THE IRRIGAGE: A NON−EVAPORATING IN−FIELD PRECIPITATION GAGE

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ABSTRACT. *Construction details and measurement data associated with a non−evaporating, in−field precipitation gage (the IrriGage) are presented. IrriGages are fabricated using standard pieces of PVC pipe and fittings. A plastic bottle is used to store collected water and is attached to the bottom of the collection barrel. Collected water is only exposed to the atmosphere through the collection barrel via a 9.5−mm drain hole. Evaporative losses from IrriGages were compared to losses from other precipitation collection devices in an in−field device evaporation study during the 2001 summer. During the study period, air temperatures often exceeded 38°C and daily grass−reference evapotranspiration rates exceed 8 mm/day. Evaporation losses from IrriGages were negligible over several weeklong measurement periods, while substantial evaporation losses were associated with standard rain gages and other collection devices.*

Keywords. *Rain gage, Precipitation gage, Irrigation uniformity.*

Many collection devices have been used for in−field measurement of rainfall or overhead sprinkler irrigation depths. Reliable and accurate collectors are needed for center pivot irrigation system uniformity evaluations. Standard rain gages can range in cost from $7 for a clear plastic, post−mounted, wedge−shaped gage to several hundred dollars for tipping−bucket recording gages. Because of the size of center pivot systems and the large number of gages required for an evaluation, non−evaporating gages are desirable. While commercial non−evaporating rain gages can be purchased for $25 to $30, this cost becomes prohibitive for many center pivot system uniformity evaluations that require 150 or more collectors. Thus, an accurate, non−evaporating and low cost collector is desirable.

Kohl (1972) evaluated the catch accuracy (from impact sprinklers) and evaporation characteristics of five different precipitation collection units in comparison to a separatory funnel device. Many of the devices included an evaporation suppressing oil (No. 2 diesel fuel). Standard oil cans (103 mm in diameter and 141 mm deep) performed as well or better than other devices for catch accuracy and evaporation suppression with respect to the separatory funnel device. Similar results were reported from a collector accuracy study under impact sprinklers by Marek et al. (1985). Standard oil cans were preferred over the more costly separatory funnel devices and the less accurate 49−mm diameter filter funnels. However, in that work, the filter funnels were attached to a collector bottle to minimize evaporation losses.

Desirable design features and characteristics for collection units were reported in those studies (Kohl, 1972; Marek et al., 1985) and are also listed in ASAE Standard S436.1, “Test Procedure for Determining the Uniformity of Water Distribution of Center Pivot and Lateral Move Irrigation Machines Equipped with Spray or Sprinkler Devices” (*ASAE Standards*, 2001). Collectors should have a sharp and symmetrical lip and should be at least 120 mm tall with inner walls and features that minimize splash losses. The ASAE standard recommends that the diameter of the entrance should be one−half to one times the height, but not less than 60 mm (however, the previously cited studies preferred a catch device with a 100−mm opening). Evaporation suppression should be used for the collector (light color) and the collected water, and the collector should minimize the effects of adhering of droplets on the inner walls. Finally, the collector units should be portable and of reasonable cost.

The objectives of this work were to develop and field test a non−evaporating, low−cost precipitation gage for sprinkler irrigation depth measurements. Furthermore, gages must meet or exceed current collector standards for sprinkler irrigation depth measurements. Design features of the IrriGage and field data will be presented.

METHODS AND MATERIALS

GAGE CONSTRUCTION

Several processes were involved in the construction of the IrriGages (fig. 1). Most of the gage materials were PVC pipe and could easily be attached by solvent welding with PVC cement. IrriGages were constructed using a 200−mm long piece of SDR 35 PVC sewer pipe for the body tube [106−mm outside diameter, 100−mm inside diameter (4−in. nominal size)], and a PVC sewer and drain cap for the barrel bottom cap [106−mm inside diameter (4−in. nominal)]. The top lip of the body tube was beveled using a router to create a “sharp edge.”

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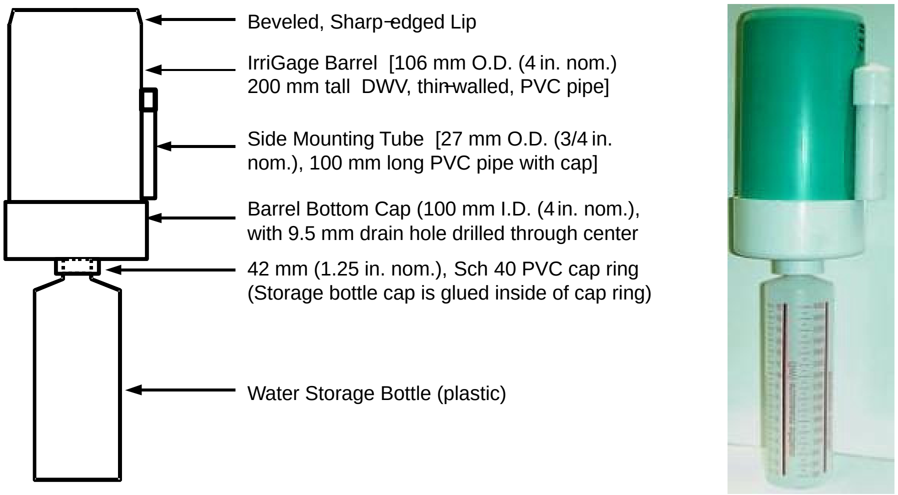

Figure 1. Construction and material details of the IrriGage with a completed device.

A 75−mm long piece of 27−mm outside diameter (0.75−in. nominal) PVC pipe was capped on one end and solvent welded to the side of the IrriGage barrel tube for use as a mounting tube. Prior to solvent welding onto the IrriGage, one edge of the side mounting tube was sanded flat to eliminate the protruding edge of the end cap and to increase the surface area of contact for the solvent welding procedure.

Several bottle types were evaluated for storage bottles. Different plastic types create a challenge to find a glue or adhesive material to attach the bottle cap to the barrel bottom cap. Some of the initial bottles had large diameter caps, which were attached to the barrel bottom cap with a silicone sealer and screws. The current storage bottle is a graduated and marked 500−mL plastic bottle with a 30−mm diameter hard plastic cap. Markings provide volumetric readings in milliliter and ounce units. Readings in milliliter can easily be converted to depth units based upon the collector surface area.

In order to secure the bottle cap to the barrel bottom cap, a 12−mm long ring of 42−mm outside diameter (1.25−in. nominal) schedule 40 PVC pipe was solvent welded onto the center of the outside of the barrel bottom cap for use as a cap ring support (fig. 1). The storage bottle cap fit inside of the cap ring and was attached to the barrel bottom cap using Plumbers Goop® adhesive and sealant, which also acted as a supportive filler between the storage bottle cap and the cap ring. After the storage bottle cap was firmly attached to the barrel bottom cap and cap ring, a 9.5−mm diameter hole was drilled through the bottle cap and barrel bottom cap.

The 500−mL capacity of the storage bottle was sufficient to hold 65 mm of precipitation and was considered adequate for most irrigation events and many rainfall events. Marek et al. (1985) prevented water entrapment in the throat region of their top collector funnel by drilling a small vent hole in the top of the storage bottle. Because the IrriGage could be used as an in−field device for multiple irrigation and rainfall events that may exceed the 65−mm depth capacity, excess water would be stored in the body tube, therefore an air hole was not drilled into the top of the storage bottle. However, as previously discussed, the 9.5−mm diameter drainage hole allowed collected water to flow into the storage bottle and was sufficiently large to allow water entry with air escape from the bottle. Generally, no water was retained in the body tube due to surface tension of the water. Periodic inspection of the drain is needed to clean any blown in or deposited debris such as leaves or bird droppings.

FIELD TESTING

Initial field tests of evaporation losses from IrriGages were conducted during a hot, dry period from 11 August to 15 August 2000 in south central Kansas, near the city of St. John. In those tests, IrriGages had a clear plastic bottle attached as the storage reservoir. Ninety gages were positioned in a line perpendicular to the direction of travel of a four span (49−m long spans) linear move irrigation machine that had low drift nozzle (LDN) sprinklers mounted on flexible drop hoses. Sprinklers were approximately 2.2 m high from the ground surface. IrriGages were positioned on 1.2−m high mounting stakes that were 1.5 m apart in a 15−m wide grassed buffer strip that was between irrigated corn plots. The linear move system was operated to apply a scheduled irrigation event and gages were used to collect application depths for an irrigation rate and uniformity study. IrriGage catch amounts were measured with a volumetric cylinder. Measured water samples were then returned to the respective gage collection bottle, which was then repositioned on its mounting stake. IrriGages were left in those field−mounted positions during the next five days. On day five, remaining water volumes in the collection bottles were measured using a volumetric cylinder and discarded. For the testing period, daily values of maximum and minimum air temperature, relative humidity, wind speed, and grass reference evapotranspiration (Penman−Monteith method: Smith et al., 1996; Allen et al., 1998) were obtained from an automatic weather station located approximately 1.6 km from the test site. Previous studies have shown that general weather data from that station correlate well with the experimental site.

A second series of field tests were conducted during the 2001 summer to evaluate the evaporative losses from IrriGages (IG) and two other precipitation collection devices. The other devices included a standard, commercially available rain gage and a capped PVC pipe. The standard rain gage (RG) was a wedge−shaped, rectangular, clear plastic tube with a 65− × 33−mm opening and was 203 mm tall. The sides were etched with storage depths in millimeters and inches.

The capped PVC pipe (PVC) was white in color, had a 300−mm deep collector barrel, and was basically similar to the previously discussed IrriGages (fig. 1) without the drainage hole or storage bottle. Thus, all collected water would remain in the collector barrel of the gage. Four replications of each gage design were placed in a randomized block design. All gages were positioned on stakes with the openings at a height of approximately 1 m above the ground at an open field location with no nearby structures or tall plant canopies.

Six, one−week long evaporation test periods were conducted between 22 June and 13 August 2001. Two of those test periods (No. 4 and 6) will not be used or discussed due to rainfall within those test periods. Rain gage (RG) devices were initiated with a 30−mm depth of water in each test while IG devices were initiated with 27 mm of water. These depths were different due to slight differences in calibration markings on the storage reservoir of each device. The initial volume of water in the PVC devices was set at an equivalent depth of 40 mm. However, due to high evaporative losses during the first test week, PVC pipe device initial equivalent depths were increased to 60 then 90 mm during test periods 2 and 3, respectively. These greater depths allowed evaporation comparisons with other measured evaporation loss data. PVC pipe device initial depths were then set to 25 mm for weeks 4, 5, and 6 and were allowed to completely evaporate within the first couple of days of those test periods.

Site related weather data were measured and characterized during each testing period. An atmometer with a grass reference evapotranspiration cover was positioned at the site to obtain an on−site evaporation measurement. Daily values of air temperature, relative humidity, wind speed, and rainfall were obtained from an automated weather station located approximately 300 m from the test site. The solar radiation sensor from that site was not functioning properly and those data were not used. Penman−Monteith grass reference evapotranspiration data (Smith et al., 1996; Allen et al., 1998) were obtained from a weather station located about 10 km away at another research site (the Konza Prairie) for comparison with the on−site atmometer data.

Evaporative water losses from the atmometer and RG devices were obtained by directly recording resultant water levels in each respective gage reservoir. Evaporative losses from IrriGage and PVC pipe devices were obtained by weighing the water in each gage with a digital balance at the beginning and end of each test period, and on one or two days within each test period.

RESIDUAL WATER FILM LAB TEST

The IrriGages were also tested in the laboratory to evaluate the amount of water that would remain on the interior and exterior walls from a rainfall or sprinkler irrigation event. One test involved only the 200−mm long pieces of the collector barrel. Six collector barrel pieces (200−mm long sections of 4−in. nominal DWV PVC pipe) were weighed, sprinkled with water on the inside and outside, and allowed to drain by gravity for approximately 60 seconds. Water on the exterior of the collector barrels was wiped off with a clean, dry paper towel. The collector barrels were then weighed to determine the mass of water remaining on the interior walls. A second test was conducted in a similar fashion using six complete IrriGage units. This second test was conducted to evaluate the amount of additional water that may remain attached to the barrel bottom caps as well as the inside walls. The same wetting, drainage, and drying procedures were used in the second test. Each of the tests was repeated three times for each collector barrel or complete IrriGage.

Table 1. General weather data during the 2000 summer testing period.

	Air Temperature			Relative Humidity	Grass Reference Evapotranspiration	Wind Speed	
Date	Max. (°C)	Min. (°C)	Avg. (°C)	(%)	(mm/d)	Max. (m/s)	Avg. (m/s)
8/11	38.7	22.1	29.7	46.7	7.5	8.9	3.7
8/12	37.6	21.2	29.3	47.4	6.2	9.8	3.1
8/13	38.7	24.2	30.9	35.1	8.8	10.8	4.9
8/14	38.7	24.8	30.5	35.0	6.7	8.5	3.0
8/15	37.8	19.6	29.2	44.5	7.5	9.8	3.1
Avg.	38.3	22.4	29.9	41.7	7.4	9.5	3.5

RESULTS AND DISCUSSION

SUMMER 2000 TESTS

General weather data for the 5−day test period in 2000 are shown in table 1. The test period had highly evaporative conditions (hot, dry, and windy) and no rainfall. Relative humidity ranged from 35% to 47% and grass reference evapotranspiration (ETo) losses ranged from 6.2 to 8.8 mm/d (table 1).

Figure 2 shows a comparison of final versus initial measured volumes from the IrriGage storage bottles from the August 2000 test period. Measured water losses ranged from 0 to 15 mm with an average of 5.5 mm (SD 3.9 mm). This average difference was significant ($p \leq 0.05$; paired sample T−test) and represents an average depth of 0.7 mm over the 5−day test period or 0.14 mm/day. The slope of the regression line in figure 1 demonstrates a close 1:1 relationship between final and initial volumes and that the greater evaporative losses occurred with the lower storage bottle volumes. However, it is possible that the measurement procedure of pouring stored water into a volumetric cylinder and then returning that water to the collector bottle could have introduced some measurement error. Thus, subsequent tests (2001) used either direct reading of collector markings or weighing collector units with a digital balance.

SUMMER 2001 TESTS

General weather data for each test period during the 2001 summer are shown in table 2. In general, the 2001 summer had very hot and dry conditions that were excellent for testing the evaporation losses from the IrriGages. Table 2 includes the average daily maximum air temperatures, average wind speeds, average relative humidities, rainfall from the nearby weather station, Penman−Monteith grass reference evapotranspiration (ETo−PM from the Konza Prairie), and site measured atmometer−based grass reference evapotranspiration data for each test period. The Penman−Monteith grass reference evapotranspiration data (ETo−PM) were used to compare with the on−site atmometer ETo data. Mean weekly ETo values were equal ($\alpha = 0.05$; paired t−test) and the atmometer data were used as the reference base for the remainder of the evaporation analyses.

Water in the PVC pipe devices typically evaporated before the end of each 7−day test period. Furthermore, evaporative losses were equal ($\alpha = 0.05$; paired t−test) to the atmometer−based grass reference ET amounts in all test periods. Thus,

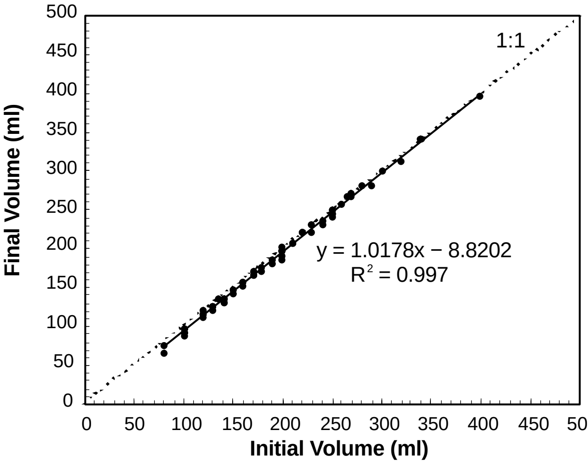

Figure 2. Initial and final storage bottle volumes from the 11−15 August 2000 test period.

those devices will not be further discussed or used for comparison purposes with the IrriGage collectors.

Cumulative evaporation losses from the atmometer, rain gage (RG), and IrriGage (IG) devices during the full duration of each testing period are shown in table 3. Rain gage evaporative losses were substantial and ranged from 12.5 to 19.4 mm or about 21% to 39% of atmometer−based reference evapotranspiration. However, IrriGage evaporation losses were negligible and averaged less than 0.13 mm out of the initial 27 mm during each of the four, week−long test periods.

RESIDUAL WATER FILM TEST

The residual water film test on the collector barrels resulted in a range of water mass from 1.9 to 3.4 g with an average of 2.6 g. Similarly, the residual water film test on the complete IrriGages resulted in a range of water mass from 1.9 to 3.6 g with an average of 2.7 g. The calibration for the IrriGages is approximately 7.8 g of collected water per mm of water depth. Thus, the water film for either case (collector barrels alone or complete IrriGages) is less than 0.4 mm and would represent at most a 3% error for most irrigation evaluation catch tests that would have at least 15 mm of water (*ASAE Standards*, 2001).

SUMMARY AND CONCLUSIONS

Design and construction specifications for a non−evaporating, in−field rainfall and irrigation gage (IrriGage) were provided. IrriGages were field tested during a hot, dry week in August 2000 to measure evaporation losses from storage bottles. Other evaporation loss tests were conducted in the summer of 2001 over four complete one−week long test periods to measure IrriGage storage bottle evaporation losses as compared to a traditional wedge−shaped rain gage and a plain piece of capped, 106−mm O.D. PVC pipe. Climatic conditions in 2000 were characterized by data from a nearby automatic weather station. In 2001, evaporation demand was measured on−site with an atmometer that had a grass reference evapotranspiration cover and compared well with Penman−Monteith grass reference evapotranspiration that was obtained from a weather station located approximately 10 km south of the field test site.

Table 2. General weather data during the 2001 summer testing periods.

Parameter	Test Period			
	1	2	3	5
Dates of test periods	6/22−6/29	6/29−7/6	7/6−7/13	7/30−8/6
No. days in test period	7	7	7	7
Avg. max. air temp (°C)	30	33	35	36
Avg. wind speed (m/s)	2.1	1.8	2.5	2.5
Avg. relative humidity (%)	73	73	66	84
Station rain (mm)	0.0	0.0	0.0	0.0
Penman−Monteith ETo (mm/d)	6.9	6.3	7.1	7.7
Atmometer ETo (mm/d)	6.7	5.9	7.1	8.4

Table 3. Cumulative evaporation losses from the atmometer (ETo), rain gage (RG), and IrriGage (IG) devices during the full duration of each testing period.

Test Period	No. Days	ETo (mm)	RG (mm)	RG/ETo (%)	IG (mm)	IG/ETo (%)
1	7	47.0	12.5	27	0.1	0
2	7	41.0	13.4	33	0.0	0
3	7	50.0	19.4	39	0.4	1
5	7	59.0	19.4	33	0.0	0
Average	7	49.3	16.2	33	0.13	<1

In 2000, storage bottle evaporation losses averaged 1.4 mm/d. However, measurement techniques could have introduced some of the measured loss. A weighing system was used in 2001 to eliminate measurement−based collector losses during the measurement process. In 2001, standard rain gage evaporation losses ranged from 1.8 to 3.1 mm/d while PVC pipe evaporation losses were substantially higher at 6.6 to 9.3 mm/d, which matched atmometer ETo rates. However, evaporation losses from IrriGages were zero during all test periods except during Test period 3 where a 0.1 mm/d evaporation loss was measured.

Water films on the inside surface of clean IrriGages will be small (<3%) for precipitation catches of 15 mm or more. Thus, the IrriGage can be a useful tool for in−field measurement of rainfall or irrigation amounts without the concern for substantial evaporation of collected water or the need to use an oil film to suppress evaporation.

The IrriGage has also been successfully field tested for center pivot evaluations by a single individual. The field technician was able deploy 150 or more IrriGages on a site and then revisit that site on another day after the system had passed over the gages and the field had dried to retrieve the field data, gages, and support stakes.

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