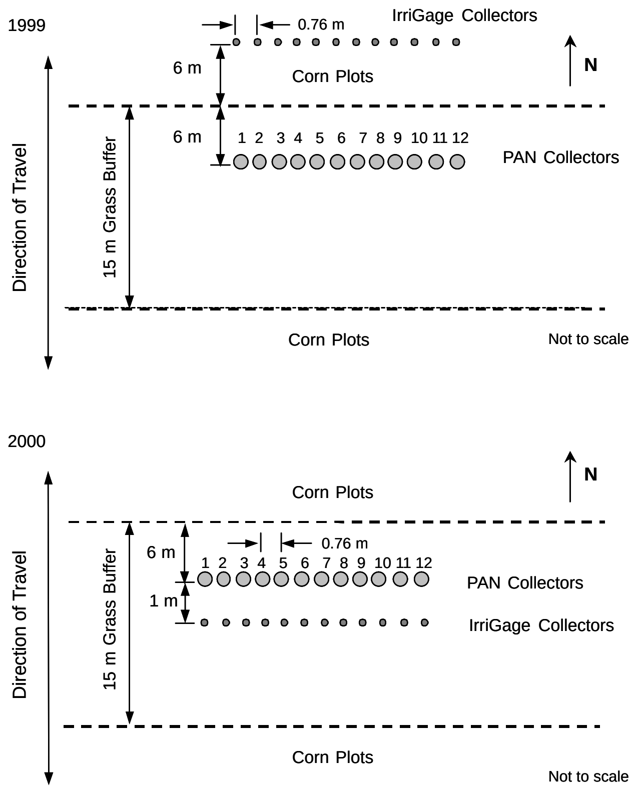

Figure 2. Field set up of the IrriGage and PAN collectors in 1999 (top) and 2000 (bottom).

transferring water from the PANs to another measuring device. The balance had a 9.0-kg scale with 25-g divisions and was initially zeroed with a dry PAN. Most of the measured water amounts were between 1.5 and 4.5 kg. The balance zero (tare weight) was checked during each test event with three to four other dry PANs. PAN collector results were used as base values to compare with IrriGage collector measurements. In 1999, IrriGage collectors and PAN collectors were evaluated using five separate sprinkler events during the growing season.

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 PANs were located (fig. 2, bottom) to eliminate potential plant interference. This time, IrriGage collectors were mounted with the openings 60-mm high using metal support rods (to increase the distance between the sprinkler discharge head and the collector opening), located 6 m from the corn plants, and about 1 m from the PANs. Five irrigation events were monitored during the 2000 summer growing season.

All tests in 1999 and 2000 were conducted in the early morning or early evening hours. At these times, wind speeds and evaporative conditions are lower than during the mid-morning to late afternoon periods. While wind speed was not directly measured during each test, average daily wind speed was available from a research station anemometer. Even though that anemometer was partially protected by a shelter belt of trees located approximately 50 m to the south of the weather station, test plots were also partially protected from wind by the corn plots to the north and south of the grass buffer. Prevailing winds typically come from the south to southwest direction. Mean collected irrigation depths were evaluated from each test event using paired sample T-Tests to compare collected data from the 100-mm diameter IrriGages to the 430-mm diameter PAN collector values. Variability in data from each test event was analyzed by F-Test comparisons between the IrriGage data set values and the PAN collector values.

2002 Field Evaluations

In 2002, three arrangements of the standard 100-mm IrriGage collectors [Single (100-S), Side-by-Side (100-SS), and Inline (100-IL)] were compared to a single row arrangement of the 150-mm collectors (150-S, fig. 3) on two experimental field sites (Manhattan, 2002 and Scandia, 2002) under three different sprinkler irrigation packages. Between the 2000 and 2002 studies, the IrriGage design was modified to include graduated bottles for direct measurement of collected irrigation amounts. Because the PANs were awkward to use, they were eliminated from this part of the study. It was believed that since the 150-mm collectors had over twice the surface area of the 100-mm IrriGages and over six times the surface area of the current ASAE recommended minimum collector diameter (60 mm), that they would be sufficiently large for test comparisons. The Manhattan, 2002 field studies were conducted at the KSU Livestock Waste Management Learning Center (WMLC), Manhattan, Kansas, under a new center pivot with seven, 55-m long spans. The last span was used for the collector evaluations. The first nine drops of the last span were installed with a Nelson S3000 spinning plate sprinkler package (Nelson Irrigation Corporation, Walla Walla, Wash.) (table 1). The remaining eight drops of that system had the Nelson D3000 fixed-plate sprinkler package (sprayhead with a coarse grooved plate).

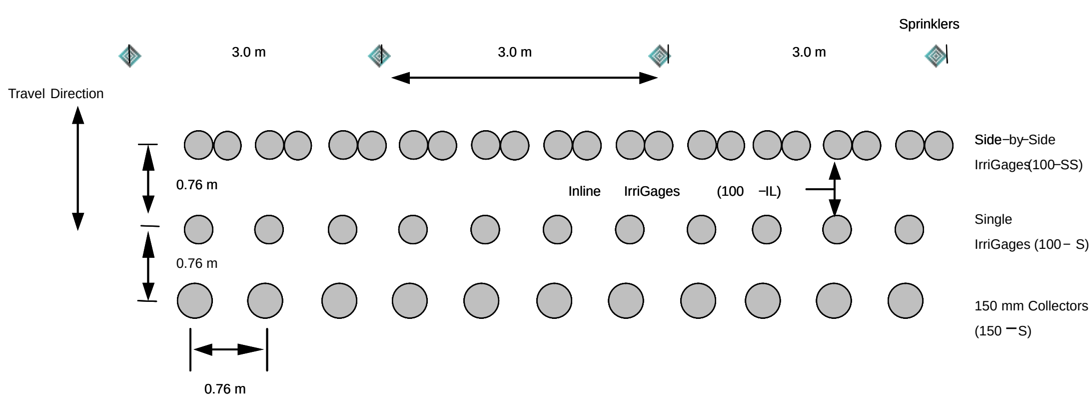

Figure 3. Field setup of the 150-S collectors, and the 100-S, 100-IL, and 100-SS IrriGage arrangements used in the 2002 tests.

Both irrigation packages were operated at 104 kPa of pressure. Sprinklers were positioned on drop tubes that were on a 3.0-m spacing and about 2.0 m above the soil surface.

Three sets of twelve IrriGage collectors for each arrangement [Single (100-S), Side-by-Side (100-SS), and Inline (100-IL)] and one row of the 150-S collector arrangement were set up under the sprinkler packages as shown in figure 3. The 100-S, 100-SS, and 100-IL IrriGage collectors and 150-S collectors were mounted on metal rods such that the openings were at a 600-mm height above the ground surface. 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 shown in figure 3 in order to evaluate these different arrangements (100-S, 100-SS, and 100-IL) of the collectors.

The Scandia, 2002 field study evaluated the same collector arrangements as the Manhattan, 2002 field study using Senninger I-Wob (wobbling plate) sprinklers (Senninger Irrigation, Inc. Orlando, Fla.) (table 1) on a new linear move irrigation system at the KSU North Central Experiment Field, Scandia, Kansas. The irrigation system had five, 55-m long spans. The first two spans (No. 1 and 2) of the linear irrigation system were used for collector evaluations in two test runs (A and B) on 12 August 2002. Irrigation drops were 3.0 m apart and 2.0 to 2.3 m above the soil surface. Collector set up was identical to the Manhattan, 2002 study (fig. 3) with four sets of 12 collectors 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^{-1}.

Average daily wind speed on the days of the 2002 field tests was obtained from weather stations located at adjacent experiment field sites. Mean collected irrigation depths were evaluated from each test event using paired sample T-Tests to compare collected data from each IrriGage arrangement (100-S, 100-SS, and 100-IL) to the 150-S collector values. Variability in data were analyzed by F-Test comparisons between datasets.

Results and Discussion

Average daily wind speeds often exceeded the 3.6 km h^{-1} (1 m s^{-1}) testing threshold recommendation in the ASAE center pivot evaluation standard (*ASAE Standards*, 2001). However, average wind speeds never exceeded the 18-km h^{-1} (5-m s^{-1}) upper threshold recommendation and were generally between 3 and 9 km h^{-1}. Furthermore, field tests were performed in the early morning or evening hours when actual wind speeds were lower than average conditions. All collectors during each test event were subjected to the same conditions and the intent of this work was to evaluate the relative performance of the collectors under normal environmental conditions that would be encountered during field evaluations of center pivot systems.

1999/2000 Field Results

Average irrigation depths and corresponding dataset variances from each set of 12 collectors for each of the five test events under the fixed plate sprinklers operated at 41, 104, and 138 kPa measured with IrriGage and PAN collectors are presented in tables 2 and 3 for 1999 and 2000, respectively. Average irrigation depths collected with IrriGage collectors in 1999 (table 2) were significantly lower than depths collected with the PAN collectors in four of the five tests for each of the three operating pressures. The IrriGage collector measured depths were 39%, 20%, and 18% lower (on average) than the PAN collector depths under the 41-, 104-, and 138-kPa sprinkler package pressures, respectively. While differences in measured mean depths were not as great under the higher pressure sprinklers, it was thought that the measured differences could be because the IrriGage collectors were in the crop canopy area and were 1.2 m high while the PAN collectors were in the grass buffer at a lower position. It was believed at that time that because the 100-mm collector opening size of the IrriGages was substantially greater than the ASAE recommended minimum of 60 mm, that those data were acceptable and that the

Table 2. Summary of measured data and statistical analyses performed to compare PAN and IrriGage collectors for five irrigation events in 1999.

Test Date	Pressure (kPa)	Mean Depth IrriGage (mm)	Mean Depth PAN (mm)	T-Test[a] Results	Difference[b] in Depths (%)	Variance IrriGage (mm^2)	Variance PAN (mm^2)	F-Test[a] Results
1 Jun 1999	41	10.7	14.3	NS	24.6	95.1	5.4	***
	104	10.6	12.5	**	15.4	12.9	4.1	**
	138	10.1	12.5	***	19.6	5.3	2.8	NS
6 Jul 1999	41	6.5	11.8	***	45.1	22.1	19.9	NS
	104	9.2	12.7	***	28.0	3.8	2.5	NS
	138	9.5	9.3	NS	−1.6	2.3	1.6	NS
15 Jul 1999	41	8.1	13.0	***	37.6	19.9	11.8	NS
	104	9.6	13.6	***	29.6	2.2	0.6	**
	138	9.7	12.4	***	21.1	2.6	0.8	**
30 Jul 1999	41	7.6	14.5	***	47.3	40.8	19.5	NS
	104	10.5	12.9	***	18.8	10.0	2.8	**
	138	9.0	13.3	***	32.7	10.7	1.2	***
9 Aug 1999	41	8.6	15.0	**	42.5	29.4	17.7	NS
	104	11.7	13.0	NS	10.3	20.3	3.3	***
	138	11.7	14.6	**	20.1	13.3	1.3	***

[a] Statistical test results were different at the 10% (*), 5% (**), or 1% (***) level of significance or not significant (NS).
[b] Depth differences were determined using the PAN results as the base value.

Table 3. Summary of measured data and statistical analyses performed to compare PAN and IrriGage collectors for five irrigation events in 1999.

Test Date	Pressure (kPa)	Mean Depth IrriGage (mm)	Mean Depth PAN (mm)	T-Test[a] Results	Difference[b] in Depths (%)	Variance IrriGage (mm^2)	Variance PAN (mm^2)	F-Test[a] Results
8 Jun 2000	41	15.4	13.1	*	−17.4%	38.	2.1	***
	104	18.3	13.4	**	−36.6%	50.8	0.5	***
	138	12.1	12.6	NS	3.4%	1.6	1.5	NS
23 Jun 2000	41	16.3	12.2	**	−33.7%	19.1	12.8	NS
	104	18.0	13.1	***	−36.9%	16.7	1.5	***
	138	16.8	13.2	**	−26.6%	19.4	0.8	***
7 Jul 2000	41	17.1	15.3	NS	−11.8%	27.2	25.9	NS
	104	22.8	15.5	***	−46.8%	71.8	2.3	***
	138	19.5	16.0	**	−22.0%	41.1	1.2	***
4 Aug 2000	41	18.1	15.5	**	−17.1%	18.3	24.4	NS
	104	20.9	14.5	***	−43.8%	68.6	2.6	***
	138	18.3	13.8	**	−33.1%	31.0	2.7	***
10 Aug 2000	41	18.8	16.5	*	−14.4%	21.6	21.2	NS
	104	20.9	15.5	***	−34.8%	44.7	12.9	**
	138	18.0	13.7	**	−31.4%	43.1	5.7	***

[a] Statistical test results were different at the 10% (*), 5% (**), or 1% (***) level of significance or not significant (NS).

[b] Depth differences were determined using the PAN results as the base value..

measured differences were primarily associated with the different measurement locations, positions, and possible corn canopy interference. This is why the collector arrangement was modified in 2000 (fig. 2) to have both PAN and IrriGage collectors in the grass buffer.

Repositioning the IrriGage collectors into the grass buffer with the PAN collectors in 2000 resulted in measured depths and relationships (table 3) that were contrary to the 1999 measured depths. The 2000 IrriGage collected depths were significantly greater than the PAN collected depths for nearly all tests. These results were not expected and were attributed to the stream-like water application patterns associated with those sprinklers. Measured differences between the IrriGage collector depths and the PAN collector depths averaged 19%, 40%, and 22% greater under the 41-, 104-, and 138-kPa sprinkler package pressures, respectively. This was a substantial shift from the 1999 measured results and still posed a question as to the appropriateness of a collector with a 100-mm diameter opening for measuring water application depths and patterns from coarse-grooved, fixed-plate sprinklers. Because the diameter of the PAN collector opening (430 mm) was greater than the IrriGage collectors (100 mm), and the variance of measured PAN data from the 104- and 138-kPa sprinkler packages (tables 2 and 3) was lower than the variance of the IrriGage data, irrigation depths from the PAN collectors were considered to be more accurate and representative of actual irrigation depths and patterns.

The "stream" type of water application pattern from the coarse-grooved, fixed-plate sprinklers is a characteristic that helps to minimize wind distortion and droplet evaporation during high wind and dry conditions. While the higher operating pressures still tend to have a "stream" type of pattern, those sprinkler patterns also have greater droplet breakup. Evidence of these characteristics is supported by the variances of the data sets. Greater dataset variances were measured with the lower pressure sprinkler packages in the PAN collector results for both years (tables 2 and 3). A sample dataset from the 4 August test in 2000 (fig. 4) shows the consistency in the measured data from the PAN collectors under the 104- and 138-kPa sprinkler packages. Also, while variable, even the PAN-based cyclic pattern associated with the 41-kPa sprinklers follows a consistent trend. However, variances associated with the datasets from the IrriGage collectors were generally significantly greater than the variances with the PAN collectors for the two higher pressure sprinkler packages in both 1999 and 2000 (tables 2 and 3). In a visual comparison of the individual data points from the 4 August 2000 test (fig. 4), some of the IrriGage measured values matched very closely to the PAN data, while others were substantially off and did not mimic measured patterns. Even though variances of the IrriGage collector datasets under the 41-kPa sprinkler package were often not significantly different from those with the PAN collectors, several measured points did not match (fig. 4). Thus, the results from 1999 and 2000 indicate that a 100-mm collector opening is probably too small to adequately measure average irrigation depths and patterns from sprinklers with fixed plate (FP), coarse-grooved deflector pads. The distinct streams of water that are common with those types of sprinklers can result in application patterns with harmonic distributions that have relatively large amplitude variations (Clark et al., 2003). Furthermore, those "streams" of water are each associated with an irrigated area that may be much larger than the opening of the IrriGage collector and the depth averaging process of collected water amounts does not appropriately represent the "average" depth of applied water.

2002 Field Results

Fixed Plate Sprinklers

Average irrigation depths from the fixed plate sprinkler package using 150-S and single IrriGage (100-S) collectors were numerically lower in all three of the 2002 tests and significantly different for two of the tests (table 4). The single row of IrriGage collectors consistently over-estimated the 150-S collector irrigation depths by 13% to 25% and were similar to the previously discussed 2000 field study results under another fixed plate sprinkler package. Use of 100-IL or 100-SS collector arrangements did not improve measured depth results in comparison with the 150-S collectors

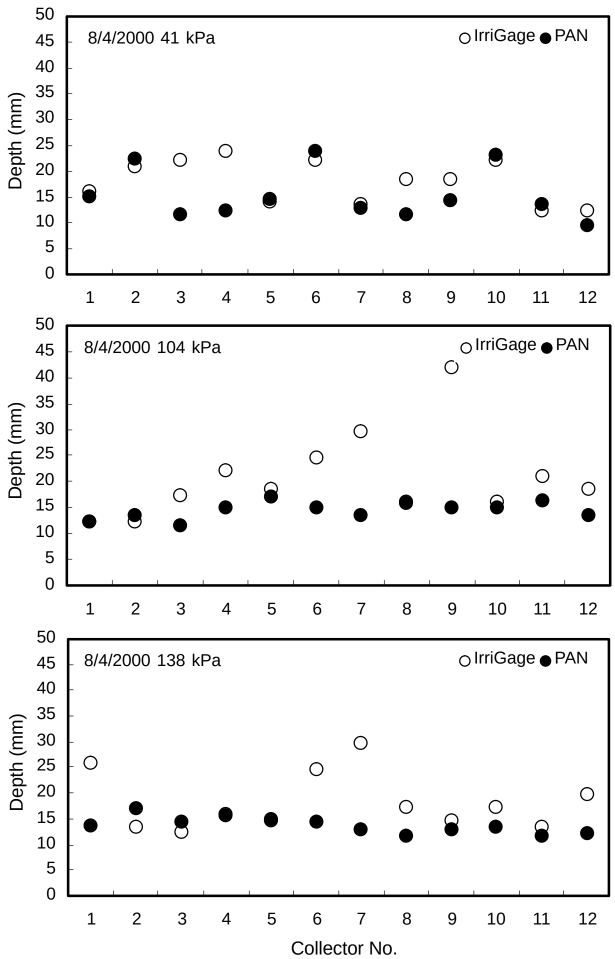

Figure 4. Individual collector measured depths from the 4 August 2000 test event for both IrriGage and PAN collectors under the 41-, 104-, and 138-kPa sprinkler packages.

(tables 5 and 6). Averaged measured depths from the 100-IL or 100-SS IrriGage arrangements were still greater than depths from the 150-S collectors. Furthermore, the 100-S, 100-IL, and 100-SS data sets had numerically greater variances (tables 4, 5, and 6). Yet, these variances were only significantly different with the data from the first test date. The individual data points from the 100-S, 100-IL, and 100-SS IrriGages at times measured the same values as the 150-S collectors (fig. 5), but generally had highly variable and inconsistent data, which again was not improved by using multiple collectors (100-IL or 100-SS).

Spinning Plate Sprinkler

Measured depths under the spinning plate sprinkler package with 100-S, 100-IL, and 100-SS collector arrangements were numerically greater than measured depths from the 150-S collectors (tables 4, 5, and 6). However, differences only ranged from 5% to 11% and were much lower than the measured differences under the 2002 fixed-plate sprinkler package. Field observations of the spinning plate sprinkler package showed visually smaller droplets and greater droplet breakup than applications from the coarse-grooved, fixed-plate sprinklers in this study. This characteristic can result in a more uniform application pattern without the “depth averaging” effects associated with the water streams from the coarse-grooved, fixed-plate sprinklers. Measured application patterns using the 150-S collectors under the spinning plate sprinkler package were very uniform for all three test dates (fig. 6) with low dataset variances (table 4). Individual collector measured data from single IrriGage collectors (100-S) tracked well with most of the 150-S collector results in all three tests (fig. 6). However, the 100-S collector number 6 consistently recorded greater depth than the 150-S collector arrangement. While we are not sure why this happened, it may be the result of a consistent drip off of the center pivot truss or sprinkler drop at that location. Collected drips in the 150-S collectors would be “depth-averaged” over a larger surface area thus minimizing the periodic greater reported depths associated with the smaller collector areas. The collectors remained at the same locations in the field for all test runs.

Dataset variances from all three IrriGage arrangements were greater than variances from 150-S collector datasets (tables 4, 5, and 6). However, these variances were substantially smaller than those associated with the 2002, fixed-plate sprinkler package, and as previously discussed, most of the individual data points from the 100-S collectors visually matched up very closely with the 150-S collector data (fig. 6). Furthermore, multiple IrriGage arrangements (100-IL, 100-SS) did not improve measured results.

Table 4. Summary of measured data and statistical analyses used to compare the 150-S and 100-S collectors in 2002.

Sprinkler Type	Test Date	Mean Depth 150-S (mm)	Mean Depth 100-S (mm)	T-Test[a] Results	Difference[b] from 150-S (%)	Variance 150-S (mm^2)	Variance 100-S (mm^2)	F-Test[a] Results
Fixed plate	16 Jul	14.1	17.5	**	24.5%	21.59	57.82	*
	31 Jul	14.3	16.2	NS	13.6%	47.34	76.19	NS
	8 Aug	14.8	18.5	**	25.2%	36.86	62.91	NS
Spinning plate	16 Jul	13.5	14.3	NS	5.5%	1.83	8.55	***
	31 Jul	14.8	16.2	**	9.3%	2.40	7.71	**
	8 Aug	14.3	15.1	NS	5.3%	2.69	14.41	***
Wobbling plate	12 Aug -1A	18.2	19.0	NS	4.3%	4.87	14.65	**
	12 Aug -1B	20.8	21.9	NS	5.3%	1.10	9.39	***
	12 Aug -2A	19.1	18.7	NS	−1.8%	0.35	3.87	***
	12 Aug -2B	20.5	21.8	*	6.5%	0.40	5.02	***

[a] Statistical test results were different at the 10% (*), 5% (**), or 1% (***) level of significance or not significant (NS).
[b] Depth differences were determined using the PAN results as the base value.

Table 5. Summary of measured data and statistical analyses used to compare the 150-S and 100-IL collectors in 2002.

Sprinkler Type	Test Date	Mean Depth 150-S (mm)	Mean Depth Results	T-Test[a] Results	Difference[b] from 150-S (%)	Variance 150-S (mm^2)	Variance 100-IL (mm^2)	F-Test[a] Results
Fixed plate	16 Jul	14.1	17.1	**	21.4	21.59	71.92	**
	31 Jul	14.3	15.4	NS	7.6	47.34	51.22	NS
	8 Aug	14.8	19.3	***	30.6	36.86	52.93	NS
Spinning plate	16 Jul	13.5	14.3	**	5.9	1.83	3.50	NS
	31 Jul	14.8	16.0	***	8.1	2.40	5.67	*
	8 Aug	14.3	15.0	NS	5.0	2.69	9.13	**
Wobbling plate	12 Aug -1A	18.2	21.1	**	15.7	4.87	19.56	**
	12 Aug -1B	20.8	23.2	**	11.6	1.10	12.62	***
	12 Aug -2A	19.1	18.5	*	−3.0	0.35	1.19	**
	12 Aug -2B	20.5	21.5	**	4.9	0.40	1.32	**

[a] Statistical test results were different at the 10% (*), 5% (**), or 1% (***) level of significance or not significant (NS).
[b] Depth differences were determined using the PAN results as the base value.

Wobbling Plate Sprinkler

Measured depths from the 100-S collectors under the wobbling plate sprinklers were not significantly different in three of the four test runs than the measured depths from the 150-S collectors (table 4). Differences ranged from 2% to 6%. As with the spinning plate sprinklers, observed application patterns had a high degree of droplet breakup with relatively small droplets and no “streams.” Resultant measured datasets from the 150-S collectors had relatively low variances (table 4) with uniform patterns (fig. 7 and 8). While wobbling plate sprinkler dataset variances from the 100-S collectors (table 4) were significantly greater than variances from the 150-S collectors, individual collector data tracked very well for most collectors in each of the field tests (figs. 7 and 8). As with the other 2002 tested sprinkler packages, multiple IrriGage collectors (100-SS and 100-IL) did not improve measurement accuracy in measured depths (tables 5 and 6) or tracking of individual collectors (figs. 7 and 8) in comparison with the 150-S collectors.

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 (the IrriGage). In 1999 and 2000 IrriGage collectors (100-mm dia.) were compared to 430 mm diameter pans (PAN). Tests in 2002 compared different arrangements (single [100-S], side-by-side [100-SS], and inline [100-IL]) of the 100-mm IrriGage to a single row of 150-mm diameter collectors (150-S). All collectors were tested to measure sprinkler irrigation system depths and variability of measured data under different sprinkler irrigation packages. Sprinkler irrigation packages tested included fixed-plate deflector pads with coarse grooves, spinning plates, and wobbling plates with different nozzle and pressure combinations. Fixed-plate sprinkler packages had visually distinct water streams with larger water droplets, while spinning and wobbling plate sprinklers had visually smaller water droplets with greater droplet breakup.

In 1999, IrriGage collectors positioned within a corn canopy measured lower irrigation depths and more variable sprinkler patterns when compared with the larger PAN collectors. Even with higher sprinkler nozzle pressures (104 and 138 kPa), IrriGage collectors did not reasonably measure irrigation depths or patterns as compared to the PAN collectors. In 2000, even though the IrriGage collector openings were lowered and collectors were repositioned into a grass buffer with the PAN collectors, measured irrigation depths and associated variances were significantly different than associated data from PAN collectors. In addition, irrigation application patterns from the IrriGage collectors under the fixed plate sprinkler package with different pressure combinations did not consistently match the PAN results.

In 2002, IrriGage collector evaluations under the fixed plate sprinkler irrigation package resulted in greater measured irrigation depths and greater dataset variances than 150-S collectors, similar to 2000 results. Additionally,

Table 6. Summary of measured data and statistical analyses used to compare the 150-S and 100-SS collectors in 2002.

Sprinkler Type	Test Date	Mean Depth 150-S (mm)	Mean Depth 100-SS (mm)	T-Test[a] Results	Difference[b] from 150-S (%)	Variance 150-S (mm^2)	Variance 100-SS (mm^2)	F-Test[a] Results
Fixed plate	16 Jul	14.1	17.2	*	22.1%	21.59	104.74	***
	31 Jul	14.3	16.0	NS	12.0%	47.34	69.03	NS
	8 Aug	14.8	19.2	*	29.6%	36.86	70.64	NS
Spinning plate	16 Jul	13.5	15.0	**	11.1%	1.83	7.73	**
	31 Jul	14.8	15.6	*	5.1%	2.40	3.95	NS
	8 Aug	14.3	15.6	***	9.2%	2.69	6.32	*
Wobbling plate	12 Aug -1A	18.2	21.4	**	17.7%	4.87	18.94	**
	12 Aug -1B	20.8	23.7	**	13.8%	1.10	16.68	***
	12 Aug -2A	19.1	18.3	**	−4.2%	0.35	0.84	*
	12 Aug -2B	20.5	21.1	***	3.2%	0.40	0.67	NS

[a] Statistical test results were different at the 10% (*), 5% (**), or 1% (***) level of significance or not significant (NS).
[b] Depth differences were determined using the PAN results as the base value.

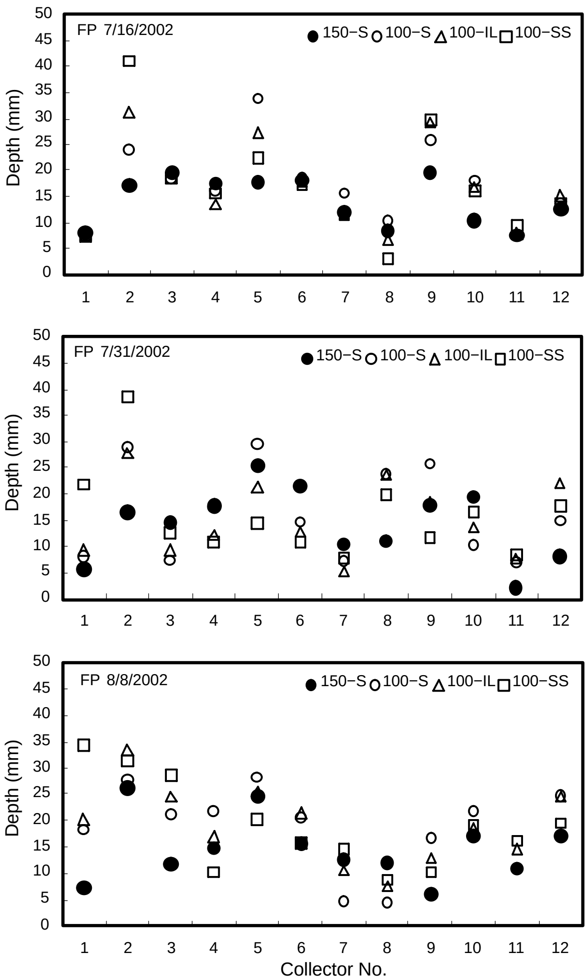

Figure 5. Individual collector measured depths under the fixed plate (FP) sprinkler package from the 16 July, 31 July, and 8 August 2002 test events for the 150-S collectors, and the 100-S, 100-IL, and 100-SS IrriGage arrangements.

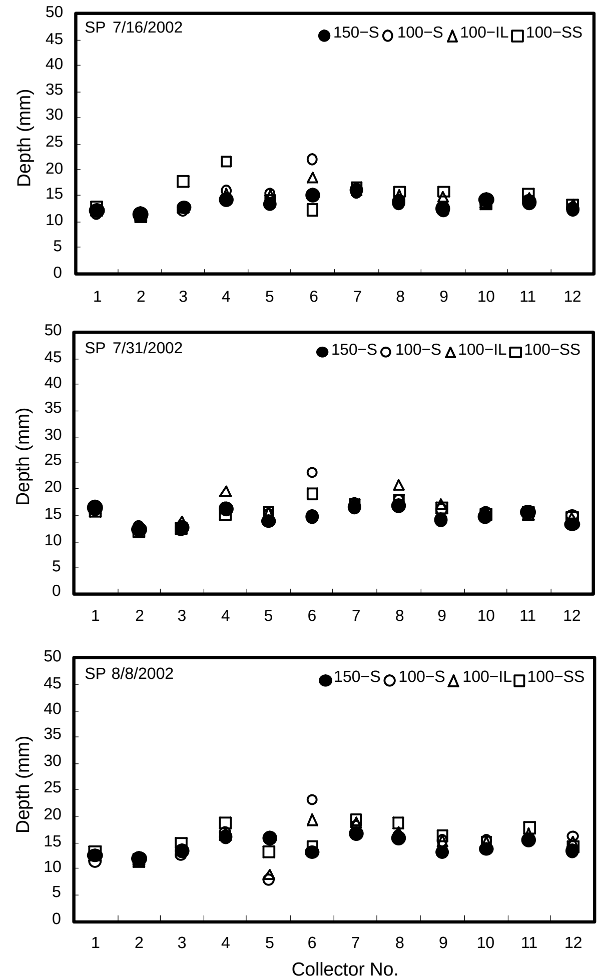

Figure 6. Individual collector measured depths under the spinning plate (SP) sprinkler package from the 16 July, 31 July, and 8 August 2002 test events for the 150-S collectors, and the 100-S, 100-IL, and 100-SS IrriGage arrangements.

IrriGage collector results did not accurately measure nor mimic the fixed plate irrigation application patterns as compared to the 150-S collectors. However, pattern representation was improved under the spinning and wobbling plate packages that also had greater droplet breakup. In addition, measured depths from 100-S collectors under the spinning and wobbling plate sprinklers were not significantly different from measured depths using the 150-S collectors.

The results of this work indicate that the current collector size criteria in the ASAE standard for testing center pivot and linear move irrigation machines (ASAE S436.1, 2001) need to be reviewed and perhaps revised. Additional research 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, coarse-grooved sprinklers that provide distinct streams of water with little pattern breakup. These results also indicate that due to pattern variability, a single IrriGage collector would not be acceptable to measure the depth of water from a center pivot (or linear move) system and that multiple collectors should be used to measure the average application depth from just a section of one of these irrigation systems.

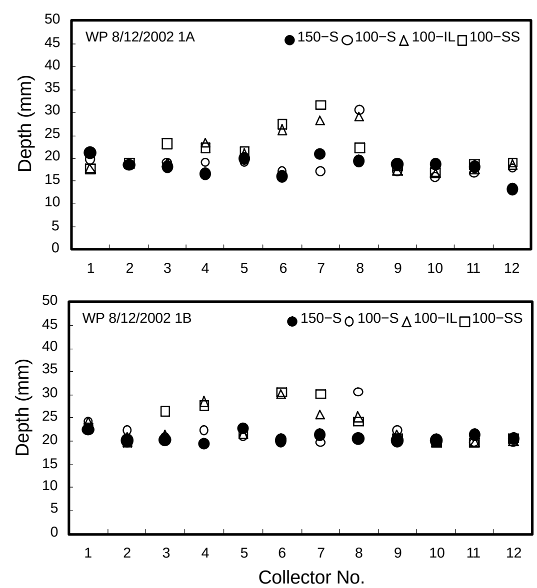

Figure 7. Individual collector measured depths under span 1 of the wobbling plate (WP) sprinkler package from the 12 August 2002 test events (1A and 1B) for the 150-S collectors, and the 100-S, 100-IL, and 100-SS IrriGage arrangements.

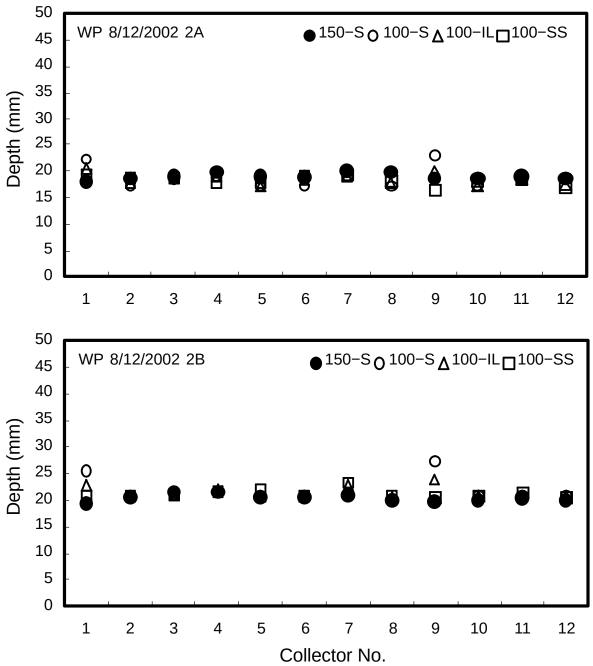

Figure 8. Individual collector measured depths under span 2 of the wobbling plate (WP) sprinkler package from the 12 August 2002 test events (2A and 2B) for the 150-S collectors, and the 100-S, 100-IL, and 100-SS IrriGage arrangements.

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