WATER DISTRIBUTION AND EVAPORATIONAL LOSS FROM SPRINKLER IRRIGATION IN CITRUS

R. C. J. KOO AND R. L. REESE

IFAS Agricultural Research and Education Center
Lake Alfred

Abstract. **Water distribution and evaporational loss of permanent overhead and volume gun irrigation systems were measured under field conditions. Higher coefficient uniformity (Cu) values were found in night irrigation than day irrigation for both systems. Water distribution was also affected by the spacing of sprinklers in permanent overhead systems with closer spacings providing more uniform water distribution.**

Evaporational loss of water was higher in day irrigation than night irrigation. The loss ranged from 11 to 19% for permanent overhead sprinkler systems and 0 to 7% for volume gun systems.

Night irrigation is recommended over day irrigation for more uniform water distribution and less evaporational loss.

The use of sprinkler irrigation to supplement rainfall is widely practiced by Florida citrus growers. Water used for irrigation is drawn either from the surface or groundwater. Increasing water needs by industry, municipalities, and agriculture are taxing both ground and surface water supplies. To obtain the max utilization from our water resources, it is necessary to use water with highest possible efficiency. Losses during periods of irrigation should be reduced to a minimum.

Uniform distribution of water is most important in obtaining high efficiency of sprinkler irrigation. Application efficiency of sprinkler irrigation has been extensively studied (1, 3, 4). The difficulty in analyzing sprinkler irrigation efficiency stems from the fact that water-loss occurs in many ways. One must separate quantitatively the component losses and evaluate relationships of these losses. Kraus (4) found evaporational losses from sprinklers are dependent upon both climatic factors and operating conditions. Losses increase with increases in temp, wind movement, and operating pressure, and with decreasing water particle size. Evaporational losses decrease with increases in relative humidity (RH) and nozzle diam. Frost and Schwalen (2), after repeated studies of each factor independently and jointly, constructed nomograms relating evaporation losses to air temp, RH, wind speed, nozzle diam, and nozzle pressure. Several investigators (6, 8) have reported much greater water loss from wind drift than evaporation during irrigation.

Water distribution and evaporational loss of several permanent overhead and volume gun irrigation systems were measured under field conditions. The measurements included both day and night operations to evaluate their efficiencies. This paper reports the findings.

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Materials and Methods

The studies were conducted both in commercial and in AREC groves in central Florida. Size of the test blocks varied from 5 to 20 acres. Juice cans 10.5 cm in diam were used to collect water. These cans were placed systematically at 10 ft intervals throughout the test area. Measurements were usually taken in an area 100 x 100 ft where sprinklers were set in a rectangular pattern or a triangular area if the spacings of the sprinklers were arranged in a triangular pattern. Placement of cans was not deviated by the presence of trees under such a system. Therefore, some of the cans were placed under the canopy or at the drip line of the trees while some cans were placed between trees. In addition, a number of cans were placed between trees in straight lines where tree canopy interference was at a minimum.

The duration of the tests varied from 9 to 14 hr depending on the system used. For day and night irrigation comparisons, the same irrigation system and hours of application time were used. A flow meter was used to measure the water discharge when available. Hourly measurements were made over a continuous 24-hr period for permanent overhead systems. Cans were placed at 10 ft intervals between 4 sprinklers. Hourly measurements were also made for the volume gun, but they were spread over a 3-week period operating between 3 to 5 hr at a time. The hourly studies were conducted in blocks where tree interference was minimal and all cans were placed in open areas between trees. Water in each can was measured with a graduated cylinder and converted to acre inch. Sprinkler nozzle diam used in the study ranged from 5/32 to 7/32 inches and operating pressure at the nozzle varied from 55 to 60 psi for permanent overhead systems. The operating pressure for travelling volume gun ranged from 65 to 75 psi at the nozzle and nozzle size varied from 1-5/8 to 1-3/4 inches in diam.

Temp and RH measurements, both inside and outside the irrigated areas, were recorded with hygrothermographs. Vapor Pressure Deficit (VPD) is the difference between the actual vapor pressure of the atmosphere and the vapor pressure of a saturated atmosphere at the same temp. The VPD values were obtained from standard tables. Wind speed was measured with a Casella Sensitive Anemometer. All water data were expressed in acre-inches and coefficient of uniformity (Cu) was calculated from standard formula (3). $Cu = 100(1-\frac{EX}{mn})$, where E = summation; X = deviation of individual observations from the mean; m = mean; and n = number of observations.

Results and Discussion

Results from the water distribution studies are summarized in Table 1. The degree of uniformity of water distribution was similar for both permanent overhead and volume gun systems, with perforated pipes having lower Cu. This is not surprising because perforated pipe is operated one line at a time and does not have an overlap pattern as do sprinkler systems. Trees interfered with water distribution of all systems. This was shown by the different quantities of water collected in cans at different locations within the test area. Cans located at the drip line of the trees usually contained more water than cans underneath the tree canopy, with cans located between trees having intermediate quantities of water. This was true for all 3 types of sprinkler irrigation systems. The Cu values showed more uniform water distribution between trees than at the drip line or under the tree canopy.

Spacing of permanent overhead (sprinkler) systems also affected water distribution with closer sprinkler spacings having higher Cu values than wider sprinkler spacings.

Comparisons of day and night irrigations were made in commercial groves and at AREC groves to measure water distribution and evaporation losses. These studies were conducted in spring, early summer, and fall. Evaporational losses may vary from 11 to 19% for permanent overhead and 0 to 7% for volume gun (Table 2). Microclimate records in the irrigated block and an adjacent nonirrigated check block showed that irrigation lowered temp and increased RH. The difference in temp and RH between the 2 blocks was much larger during day irrigation than night irrigation. Under Florida conditions, the VPD at night is usually near zero. Night irrigation resulted in more uniform water distribution than day irrigation as shown by higher Cu values. The difference in wind velocity between day and night undoubtedly affected the uniformity in water distribution.

Table 1. Water distribution of sprinkler irrigation.

Grove	System	Sprinkler spacing	All cans Measured	All cans Cu^z	Between trees Measured	Between trees Cu	Tree drip line Measured	Tree drip line Cu	Under tree Measured	Under tree Cu
		ft	inches	%	inches	%	inches	%	inches	%
A	Permanent	60 x 65	1.70	67	1.85	79	2.26	82	1.25	65
B	Permanent	58-66-75	1.36	62	1.60	84	1.76	76	1.10	52
C	Permanent	60 x 90	1.88	56	1.98	80	1.95	71	1.75	30
D	Permanent	77-80-95	1.52	56	1.56	84	1.85	65	1.36	55
	Average		1.61	60	1.75	82	1.95	73	1.36	50
E	Volume gun	--	.97	58	.80	74	1.00	58	1.01	59
F	Volume gun	--	1.21	54	1.22	93	1.02	92	1.25	24
G	Volume gun	--	1.00	62	1.06	70	1.08	77	.78	53
	Average		1.06	58	1.03	79	1.03	76	1.01	45
H	Perforated pipes		1.88	40	1.92	38	2.38	33	1.48	47

[z]Cu--coefficient uniformity.

It has been assumed for comparison purposes that no evaporation took place during the night irrigation runs. Some evaporation could have taken place during portions of the night irrigation period even though the average VPD is close to zero. To obtain more precise information on the effects of microclimate on evaporation of sprinkler irrigation and to obtain a wider range of conditions in a relatively short time, hourly measurements of permanent overhead irrigation were made over a 24-hr period. Water temp in the cans was also measured. The data showed that evaporation varied from 0 to 24% during the 24-hr period (Table 3). Air temp ranged from 70 to 94°F (21 to 34°C) in the check block and 70 to 83°F (21 to 28°C) in the irrigated block. RH ranged from 37 to 100% in the check block and 60 to 100% in the irrigated block. VPD ranged from 0 to 0.48 psi in the check block and 0 to 0.22 in the irrigated block.

A 9-hr period (11 PM through 7 AM) during the night irrigation was chosen as having zero evaporation. RH was 100% during this period both in the check and irrigated blocks. Water temp in the cans was same as the ambient air temp so little or no evaporation would occur. Evaporation losses during daylight hours ranged from 8 to 24%. Highest evaporation losses occurred in a 3-hr period (2 through 4 PM) when temp in the check block ranged from 92 to 94°F, RH was 40%, and winds were 5 to 6 mph. Under these conditions, a high VPD was produced with evaporation losses ranging from 20 to 24%. These "extreme" conditions seldom occur throughout an entire 10 to 12-hr irrigation period, which may explain the lower evaporational loss found in normal irrigation (Table 2). Highly significant correlations were found between microclimatic factors and evaporation losses. Water temp in the cans followed ambient air temp closely and usually ranged between the temp of the check and the irrigated block.

Hourly measurements were also made for the volume gun during 3 to 5-hr periods over a 3-week span. This span was necessary because of higher rates of water discharge of the volume gun. Not all the data were included in Table 4 because of a malfunction of the anemometers. In general, less evaporation was recorded for the volume gun than for the permanent overhead system except for 1 period (2 to 5 PM) when strong winds prevailed. Average hourly winds ranged from 7.2 to 8.3 mph and evaporation losses ranging from 18 to 30%. It should be pointed out that not all water losses were through evaporation; wind drift accounted for part of the loss. The water distribution pattern was reduced

Table 2. Comparisons of day and night irrigations.

Treatment		Air Temp Ck.	Air Temp Irrig.	R. Humidity Ck.	R. Humidity Irrig.	Wind speed	VPD[z] Ck.	VPD[z] Irrig.	Water Meas.	Water Cu	Evaporation
		°F	°F	%	%	mph	psi	psi	inches	%	%
Perm. Overhead											
Gv. A.	Night	70.2	68.8	89.8	95.4	.5	.04	.02	1.37	84	0
	Day	78.8	74.5	63.8	80.9	3.8	.17	.08	1.18	78	14
Gv. B.	Night	63.8	63.3	99.5	99.7	.1	0	0	1.84	67	0
	Day	80.3	77.6	58.7	72.5	4.9	.21	.13	1.50	62	19
Gv. C.	Night	73.9	72.5	96.4	99.8	1.7	.02	0	1.66	87	0
	Day	87.4	79.2	57.8	80.2	4.0	.27	.10	1.47	75	11
Volume Gun											
Gv. A.	Night	66.2	61.3	94.0	99.2	--	.02	0	2.17	74	0
	Day	90.6	76.6	42.4	75.4	--	.41	.11	2.01	67	7
Gv. B.	Night	61.5	60.0	96.0	98.0	.4	.01	0	1.31	84	0
	Day	83.0	76.3	36.7	61.7	4.5	.35	.16	1.33	79	0
Gv. C.	Night	76.5	74.0	93.0	99.0	.8	.03	0	1.99	86	0
	Day	87.9	82.5	60.6	82.5	4.8	.25	.09	1.86	84	7

[z]Vapor Pressure Deficit.

Table 3. Comparison of day and night irrigation of permanent overhead in hourly measurements.

Time	Air Temp Ck.	Air Temp Irrig.	R. Humidity Ck.	R. Humidity Irrig.	Wind speed	VPD[z] Ck.	VPD[z] Irrig.	Water Temp	Water Meas.	Water Cu	Evaporation
	°F	°F	%	%	mph	psi	psi	°F	inches	%	%
11 PM-7 AM	72.2	71.3	100	100	1.0	0	0	72.2	.284	87	0
8 AM	75	75	96	100	.6	.02	0	75.5	.260	81	8
9 AM	79	78	85	100	2.0	.07	0	83.0	.245	81	14
10 AM	84	79	69	96	4.4	.18	.04	84.0	.262	77	8
11 AM	87	78	60	84	5.5	.25	.07	85.0	.253	65	11
12 AM	90	79	57	82	4.9	.30	.09	86.5	.260	70	9
1 PM	91	80	50	74	5.7	.36	.13	88.0	.241	66	15
2 PM	92	79	40	67	6.1	.44	.16	87.0	.224	75	21
3 PM	93	82	40	63	4.9	.47	.20	88.5	.216	76	24
4 PM	94	83	40	60	5.0	.48	.22	88.5	.228	79	20
5 PM	92	82	37	60	4.7	.46	.21	85.5	.252	73	11
6 PM	90	79	46	86	2.6	.37	.07	83.5	.260	78	8
7 PM	82	77	74	95	1.7	.14	.02	80.0	.248	81	13
8 PM	81	77	80	100	3.2	.10	0	79.0	.250	81	12
9 PM	78	76	87	100	4.3	.06	0	77.5	.255	84	10
10 PM	77	75	92	100	3.8	.04	0	76.5	.260	89	8
C.C. (r)[y]	.80**	.83**	-.78**	-.75**	.74**	.61*	.68**	.84**			

[z]Vapor Pressure Deficit.

[y]Correlation coefficients between per cent evaporation and climatic variables are calculated for the 24-hr period.

by as much as 75 ft on the windward side and gained as much as 125 ft on the leeward side during this windy period. Several cans were found to contain little or no water during the measurements. This was reflected in low Cu values for that period. Wind drift observations were in agreement with findings elsewhere (2, 4, 6). Hourly measurements of evaporation for the volume gun are in general agreement with regular irrigation measurements (Table 2) except for the period of strong wind when the data were confounded by drift.

Unlike permanent overhead, no significant correlations were found for the volume gun between microclimatic factors and evaporation except for wind speed and VPD in the irrigated block. However, the correlations for these 2 factors were not significant if the data confounded by wind drift were not included.

The effects of sprinkler irrigation on microclimate in the grove is significant. It will lower the temp from 1 to 13°F and raise the RH 1 to 40% under the conditions studied here. These values were higher than values reported when sprinkler irrigation was used to cool fruit on trees (5, 7, 9). Differences in the irrigation rates may partially account for the difference. Much lower rates were used for fruit cooling.

Reasons why significant correlations between microclimate and evaporation in the grove were found for permanent overhead but not found for volume gun are not clear. It is possible that the different operating pressures and nozzle diam may account for part of the difference. All the permanent overhead systems measured operated at the pressure specified by manufacturers, which was 55 psi at the nozzle. The specified pressure for the traveling volume guns is 80 psi. The operating pressure at the nozzles for the guns studied ranged from 65 to 75 psi. Since nozzle diam and operating pressure, together with microclimatic factors in the grove, affect evaporation (2, 3, 6), operation at a lower pressure does not disperse the water stream into as small a particle size as does a higher operating pressure. With larger droplet size, the evaporation rate is reduced. The lower evaporation rate may have distorted the correlations and made them insignificant.

It may be advantageous to operate the

Table 4. Comparison of day and night irrigations of volume gun in hourly measurements.[y]

Time	Air Temp Ck.	Air Temp Irrig.	R. Humidity Ck.	R. Humidity Irrig.	Wind speed	VPD Ck.	VPD Irrig.	Water Temp	Water Meas.	Water Cu	Evaporation
	°F	°F	%	%	mph	psi	psi	°F	inches	%	%
9 PM-12 AM	76	74	97.5	100	.7	.01	0	77	.501	85	0
7 PM	81	76	77	92	.7	.12	.03	82	.552	88	0
8 PM	78	75	88	96	.9	.06	.02	79	.514	87	0
12 PM	86	81	58	84	4.3	.26	.08	86	.520	91	0
1 PM	88	80	49	83	3.9	.33	.08	86	.552	90	0
11 AM	89	87	52	80	4.2	.32	.13	85	.498	86	2
1 PM	91	83	62	81	5.9	.27	.10	92	.474	87	5
6 PM	84	79	73	84	4.9	.15	.08	84	.475	90	5
2 PM	94	85	41	70	3.4	.46	.18	90	.473	85	6
3 PM	84	80	65	87	4.3	.20	.06	82	.462	92	8
10 AM	86	84	70	98	4.8	.18	.01	86	.459	89	9
4 PM	86	80	60	82	4.6	.24	.09	85	.451	89	10
2 PM[z]	93	84	52	76	7.2	.36	.14	91	.411	72	18
3 PM[z]	94	89	51	73	8.1	.38	.18	92	.401	59	20
5 PM[z]	93	87	55	76	7.9	.34	.15	87	.394	69	21
4 PM[z]	93	87	54	72	8.3	.35	.18	90	.353	60	30
C.C. (r)	-.26	-.31	.06	.22	.85**	-.46	-.65**	.28			

[z]Portion of the water loss is due to drift under strong wind. (See text.)

[y]Data collected from 6 AM to 10 AM and 11 AM to 3 PM are not included because of a malfunction of anemometers.

traveling volume gun at a pressure lower than suggested by manufacturers (80 psi) to reduce evaporational loss. The present study showed that when operating between 65 to 75 psi, water distribution from the traveling gun is as effective as that from permanent overhead systems.

Night irrigation is preferable over day irrigation both from standpoint of lower evaporation losses and more uniform water distribution. This is especially true for permanent overhead systems. While the evaporation losses from the volume gun are less than half the permanent overhead in day operation, wind drift is an important factor and operating during high winds should be avoided.

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