CATCH-CAN PERFORMANCE UNDER A LINE-SOURCE SPRINKLER

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ABSTRACT. *A line-source sprinkler configuration provides a linearly decreasing irrigation application rate perpendicular to the sprinkler line and has been utilized to study crop response to variable irrigation amounts. The effect on measured irrigation application depths from using various types of catch-cans in those studies is not known. Derived relationships between crop yield and applied water is dependent on the accuracy of measured catch-can water volumes. The purpose of this study was to evaluate catch-can characteristic effects on measurement of sprinkler irrigation depths in a line source. This was accomplished by evaluating six types of catch-cans: (1) 83 mm diameter polypropylene separatory funnel (with evaporation-suppressing oil), (2) 82 mm diameter PVC reducer can (with evaporation-suppressing oil), (3) 151 mm diameter metal can, (4) 64 × 59 mm wedge rain gauge, (5) 146 mm white plastic bucket, and (6) 100 mm diameter clear plastic funnel rain gauge. The cans were placed at five application rate conditions (2.8, 5.5, 8.7, 12.6, and 14.8 mm/h). Cumulative catch depths differed among the catch-can types. However, only the metal can and white bucket cumulative application depths at the lowest application rate were statistically different from those of the control (separatory funnel). Catch-cans with a larger diameter opening exhibited less variation in catch depths. Measured evaporation of standing water from catch-cans varied from 0.04 mm/h (funnel rain gauge) to 1.81 mm/h (separatory funnel without evaporation-suppressing oil). Water applied to a bucket's sidewall evaporated at a higher rate than standing water. Inaccuracy of application depth measurement may occur at low application rates even when catch-cans meet the ASAE Standard. The relatively good performance of the funnel rain gauge and catch-cans with evaporation-suppressing oil (and subsequently less depth than the ASAE Standard requires) suggests that it may be appropriate to re-evaluate the standard to consider such devices.*

Keywords. *Catch-can, Evaporation, Line-source sprinkler, Sprinkler irrigation.*

The concept of using a single line-source sprinkler to impose a continuous variable water application across a field research plot was introduced in the early 1970s (Hanks et al., 1976; Bauder et al., 1975; Willardson et al., 1987; Hanks et al., 1980). Subsequently, many line-source sprinkler research studies of crop yield response to variable amounts of irrigation water have been conducted (Peel et al., 2004; Jensen et al., 2001; Asay et al., 2001; Guttieri et al., 2000; Meyer and Marcum, 1998). The sprinkler spacing in the line source was empirically determined such that variation in irrigation application depth parallel to the line was minimized, whereas application depth perpendicular to the line decreased linearly with distance from the line. Various types of catch-cans have been used to measure line-source sprinkler irrigation application depths including, among others, galvanized-metal fruit or coffee cans, plastic cups, 100 mm diameter aluminum irrigation pipe, wide-mouth glass canning jars, and cottage cheese containers. The correctness of crop yield and water relationships derived in these studies is dependent on the accuracy of irrigation depth measurement. Thus, the accuracy of the catch-can measurement of irrigation depth is important. Evaporation of water from the catch-cans during the irrigation event may also affect the irrigation depth measurement accuracy.

Kohl (1972) compared several different types of precipitation gauges to a separatory funnel gauge with evaporation-suppressing oil (fig. 1). The gauges were set at arcs of different distances from a single sprinkler to produce different application conditions. Over the range of application rates, depths in all the catch-cans were less than that of the separatory funnel. Evaporation from the catch-cans generally increased as the application rate decreased. All gauges performed exceptionally better at night than during daytime irrigations, indicating that evaporation from the catch-cans was the major source of error. Kohl (1972) also pointed out the potential increase in evaporation due to droplets of water clinging to the inner sidewall of a catch-can. Thus, the type of material that a catch-can is composed of may have a significant effect on evaporation from the catch-can and on irrigation depth measurement.

The accuracy of irrigation depth measurement of several catch-cans was also studied by Marek and Howell (1987). However, their study was performed under laboratory conditions with minimal wind and evaporation effects. In their tests, all gauges measured an irrigation depth within 2% of the reference (separatory funnel) with the exception of one (oil-can gauge).

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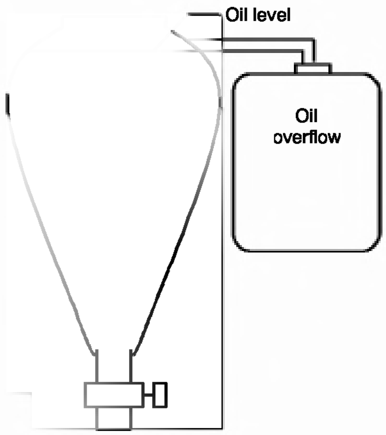

Figure 1. Separatory funnel.

Catch-cans may estimate irrigation depth differently in the presence of wind. Livingston et al. (1985) tested two catch-can diameters, 106 and 79 mm, with wind velocities from 3.3 to 6.3 m/s. As wind velocities increased, the percentage catch decreased. Additionally, the larger the catch unit diameter, the greater the magnitude decrease in catch. Catch-cans of different characteristics perform differently in windy conditions.

Evaporation from the catch-can both during and after irrigation may affect the accuracy of the measurement of irrigation depth. Clark et al. (2004) designed and tested the Irrigage, a catch-can designed to prevent evaporation from the gauge. The 100 mm diameter Irrigage consisted of a PVC pipe with a cap on the bottom. A plastic bottle was attached to the bottom of the device to store collected water. Clark et al. (2006) evaluated the Irrigage in measuring irrigation depths under low-pressure pivot irrigation systems against larger diameter collectors. The purpose was to evaluate performance of catch-cans under low-pressure pivot nozzles that provide streams of water with little break up. The Irrigage was compared to a 430 mm diameter catch-can with a height of 100 mm under three types of nozzle packages: fixed-plate deflector pads with coarse grooves, spinning plates, and wobbling plates. The irrigation depths and variability were greater in the Irrigage's measurements as compared to the 430 mm diameter catch-can. The Irrigage was also compared to a 150 mm catch-can and again measured greater irrigation depths with greater variability under the fixed-plate sprinklers. The Irrigage estimated irrigation depths that were 2% and 9% greater than the 150 mm catch-can under the spinning plate and wobbling plate sprinklers, respectively. Clark et al. (2006) suggested that the ASAE Standard for the minimum diameter of catch-cans under a low-pressure sprinkler package be re-evaluated.

Many factors affect accurate irrigation depth measurement by catch-cans. These factors include: catch-can opening area, catch-can color, catch-can height, environmental conditions, area of exposed water surface, sprinkler droplet characteristics, sprinkler application rate, and catch-can placement height. ASAE Standard S436.1 (*ASAE Standards*, 2001) recommends the following criteria for catch-can devices used in center-pivot uniformity evaluations: first, the catch-can should have a minimum diameter of no less than 60 mm and a minimum height of 120 mm; second, the diameter of the can should be one-half to one times the can height; and finally, the can should be light-colored to minimize absorbed energy by the catch container.

The purpose of this study was to evaluate the effects of catch-can characteristics on measurement accuracy of sprinkler irrigation depths under a line-source sprinkler. This was accomplished through three experiments: (1) comparison of six types of catch-cans in measuring application depths at varying application rates, (2) measurement of standing evaporation from the six catch-cans, and (3) measurement of evaporation from catch-cans with water applied to the inner sidewalls. Additionally, an estimate was made of the losses between metered pipeline supply water and catch volume in the line-source study area.

Material and Methods

Catch-Can Comparison

Six types of catch-cans were evaluated (fig. 2): (1) 83 mm diameter, 190 mm deep polypropylene separatory funnel (with evaporation-suppressing oil); (2) 82 mm diameter, 130 mm deep white PVC reducer can (with evaporation-suppressing oil); (3) 151 mm diameter, 173 mm deep metal can; (4) 64 × 59 mm rectangular opening, 336 mm deep clear wedge rain gauge (Tru-Check, Edwards Mfg. Co., Albert Lea, Minn.); (5) 146 mm diameter, 190 mm deep white plastic bucket (2.3 kg cottage cheese container); and (6) 100 mm diameter, 85 mm deep (to bottom of funnel) clear plastic funnel rain gauge.

All catch-cans met ASAE Standard S436.1 (*ASAE Standards*, 2001) for 60 mm minimum diameter, with the exception of the wedge rain gauge (rectangular opening, 59 mm minimum dimension). The wedge rain gauge's opening area was 3776 mm^2, which is a greater area than that of a 60 mm diameter circular catch-can. The ASAE Standard refers to catch-can height, and it was assumed that the height of the can also referred to depth to the surface on which a sprinkler droplet could impact. The metal can, white bucket, and wedge rain gauge all met the minimum depth (120 mm) requirements of the ASAE Standard. The depth of the separatory funnel and PVC reducer catch-cans was less than the minimum depth requirement due to their being filled with the evaporation-suppressing oil. A funnel was installed near the

Figure 2. Catch-cans in the field, from left to right: metal can, separatory funnel, wedge rain gauge, funnel rain gauge, white bucket, and PVC reducer.

top of the funnel rain gauge; thus, it did not meet the minimum depth standard. All gauges were light in color with the exception of the metal can and clear rain gauges.

Number 2 diesel fuel was used as the evaporation suppressant in the separatory funnel and PVC reducer gauges. The separatory funnel's opening was tapered inward (fig. 1). This allowed the majority of sprinkler droplets to impact the oil surface without hitting the container's inside wall, which minimized evaporation from droplets clinging on the inside wall of the container. The top portion of each separatory funnel was cut off to provide a larger opening, and the lips were sharpened. A drainage tube was installed near the top of the container to drain excess diesel fuel as the funnel filled with water. The disadvantage of the separatory funnel device is that its effective depth is decreased when filled with diesel fuel, thus violating the ASAE Standard for catch-cans that height should be at least equal to the diameter. Observation in the field showed minor splash out when sprinkler droplets hit the oil surface.

The PVC reducer gauge (fig. 3) was designed to function similarly to the separatory funnel. This catch-can was built by connecting a 101.6 × 76.2 mm (4 × 3 in.) PVC reducer, a length of 101.6 mm (4 in.) PVC pipe, and a 101.6 mm (4 in.) cap with a drain hole. The 76.2 mm (3 in.) end of the reducer was cut to a length of approximately 30 mm, thus minimizing the inner sidewall area that sprinkler droplets would impact, cling to, and potentially evaporate from. The PVC reducer was also filled with evaporation-suppressing oil. A drainage line was placed near the top of the container to drain off excess oil, as was done in the separatory funnel. The PVC reducer catch-can exhibited potential advantages over the separatory funnel. It provided a sharper lip edge than the separatory funnel, and the materials used to build the device were readily available and inexpensive.

Both the PVC reducer catch-can and the separatory funnel catch-can were used with evaporation-suppressing oil to provide low evaporation characteristics and thus more accurate irrigation depths for comparison purposes. The other containers were selected due to their observed use in other studies of irrigation depth measurement and not necessarily due to their conformity with the ASAE Standard.

Experimental Site and Setup

The catch-can comparison tests were performed at a line-source sprinkler experiment site on a grass/legume pasture mixture located at a high elevation (1912 m above mean sea level) north of Randolph, Utah. Measurement of sprinkler application variation was accomplished by placing catch-cans at five distances (perpendicular) from the sprinkler line:

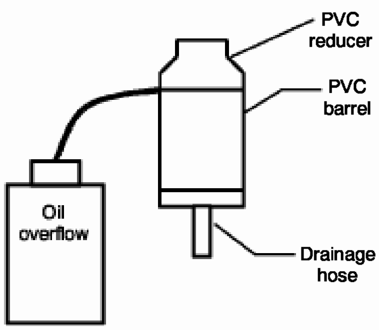

Figure 3. PVC reducer catch-can.

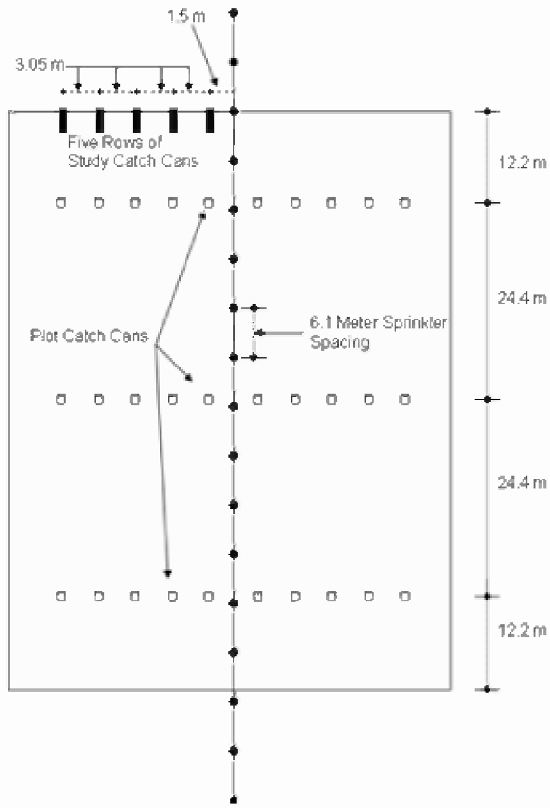

Figure 4. Plan view of line-source experimental set up (not to scale).

1.50 m (I5), 4.55 m (I4), 7.60 m (I3), 10.65 m (I2), and 13.70 m (I1). The symbols I1 through I5 denote the lowest through highest water application rates. A row of white buckets (five on the east and five on the west) were placed at three locations in the plot to estimate application depths on the plot (fig. 4). The 17 sprinklers were spaced at 6.1 m along the north-south line, and each had a 3.96 mm (5/32 in.) main nozzle and a 2.38 mm (3/32 in.) 7° slotted spreader nozzle. This system met criteria set forth by Hanks et al. (1976) to provide uniform irrigation parallel to the sprinkler line. The nozzle configuration and sprinkler spacing produced the line-source condition of a linearly decreasing distribution of irrigation application with distance perpendicular to the sprinkler line (fig. 5).

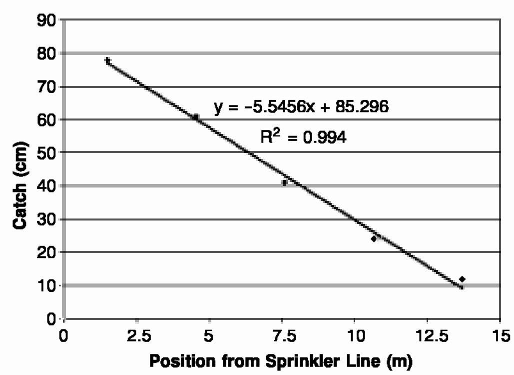

Figure 5. Total seasonal irrigation depth (average of three replications) west of sprinkler line as measured in white buckets (Randolph, Utah, May to September 2004).

Three catch-cans of each type were set at each of the five distances from the sprinkler line (I1, I2, I3, I4, and I5), as shown in figure 6. This provided three replications of the six types of catch-cans at each irrigation level. The catch-cans were placed in random order to average out any minor variations in longitudinal application rates (fig. 7). The catch-cans were placed with their openings at the same height (approx. 350 mm) and leveled. All grass near the catch-cans was trimmed below the catch-can height to prevent interference. The experimental catch-cans were set up on the immediate north side of the plot to prevent damage to the crop study area. To ensure proper sprinkler pattern overlap to provide linear distribution of application depths, two sprinklers were placed north of the catch-can study area (fig. 4). The observed radius of throw of each sprinkler was less than 15.24 m. A third sprinkler to the north of the catch-cans would have required a radius of throw of 18.3 m to reach the study catch-cans. The catch-can study area was under the influence of five sprinklers (two north, one at the boundary, and two within the grass plot area, fig. 4); thus, a complete line-source irrigation pattern with linear application depths was provided perpendicular to each of the study catch-cans.

The catch-can comparison tests were completed at six irrigation events throughout the summer of 2004 (19 May, 2 and 9 June, 21 July, 4 and 11 August). A similar test was completed with the catch-cans on 14 July; however, the PVC reducer and separatory funnel were not filled with diesel fuel. This test was to evaluate the effect of the evaporation-suppressing oil relative to the other types of catch-cans.

Figure 6. Catch-can setup in the field from I1 (nearest row of catch-cans) to I5 (furthest row of cans) with line-source sprinklers in background (Randolph, Utah, 2004).

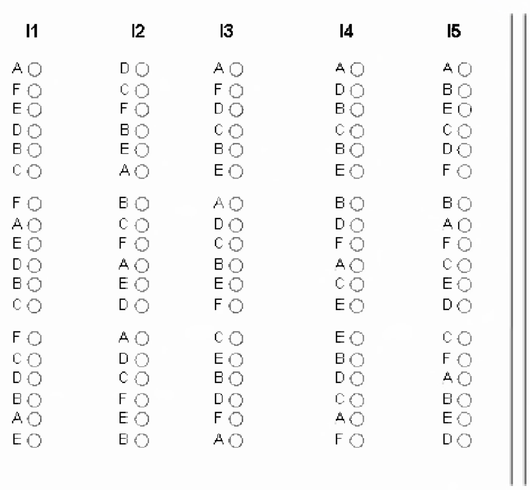

Figure 7. Randomized catch-can setup on north end of the plot. Letters denote different catch-can types.

Each irrigation event began between 6:00 and 8:00 a.m. and ended no later than 2:00 p.m., which minimized the effects of prevalent afternoon winds. The duration of irrigation ranged from 3.6 to 5.5 h (5.25 h on 19 May, 3.6 h on 2 June, 4.6 h on 9 June, 5.5 h on 14 July, 3.8 h on 21 July, 4.5 h on 4 August, 4.1 h on 11 August, and 3.9 h on 15 September).

The irrigation line pressure was maintained at approximately 386 to 400 kPa (56 to 58 psi) at a gauge 6 m upstream of the first plot sprinkler at all irrigations. Supply water flow rate and volume were measured with a calibrated in-line turbine-type flowmeter (McCrometer, Inc., Hemet, Cal.) also upstream of the plot.

Prior to irrigation, each catch-can was set and leveled. The PVC reducer and separatory funnel were filled with diesel fuel to approximately 25 mm below the lip of the can prior to irrigation. Immediately following each irrigation event, the catch volume was measured from each catch-can using a "to contain" volumetric graduated cylinder. Some water droplets clung to the catch-can, so it was impossible to measure every water droplet in the graduated cylinder. The error cause by this is minor under the higher application depths, but it could become an issue at the lower application depths. The containers with diesel fuel catch volumes were measured by extracting the water from the bottom of the container through the drainage lines. The water was allowed to drain into the graduated cylinder along with a small amount of diesel fuel to ensure that all water was collected from the catch-can. The oil-water interface was observed in the graduated cylinder. The volume of each container's catch was divided by its opening area to obtain irrigation application depth. The process of measuring all catch-cans took approximately 45 min. This may have caused minor bias due to some catch-cans having a longer time for water to evaporate.

Two electronic weather stations (CR10X, Campbell Scientific, Logan, Utah; 10 s sample interval), located 5 m east and west of the plot, recorded wind speed, relative humidity, and air temperature at 15 min intervals. A third weather station, located approximately 150 m south of the plot, recorded wind speed, relative humidity, and air temperature at 1 h intervals.

Statistical Analysis

The objective of the catch-can study was to determine the consistency of catch depths measured by the different types of cans. Thus, the catch depth data were statistically evaluated to determine if the mean catch depths of the catch-cans were significantly different. The sums of all irrigation mean catch depths for each catch-can at each irrigation level were evaluated using one-way between-subjects ANOVA, and the Dunnett Post-hoc analysis introduced by Dunnett (1955) was used for comparing means of treatments against the means of a control group.

The following assumptions were made to warrant the use of the Dunnett comparison procedure: (1) the data were normally distributed and the variances were equal, and (2) the treatment effects were additive (Steel and Torrie, 1980). The Levene test was used to test for homogeneity of variances. The SPSS statistical program was used to perform the ANO-

VA and the post-comparison test using the Dunnett procedure (SPSS, 2003). Significant differences in means were then determined from the results of the analysis.

Standing Evaporation

At selected irrigations (19 May, 2 June, and 21 July), one of each type of catch-can was partially filled with water (300 to 1000 mL), weighed just after irrigation began, and then placed west of the plot outside the irrigated area. At the end of the plot irrigation and after the measurement of the catch-cans on the plot, these pre-filled catch-cans were weighed again to determine the evaporation loss from standing water in each catch-can. The evaporation rate was determined by the difference in weight divided by the time interval between the beginning and ending weight measurements. The time duration for each experiment was 5.5 h on 19 May, 3.6 h on 9 June, and 3.8 h on 21 July. Relative differences in evaporative characteristics of the study catch-cans were determined from these experiments.

Sidewall Evaporation

An experiment was set up to evaluate evaporation from catch-cans due to water droplets clinging to the sidewall of the catch-can. Kohl (1972) suggested that this sidewall evaporation may cause significant error in irrigation application depth measurements. A device was set up to apply a known volume of water to the inside walls of a catch-can. The device used tubing and syringes attached to a 1500 mL plastic bottle to drip water down the sides of a catch-can. The syringes were positioned on the inside of the catch-can inside wall, and valves were used to control the water flow.

The droplet evaporation device applied approximately 900 to 1000 mL of water to a catch-can by dripping water down the catch-can walls. Due to the difficulty of controlling the water flow, if the 1500 mL bottle drained prior to the end of the time period, it was refilled with the drained water and continued to drip. Thus, the dripping occurred throughout the duration of the experiment. During each drip test, another catch-can of the same type was filled with a known volume (700 to 900 mL) of water and placed next to the dripper setup to evaluate standing water evaporation.

The following procedure was employed for each sidewall evaporation experiment. First, the 1500 mL bottles, each dripper device, and the catch-cans that were to receive water from the dripper devices were weighed dry. The 1500 mL bottles were then filled with water and re-weighed. The corresponding catch-cans for the standing evaporation test were filled and weighed. The drip test catch-cans were set up, the valves were opened to begin dripping down the sidewalls, and the time was recorded. At the end of the experiment, the standing water catch-cans were re-weighed. Each dripper device was drained into the catch-can that it had been dripping into, and the drip test catch-cans were re-weighed. In addition, each 1500 mL bottle was weighed to account for residual water in the bottle, and each dripper device was weighed to account for residual water in the tubing and syringes. Thus, the amount of evaporated water was the difference in weight between the water originally weighed in the 1500 mL bottle and the water in the catch-can after the duration of dripping. This amount was corrected by subtracting the residual water left in the bottle and the dripper device.

The standing versus sidewall evaporation comparison was performed at the USU Department of Biological and Irrigation Engineering (BIE) River Lab field plot in Logan, Utah. The experiment was performed with three white bucket catch-cans four times (22 July, 30 July, 8 August, and 1 September 2004). A similar experiment was conducted with a white bucket and two metal cans (8, 9, 10, and 13 September 2004). The difference between the standing evaporation and the sidewall evaporation was taken to be a relative measurement of the evaporation caused by droplets of water clinging to the sidewalls of catch-cans.

Plot Catch Efficiency

The estimated irrigation volume applied to the plot as estimated by the catch-cans was compared to the volume measured by a calibrated flowmeter installed in the irrigation supply line. The on-plot water was estimated from the three rows of white bucket catch-can on the plot. The nature of a line-source sprinkler technique requires that sprinklers be placed outside the experimental plot boundaries, north and south of the plot in our situation, to ensure the line-source effect throughout the plot to the north and south boundaries. The amount of water applied outside the boundaries was estimated from catch-cans (white buckets) placed in a square 3.05 m grid north and south of the plot for the irrigation on 18 August 2004. During the 18 August irrigation event, low wind conditions (average of 9.7 km/h), cool temperatures (average of 13.4°C), and high relative humidity (average of 89%) were observed.

The effective portion of irrigation (*Re*) was calculated as:

$$Re_{can} = \frac{V_{can}}{V_{meter}} * 100 \qquad (1)$$

where Re_{can} is the effective portion of irrigation as measured by the catch-cans (%), V_{can} is the volume of water applied as estimated by the catch-cans both inside and outside the plot area, and V_{meter} is the volume of water measured by the calibrated flowmeter for the irrigation event.

Results and Discussion

Catch-Can Comparison

Cumulative catch depths of the six irrigation events expressed as percentages of the separatory funnel catch depth are shown in table 1. The application rates ranged from 2.8 mm/h (I1 irrigation level) to 14.8 mm/h (I5 irrigation level). The catch-can experiments were performed in mild weather conditions, i.e., average temperature ranging from 10.9°C (51.7°F) to 20.8°C (69.5°F) with an average of 17°C, wind speed ranging from 3.5 to 12.1 km/h with an average of 7.0 km/h, and relative humidity ranging from 40% to 52% with an average of 46%.

Estimated depth in the funnel rain gauge was 104% of that of the separatory funnel at the I1 irrigation level, whereas the metal can and white bucket estimated 94% and 93%, respectively. At the I2 level, the white bucket, metal can, funnel rain gauge, and PVC reducer catch depths were 94%, 96%, 96%, and 98%, respectively. At irrigation levels I3 through I5, the catch depths did not vary more than 4% above or below that of the separatory funnel catch depth. The metal can had the greatest catch depths at irrigation levels I3 through I5. The separatory funnel catch depths were greater than all catch-cans at all water levels, with the exceptions of the funnel rain gauge and PVC reducer at I1, the metal can and wedge at I3, and the metal can at I5.

Table 1. Comparison of cumulative catch depths of six irrigation events, relative to the separatory funnel catch depth, at varying application rates.

Irrigation Level	Distance from Line Source (m)	Separatory Funnel Application Rate (mm/h)	Percentage of Separatory Funnel Rate (%) Funnel Rain Gauge	White Bucket	Metal Can	PVC Reducer	Wedge
I1	13.70	2.8	103.9	93.4	93.6	101.2	99.6
I2	10.65	5.5	95.9	94.2	95.9	98.1	98.2
I3	7.60	8.7	98.8	97.4	101.2	95.9	100.4
I4	4.55	12.6	97.8	96.4	99.5	97.4	97.2
I5	1.50	14.8	98.9	97.6	103.1	97.6	98.3

Table 2. Average of irrigation application depth measurements for six catch-can types (all values in mm).

Irrigation Level	Metal Can	White Bucket	Funnel Rain Gauge	Separatory Funnel	PVC Reducer	Wedge	Std. Dev. among Catch-Cans	Average at Irrigation Level
I1	11.7	11.6	13.0	12.5	12.6	11.8	0.6	12.2
I2	23.5	23.0	23.6	24.3	24.4	24.3	0.6	23.9
I3	38.1	36.6	37.2	37.6	36.7	35.6	0.9	37.0
I4	53.7	51.8	52.9	53.6	51.9	41.7	4.6	50.9
I5	65.9	62.3	63.6	63.4	62.5	49.8	5.8	61.3
Average	38.6	37.1	38.1	38.3	37.6	32.6	2.2	

Table 3. Average coefficient of variation of irrigation application depth for six irrigation events for each catch-can type (all values in %).

Irrigation Level	Metal Can (179.1)[a]	White Bucket (167.4)[a]	Funnel Rain Gauge (80.1)[a]	Separatory Funnel (54.2)[a]	PVC Reducer (53.2)[a]	Wedge (37.8)[a]	Average at Irrigation Level
I1	3.4	4.3	3.1	6.1	5.8	12.9	6.0
I2	1.4	6.2	4.3	2.6	5.1	3.2	3.8
I3	2.4	2.5	3.3	3.6	3.8	16.2	5.3
I4	2.9	4.4	3.9	5.6	3.4	4.1	4.1
I5	3.8	3.5	3.5	3.0	2.0	5.5	3.6
Average	2.8	4.2	3.6	4.2	4.0	8.4	

[a] Value in parentheses is opening area (cm^2).

The catch-can comparison test in field conditions showed greater variance from the separatory funnel than the laboratory tests performed by Marek and Howell (1987). Their tests showed no greater variance than 2% from the separatory funnel. In our field studies, the variance was as great as 6.6%. However, it is important to note that Marek and Howell's tests were performed for only 30 min. They also found that as collector diameter increased, the mean deviation in catch depth decreased. Similar results were demonstrated in our comparison. Table 2 contains the average application depths, and table 3 contains the coefficient of variation for each catch-can's measured depths for the season. The largest opening area (metal can, 179.1 cm^2) showed the smallest coefficient of variation (2.8%), whereas the catch-can with the smallest opening area (wedge, 37.8 cm^2) had the greatest coefficient of variation (8.4%). The white bucket had a rather high coefficient of variation for its large opening area. This may have been caused by the 3 to 4 mm lip on the edge of the bucket. Variation was greatest at the lowest irrigation level (I1). This may have been because measurement errors were magnified by the lower irrigation depth measurement.

Catch depths were significantly affected (statistically) by catch-can type only at the lowest application rate ($F(5, 12) = 8.411$, $p = 0.001$) for a one-way, between-subjects ANOVA. At the other irrigation levels, the p-values were greater than 0.001; thus, the mean catch depths were not significantly different (Winward, 2004).

The assumption of homogeneity of variances for the use of the Dunnett test was evaluated with the Levene test. The assumption of homogeneity of variance was valid at all irrigation levels except I3. Thus, the Dunnett test was not valid at the I3 level.

The Dunnett post hoc comparison (Dunnett, 1955) of each catch-can's irrigation depth with the separatory funnel as the control (Dunnett (2-sided), $p < 0.05$) demonstrated that the metal can and white bucket predicted irrigation depths that were significantly different from that of the separatory funnel only at the I1 irrigation level. The p-values at the I1 irrigation level for the metal can and white bucket were 0.035 and 0.030, respectively. The p-values for all other catch-can/irrigation level combinations were greater than 0.05; thus, the differences with respect to the separatory funnel were not statistically significant. The I3 irrigation level could not be validly evaluated with this test due to the lack of homogeneity of variances.

Post hoc comparison of each catch-can's irrigation depth with the PVC reducer as the control, not shown here but reported previously by Winward (2004) (Dunnett (2-sided), $p < 0.05$), also demonstrated that the metal can and white bucket predicted irrigation depths that were significantly different from that of the PVC reducer only at the I1 irrigation level. The results, calculated with six irrigation cumulative or total depths, were similar to that of the analysis with the separatory funnel as control.

Although the results of the catch-can test without evaporation-suppressing oil in the separatory funnel or the PVC reducer (table 4) may be somewhat inconclusive due to the fact that these catch-cans were evaluated at a single irrigation, the funnel rain gauge consistently caught more than the separatory funnel, except at I1.

Table 4. Comparison of relative cumulative catch depths of different catch-cans with no evaporation-suppressing oil in the separatory funnel or PVC reducer at one irrigation event, relative to the separatory funnel catch depth, at varying application rates.

Irrigation Level	Distance from Line-Source (m)	Separatory Funnel (No Oil) Application Rate (mm/h)	Percentage of Separatory Funnel Rate (%)				
			Funnel Rain Gauge	White Bucket	Metal Can	PVC Reducer (No Oil)	Wedge
I1	13.7	2.8	98.3	90.2	86.9	95.0	73.1
I2	10.65	5.5	101.6	96.6	101.2	98.5	107.8
I3	7.6	8.7	100.2	95.5	100.8	95.8	69.0
I4	4.55	12.6	101.7	100.7	104.3	99.4	--
I5	1.5	14.8	101.0	98.0	103.5	99.2	--

Standing Evaporation

The amount of evaporation from standing water in each catch-can was measured at three irrigation events (19 May, 2 June, and 21 July) for all catch-can types (table 5). There were large differences in evaporation characteristics among the catch-cans, indicating potential differences in irrigation depth measurement with different types of catch-cans. The metal can, separatory funnel, and white bucket exhibited the highest evaporation (12.8, 9.8, and 8.4 g/h, respectively), whereas the funnel rain gauge was the lowest at 0.3 g/h. However, when these rates are converted to depth evaporation rates, the separatory funnel exhibited the greatest evaporation depth rate of 1.8 mm/h, and the funnel rain gauge was by far the lowest at 0.04 mm/h. This underscores the importance of taking steps to minimize evaporation loss from catch-cans. With daily evaporation losses of about 0.5 mm (0.5 = 12 h × 0.04 mm/h), the funnel rain gauge could be used as a catch device with minimal error due to evaporation in studies where field visits may be made weekly. Because the standing evaporation amount was not obtained under sprinkled conditions, it is not the magnitude of evaporation loss within the plot. However, it does suggest the evaporative characteristics of the catch-cans relative to each other.

The catch-can analysis showed that the higher-evaporating catch-cans generally predicted less irrigation application at the lower irrigation application rates (with the exception of those catch-cans in which evaporation-suppressing oil was used). This suggests that evaporation of water from the catch-can's water surface and water droplets clinging to the sidewall may be an appreciable component of error in catch-can irrigation depth measurement. The separatory funnel with oil to suppress evaporation measured the greatest application depth at all locations, with the exception of the funnel rain gauge and PVC reducer at the I1 level (table 1). Both the funnel rain gauge and the PVC reducer with evaporation suppressant are low-evaporating catch-cans. It is suggested that the evaporative characteristics have a greater potential effect than the loss of water due to splashing because of an excessively shallow catch-can container. It is important to minimize surface area both of droplets on the sidewalls of the catch-can and of the pooled water in the catch-can. This suggests consideration of a maximum diameter standard for catch-cans as well as the existing minimum diameter standard.

Table 5. Evaporation rate from standing water in catch-cans and equivalent depth, average of three events (19 May, 2 June, and 21 July 2004) at the pasture research plot near Randolph, Utah.

	Evaporation Rate (g/h)	Evaporation Rate in Equivalent Depth out of Container (mm/h)[a]
Wedge rain gauge	1.7	0.44
PVC reducer	3.8	0.71
Separatory funnel	9.8	1.81
Funnel rain gauge	0.3	0.04
White bucket	8.4	0.52
Metal can	12.8	0.72

[a] Assuming 1 g water = 1 cm^3.

Sidewall Evaporation

The results of the sidewall versus standing water evaporation trials are summarized in tables 6 and 7. Four experiments were conducted (on 22 July, 30 July, and 8 August at the River Lab plot in Logan, Utah, and on 1 September at the Randolph plot) using three replications of white bucket catch-cans. Three dripper devices and three standing evaporation catch-cans were used. The length of each experiment averaged 3.9 h. The dripping rate was difficult to control and consequently varied. However, dripping was ensured through the duration of the experiment by refilling the bottles with the dripped water. This refilling was not needed more than once for any of the experiments. Therefore, the maximum potential dripping rate would have been 2000 mL per 4 h, or 500 mL/h. This is an equivalent irrigation rate of 119 mm/h in the white bucket or 112 mm/h in the metal can. It would have been best to keep dripping rates constant; however, this was not possible with the dripper device. The purpose of the comparison was to gain some insight into evaporation from the sidewall, not to come up with a precise amount, and the experiment served this purpose. Evaporation from the catch-can from dripping averaged 17.5 g more than evaporation from standing water in the same time period. This is a difference of 1.04 mm of water depth as measured in the white bucket (assuming 1 g of water is equivalent to 1 cm^3) in a 4 h period.

Dripping versus standing evaporation for the four trials using one white bucket and two metal cans are given in table 7. The duration of each of these trials was 3 h. The overall average difference in evaporation was 17.5 g for the white bucket, 18.2 g for metal can 1, and 17.8 g for metal can 2. This is equivalent to 1.04 mm irrigation depth in the white bucket, and 1.02 and 1.00 mm irrigation depth in the metal cans.

Sidewall evaporation was greater than standing evaporation. The evaporation of water from the sidewalls of a catch-can could cause underestimation of irrigation depth. However, the dripper experiment did not fully simulate the microclimate of a catch-can under sprinkler irrigation; thus, the magnitude of this evaporation cannot be estimated from this comparison.

Plot Catch Efficiency

The result of the completed plot catch efficiency measurements on 18 August 2004 showed that the catch-cans accounted for 92.7% of the total volume of water (83.3 m^3)

Table 6. Standing evaporation subtracted from dripping evaporation, and average temperature, relative humidity, and wind speed, and total solar radiation for the evaporation period at the USU-BIE River Lab plot (22 July, 30 July, and 8 August 2004) and at the Randolph pasture plot (1 September 2004).

Date	Start Time	End Time	White Bucket 1[a] (g)	White Bucket 2[a] (g)	White Bucket 3[a] (g)	Average Temp. (°C)	Average RH (%)	Average Wind Speed (m/s)	Total Solar Radiation (cal/cm^2)
22 July	11:17	15:07	20.3	20.3	26.5	26.4	11	2.0	264
30 July	10:05	14:05	13.0	7.7	4.9	24.9	12	1.4	255
8 August	12:45	17:15	15.7	24.7	12.4	26.3	11	1.7	368
1 September	9:00	12:15	12.5	20.8	30.9	17.0	35	0.9	163
		Average:	15.4	18.4	18.7				
			Overall average difference = 17.5 g[b]						

[a] Difference between dripping and standing evaporation from a white bucket catch-can (g).
[b] Average difference between dripping and standing evaporation for all catch-cans and all trial dates.

Table 7. Standing evaporation subtracted from dripping evaporation and average from one white bucket and two metal cans, and average temperature, relative humidity, and solar radiation for the evaporation period at the USU-BIE River Lab plot (2004).

Date	Start Time	End Time	White Bucket[a] (g)	Metal Can 1[b] (g)	Metal Can 2[b] (g)	Average Temp. (°C)	Average RH (%)	Average Wind Speed (m/s)	Total Solar Radiation (cal/cm^2)
8 September	12:30	15:30	28.1	34.7	9.1	23.2	13	1.5	166
9 September	11:00	14:00	25.8	18.0	29.3	22.3	13	1.5	176
10 September	11:00	14:00	14.5	9.9	10.0	23.9	12	2.3	183
13 September	12:00	15:00	8.7	7.5	9.1	18.6	14	1.8	197
		Average:	17.5	18.2	17.8				
			Overall average difference = 17.8 g[c]						

[a] Difference between dripping and standing evaporation from a white bucket catch-can (g).
[b] Difference between dripping and standing evaporation from a metal catch-can (g).
[c] Average difference between dripping and standing evaporation for all catch-cans and all trial dates.

delivered to the plot at the sprinkler nozzle. The losses could be due to evaporation of droplets in the air, catch-can measurement errors, and the inherent error that results from catch-cans measuring only a small portion of the overall irrigated area. What portion of water was lost due to evaporation of droplets in the air and measurement errors in the catch-cans cannot be determined. However, Kohl (1972) theorized that most of the water lost in wind-loss evaporation experiments was due to evaporation from the catch-can.

Conclusions

The type of catch-can did not have a significant effect on estimation of irrigation depth at application rates higher than 5.5 mm/h, as observed in this study where windy periods were avoided. Generally, the separatory funnel with evaporation-suppressing oil estimated the greatest irrigation depths. Greater variance in irrigation depths measured among the catch-cans was observed as the application rate decreased. At lower application rates, the type of catch-can had a significant effect on estimated irrigation depths. Thus, in research and irrigation system evaluations where the application rates are low, or perhaps with single sprinklers, significant errors in irrigation depth measurements are possible with catch-cans.

Evaporation from a catch-can under a simulated sprinkler application condition (dripper device) was greater than evaporation from a similar catch-can with standing water. This evaporation could be a source of potential error in measurement of sprinkler application depths.

The estimate of the plot catch efficiency, using white bucket catch-cans, accounted for about 93% of the measured supply water. The 7% loss could be attributed to wind drift and evaporation loss, catch-can evaporation loss, measurement error, and/or meter error.

This study confirmed the value of following the ASAE Standard for catch-cans. The wedge rain gauge with a small opening area showed large standard deviations relative to catch depths, while the metal can, which had the largest opening, showed the least standard deviation relative to catch depths in the catch-can comparisons. This supports the minimum diameter of 60 mm guideline to maintain consistent measurement depths. Droplets of water were observed splashing out of the shallow containers in the field, thus supporting the minimum diameter guidelines set by the ASAE Standard. It may be appropriate to consider establishing a maximum diameter for catch-cans. A very large diameter device may have a larger evaporative water surface area compared to water volume. However, further investigation is needed to warrant such action.

Large differences in estimated irrigation depth by catch-can type may be realized under conditions that cause higher evaporation rates from the catch-cans, and thus may necessitate further care in measurement of irrigation application depths with catch-cans.

Both the PVC reducer and the separatory funnel were used with evaporation-suppressing oil to reduce evaporation. The relatively good performance of the funnel rain gauge and of the catch-cans with evaporation-suppressing oil, all with less depth than required by the ASAE Standard, suggests that it may be appropriate to re-evaluate the standard to consider such devices.

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