DROP SIZE DISTRIBUTIONS FOR IRRIGATION SPRINKLERS

D. C. Kincaid, K. H. Solomon, J. C. Oliphant

ABSTRACT. *A set of drop size distribution data is presented covering a wide range of sprinkler types including single nozzle impact sprinklers with straight bore and square nozzles, and sprayheads with various types of deflector plates. Drop sizes were measured by the laser-optical method and comparisons with other types of drop size measurement techniques are presented. Distributions are parameterized with an exponential function, and a method is provided to estimate the parameters given the sprinkler type, nozzle size, and pressure head.* ***Keywords.*** *Irrigation, Sprinklers, Drop size.*

Sprinkler irrigation can be defined as any irrigation system which distributes water as discrete droplets through the air. The variety of sprinkler devices available has increased dramatically in recent years, from the conventional single or double nozzle impact sprinkler with many types of nozzles to various types of deflection-plate sprinklers which influence the drop sizes and water distribution patterns over a wide range of flow rates and pressures.

Accurate knowledge of drop size distributions for sprinklers is important because evaporation and drift losses are controlled by the extreme small size ranges and drop impact energy on the soil is determined primarily by the largest size ranges. Selection of a specific sprinkler package for a sprinkler system operating on particular soil, slope, crop, and climate conditions will be aided by knowledge of the drop sizes.

Several articles have been published describing the drop size distributions of specific types of sprinklers (Kohl, 1974; Kohl and DeBoer, 1984; Solomon et al., 1985; Kohl and DeBoer, 1990). The reported data were collected using pellet, stain, and photographic methods. This article presents additional data using a laser-optical method compared with some distributions determined by some of the previously used methods, so that the entire body of published data is more comparable. The main objective is to parameterize the data and present a method to predict the parameters as a function of nozzle size and pressure.

DROP SIZE MEASUREMENT

LASER METHOD

Laser equipment has recently become available for particle size measurement and offers the potential for relatively high speed data collection compared to previous methods. The laser tests reported here were conducted at the indoor facility of the Center for Irrigation Technology, Fresno, California. The equipment included a sprinkler test stand with radial-leg pattern measurement collectors placed at 0.5-m intervals. The facility and laser-optical equipment was described by Solomon et al. (1991). The instrument, a Particle Measuring System GBPP-100S, projects a flat, horizontal laser beam 13 mm wide × 500 mm long, impinging on a detector array with 64 elements, 0.2 mm apart. The instrument measures drop sizes from 0.2 to 13 mm in 0.2-mm increments, and counts the number of drops in each size increment. It also measures drop velocity by determining how fast a droplet passes through the laser beam.

The main problem with the laser method is that multiple drops, simultaneously moving through the laser beam, produce overlapped images which appear as a larger drop, causing overestimation of drop sizes (Kohl et al., 1985). The instrument calibration was checked by using glass beads of known diameter as small as 0.25 mm to simulate water drops. It was found that very small drops passing through the ends of the laser beam gave drop sizes too large. However, the instrument was accurate when drops fell near the center of the beam length. This problem was greatly reduced by the computer estimation of drop velocity and subsequent rejection of drops whose velocities were not consistent with the size class (Solomon et al., 1991), and by using a shield over the ends of the laser beam to reduce the effective length of the beam window area, thus reducing the probability of overlapped droplet images.

By running repetitive tests, it was found that as the window area was reduced (with the window centered on the beam) the overall drop size distribution was shifted toward the smaller sizes, but a longer time period was required to measure a sufficient number of drops to accurately describe the distribution. Also, a very small window length could cause problems with larger drops

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being split by the edges of the shield. The shield has a sharp edge angled to minimize edge splash. Drops impacting the edge would be split, but these drops would tend to have odd velocities, and would tend to be rejected. The optimum length of the window was found to be about 100 mm and was used for the tests reported here. Also, for the sprinklers tested here, the vertical trajectory angles were between 0 and 25°, so that the drop sizes tended to be segregated with distance from the sprinkler. At each distance position, the range of drop sizes was relatively narrow.

Drop size distributions were measured at 2 m radial distance increments for single nozzle sprinklers, and at 1 m intervals for the spray heads whose wetted radii were less than about 8 m. A total of 10,000 drops were measured at each position except for the 12 and 14 m positions for the large radius sprinklers where only 4,000 drops were measured to save time. These subdistributions were then combined into an overall distribution for each sprinkler-nozzle pressure combination by weighting them according to the fraction of the total volume falling within each interval. Radial application rate profiles were measured at 0.5 m intervals. The fraction of the total volume falling within each 1 to 2 m drop size measurement interval was determined by weighting the application rate data by distance from the sprinkler. The nozzle height above the collectors and laser instrument was 0.7 m for the impact sprinklers, and 3 m for the spray heads. These heights allowed the drops to approach a nearly vertical fall trajectory through the laser window. The spoon spray from the drive arm of the impact sprinklers was included in these drop size distributions.

The laser method indicated a few large drops in the 7 to 9 mm range, which appeared to distort the distribution toward the large sizes as compared to the other methods described later. Studies of large raindrops have shown that drops larger than about 5.5 mm are unstable and break up, although larger drops can exist for short periods of time (Fournier D'Albe and Hidayetulla, 1955; Pruppacher and Pitter, 1971; McTaggart-Cowan and List, 1975). These studies also showed that when large drops break up, many small drops are produced, predominantly in the 1 to 2 mm size range. The laser measures the maximum horizontal width of a drop and thus overestimates the sizes of the larger drops, which become highly distorted. Beard (1976) found that drops begin to flatten at 1 mm diameter and distortion increases with drop size. He presented the following equation to quantify the distortion factor,

$$d_m/d_0 = 0.973 + 0.027\ d_0 \qquad (1)$$

where d_m is the horizontal projected diameter (mm) and d_0 is the equivalent spherical diameter, $1\ \text{mm} < d_0 < 7\ \text{mm}$.

Drop size data from the laser method were adjusted according to the following procedure. All drops larger than 7 mm were discarded with the assumption that they are highly distorted or overlapped drops and thus not reliable measurements. Drops between 1 and 7 mm were adjusted according to equation 1, and the percentage volumes were then renormalized.

PHOTOGRAPHIC METHOD

Drop sizes estimated by the photographic oil-immersion technique (Eigel and Moore, 1983) were compared with drop size estimates from the other methods, especially to check the upper and lower extremes of the size distributions. The main advantage of this technique is that it does not require calibration, and the accuracy depends only upon the resolution and magnification of the photographic enlargement.

Following the procedures of Eigel and Moore (1983), we used a 2:1 mixture of STP oil treatment and heavy mineral oil in 100-mm-diameter petri dishes filled to a depth of 8 to 10 mm. Samples of the drops were caught in the dishes and immediately photographed. Drops were photographed against a dark background and illuminated with a circular fluorescent light placed about 60 mm above the dish. We used a 35-mm camera with a 55-mm lens and 32-mm extension tube. Fujichrome 100 color slide film, exposed for one-half second at an aperture of f8 gave good contrast and definition of drops. Slides were projected on a 0.89 × 1.35 m screen, which resulted in a 30:1 magnification ratio. With this method, drops as small as 0.1 mm diameter could be measured. Drops were manually categorized and counted in size classes of 0.2 mm, and in addition, a 0.1 mm size class (0 to 0.15 mm) was added to determine whether a significant volume of drops smaller than 0.2 mm was being excluded by the other methods.

To determine whether large drops would break up on impact with the oil, individual 6-mm drops were formed with small tubing and dropped from a height of 4 m into the oil mixture in the petri dishes. Since no break up was observed, we are confident that this method can collect and measure the largest drops from sprinklers.

OTHER METHODS

Much of the previously published data on sprinkler drop sizes was measured by the flour pellet method (Kohl, 1974; Laws and Parsons, 1943). This method involves catching drops in a pan of sifted wheat flour, drying the flour, and sieving the dried pellets into different size categories. A calibration equation relates the pellet mass to drop size. The minimum drop diameter measured with this method is about 0.3 mm. Eigel and Moore (1983) state that this method is difficult to calibrate for small drop sizes. The other method used in the study was the stain method (Solomon et al., 1985; Hall, 1970), in which drops are caught on a treated paper and allowed to dry. The resulting stains are measured and converted using an equation which relates stain size to drop size.

COMPARISON OF DROP SIZE MEASUREMENT METHODS

Drop size comparisons between the laser and photo methods are shown in figures 1 and 2 after the laser data were adjusted for distortion, as described previously. The two methods produce similar drop size distributions, but the laser still tended to overemphasize the largest drop sizes, particularly with the lower pressure sprinkler, which gave larger overall drop sizes (fig. 2). The laser also estimated lower percentage volumes in the sub-millimeter size ranges. Volume percentage in the 0.1 mm size class was insignificant.

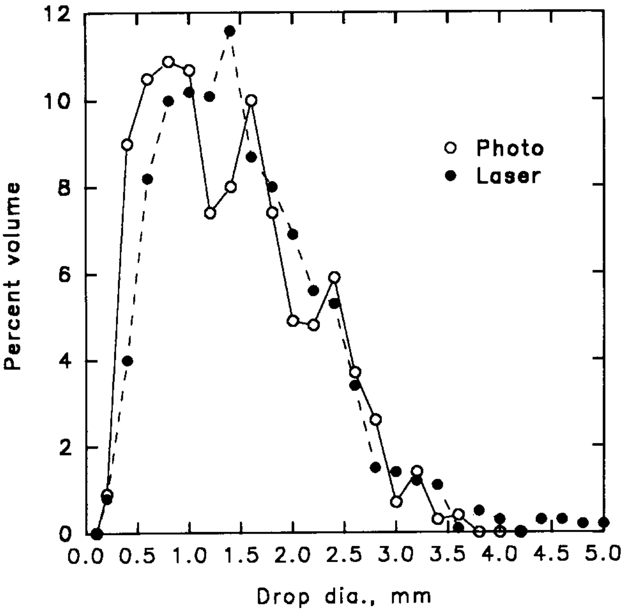

Figure 1–Drop size distributions by photo and laser methods for an impact sprinkler at 402 kPa pressure and 3.5 mm nozzle (Test 4).

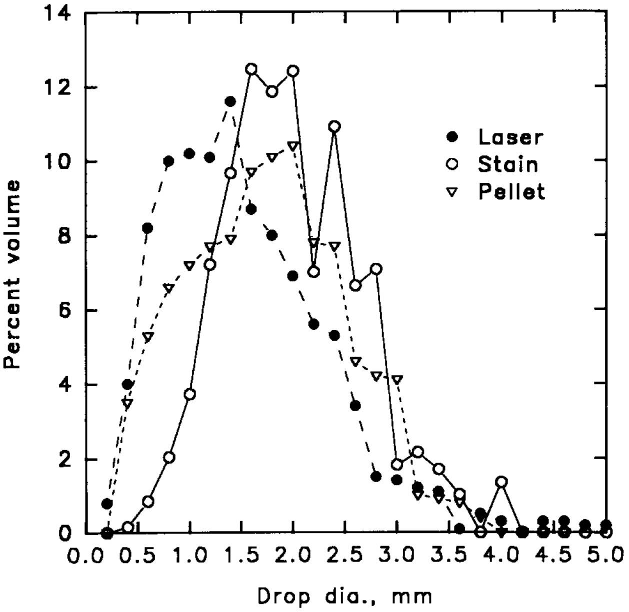

Figure 3–Drop sizes by three methods for an impact sprinkler with 3.5 mm nozzle at 402 kPa pressure (Test 4, stain data from Solomon et al., 1985; pellet data from Kohl, 1974).

The pellet and stain methods are shown in figure 3 for an impact sprinkler, and in figure 4 for a spray head (Nelson Spray I with flat, smooth plate). Data for the pellet method was taken from Kohl (1974) and Kohl and DeBoer (1984), and digitized on 0.2 mm increments (data for 0.2-mm drops was estimated from the graphs). Data for the stain method were measured by the first author. Since the data were measured with different experimental setups, some of the differences could be due to test procedures. However, some method differences are apparent.

The pellet method compares well with the laser method overall. The stain method appears to underestimate the percent volume in small drops, and thus gives a larger percentage in the medium drop size range. This may be due to the fact that the small stains tended to be faint or hidden by larger stains, and this leads to underestimating the numbers of small drops.

LASER TESTS AND THEIR PARAMETERIZATION

DESCRIPTION OF SPRINKLERS

Two main types of sprinklers were tested—single nozzle impact drive sprinklers (tests 1 through 27, table 1), and

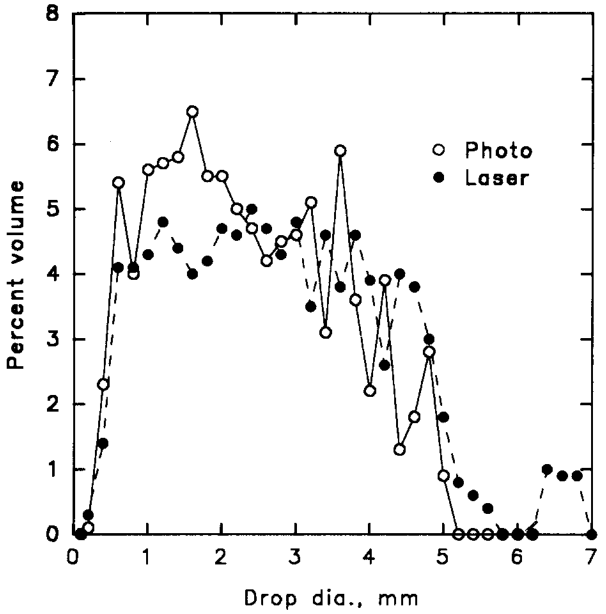

Figure 2–Drop size distributions by photo and laser methods for an impact sprinkler at 206 kPa pressure and 3.7 mm nozzle (Test 5).

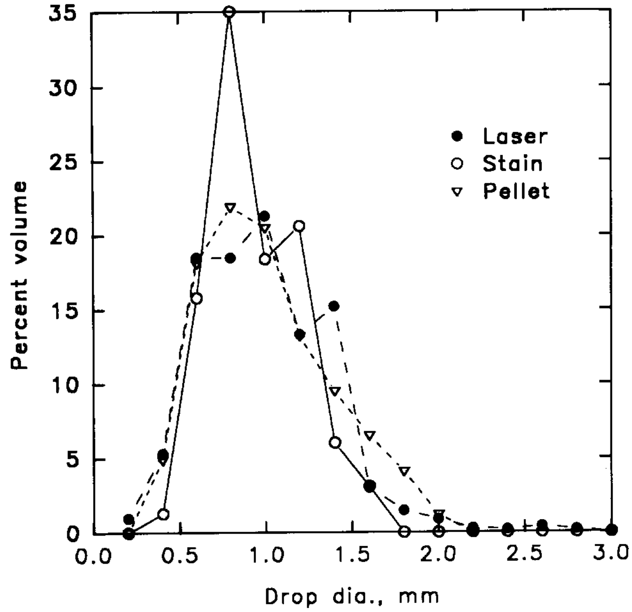

Figure 4–Drop sizes by laser, stain, and pellet methods for a smooth plate spray head with 4.6-mm nozzle at 206-kPa pressure (Test 70).

Table 1. Sprinkler and nozzle types tested by laser method

Test Nos.	Sprinkler	Nozzle or Plate Type	Trajectory Angle (approx. °)
1-10	Rainbird 30	Straight bore	25
11-17	Nelson F85	Straight bore	25
18-22	Nelson F32	Flow control, 4-5 gpm	23
23-27	Rainbird 30	CD (square)	25
28-33	Senninger Wobbler	6 groove, high angle	30
34-39	Senninger Wobbler	9 groove, low angle	15
40-44	Nelson Rotator D4	4 groove plate	8
45-49	Nelson Rotator D6	6 groove plate	12
50-53	Nelson Rotator D6S	6 groove spinning plate	12
54-59	Nelson Spray I	Concave, medium (30) groove	6
60-61	Senninger LDN	Single (36) groove plate	5
62-63	Senninger LDN	Double grooved plate	–5
64-65	Senninger LDN	Triple grooved plate	±5
66-75	Nelson Spray I	Flat, smooth plate	0

spray heads in which the jet impinges on a fixed or moving plate (tests 28 through 75). The tests are grouped in table 1 by sprinkler and nozzle or plate type, and trajectory angle. The impact drive sprinklers include a wide range of straight bore nozzle sizes, flow control nozzles in which the round orifice size decreases with increasing pressure, and square orifice (CD) nozzles. The spray heads use deflector plates with various numbers or sizes of grooves to subdivide the jet and produce a distinct application pattern. In general the more grooves used, the smaller the drop sizes for a particular nozzle size and pressure. The Wobbler sprinkler uses a rapidly wobbling deflector to produce a continuous spray pattern. The Rotators use a rotating plate with different numbers of grooves and trajectory angles, and slow or fast (spinning plate) rotation. The Spray I head uses fixed plates, either grooved or smooth. The LDN head uses fixed plates in a single or stacked arrangement where the flow is divided between multiple plates, to maintain a relatively constant flow per plate over a wide range of nozzle sizes, which in turn maintains a narrow range of drop sizes.

PARAMETERIZATION OF DROP SIZE DISTRIBUTIONS

The upper limit log normal (ULLN) model (Mugele and Evans, 1951; Solomon et al., 1985) has been found to fit drop size distributions quite well. However, the ULLN model involves three parameters (including the maximum drop size), which must be optimized. Li et al. (1994) used an exponential model which fit the distributions as well as the ULLN model, and was simpler. The exponential model used in this article is given by:

$$P_v = (1 - \mathrm{EXP}[\,-0.693\,(d/d_{50})^n]) \times 100 \qquad (2)$$

where

d = drop diameter (mm)
P_v = percent of total discharge in drops smaller than d
d_{50} = volume mean drop diameter (mm)
n = dimensionless exponent

Figures 5, 6, and 7 show distributions modeled by equation 2 (lines) compared to measured data points. The model fits the data very well overall, but the model tends to overestimate percentage volumes for smaller drop sizes, as discussed in more detail later.

Exponential model parameters for individual tests are given in table 2 for impact-type sprinklers and in table 3 for the other sprinklers and spray heads. The listed data include sprinkler base pressure, effective nozzle diameter (computed from flow rate and pressure for noncircular and flow control nozzles) mean volumetric drop size, d_{50}, exponent n and standard error of estimate for equation 2. The last three columns are the volume percent of the spray in drops smaller than 0.5 mm, smaller than 1 mm, and larger than 3 mm. The small size ranges are of most interest for predicting spray drift and evaporation. Edling (1985) found that evaporation and drift increased greatly as drop size decreased from 0.6 to 0.3 mm. The percent volume in large drops is of interest for predicting and water drop impact energy. Stillmunkes and James (1982) found that for a particular drop size, the kinetic energy decreases

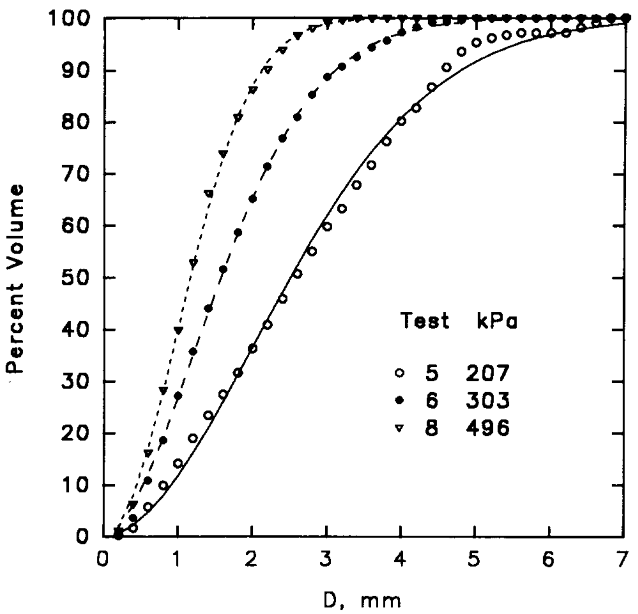

Figure 5–Laser drop sizes for an impact sprinkler with a 4-mm nozzle at three pressures (lines are eq. 2 fitted to data).

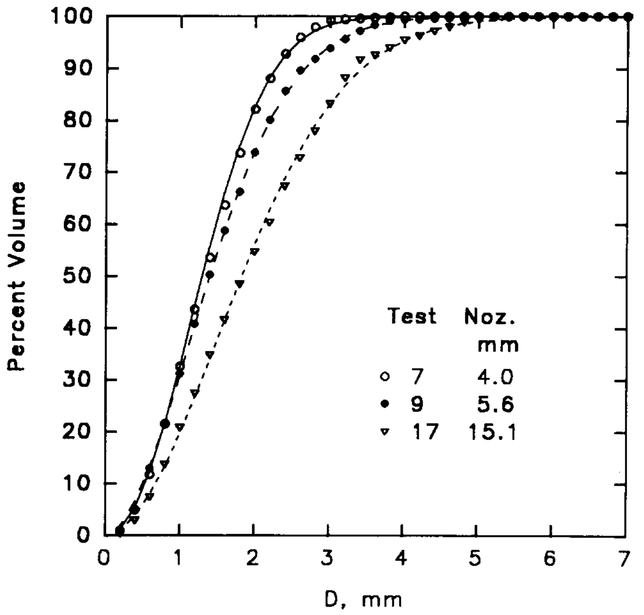

Figure 6–Laser drop sizes for an impact sprinkler with three nozzle sizes at 413-kPa pressure.

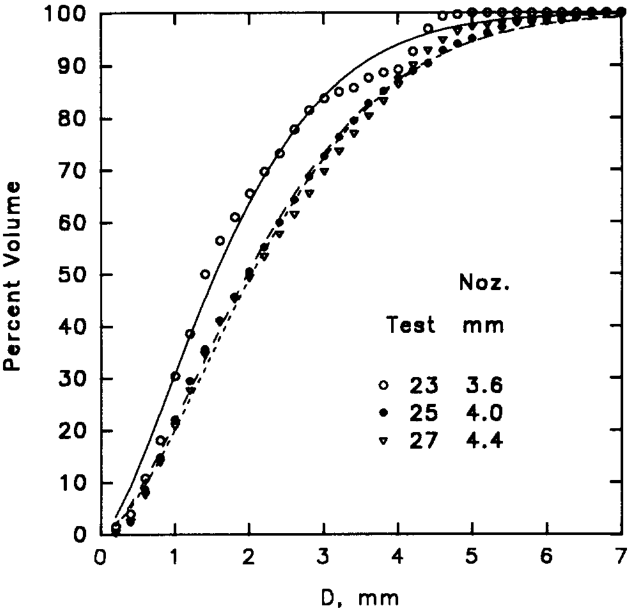

Figure 7–Laser drop sizes for an impact sprinkler with CD (square) nozzles at 207-kPa pressure.

rapidly as drop size decreases below 3 mm. The percent volume in a particular size range can be calculated by equation 2 if values of d_{50} and n are known. Figure 8

Table 2. Laser drop size distribution test results and parameter values for equation 2 for impact sprinklers, by sprinkler and nozzle type

Test	Pressure (kPa)	Nozzle (mm)	d_{50} (mm)	n	Error (%)	<0.5 mm (% vol)	<1 mm (% vol)	>3 mm (% vol)
Rainbird 30 — Straight Bore								
1	137	3.04	2.52	1.52	4.72	1.1	14.5	44.7
2	274	3.08	2.00	1.63	1.45	2.6	14.7	27.1
3	402	2.96	1.32	1.88	0.98	5.6	23.8	5.0
4	402	3.46	1.32	1.95	0.62	4.8	23	4.2
5	206	3.73	2.51	1.86	1.92	1.7	9.9	40.2
6	304	3.86	1.57	1.76	0.62	3.7	18.7	11.2
7	402	3.77	1.30	2.16	0.70	4.9	21.5	0.7
8	499	3.70	1.16	2.00	0.71	6.3	28.3	0.8
9	411	5.44	1.40	1.87	0.44	4.8	21.7	6.0
10	548	5.45	1.19	1.93	0.78	6.5	28.4	2.5
Nelson F85 — Straight Bore								
11	206	9.30	2.87	2.07	2.42	1.2	6.3	49.9
12	411	9.33	1.73	1.73	1.00	3.5	15.5	16.9
13	617	9.34	1.70	1.70	0.85	3.7	16.3	16.3
14	206	12.23	2.84	1.89	1.69	1.3	6.5	48.8
15	617	12.23	1.74	2.16	0.54	1.7	11.4	11.1
16	206	15.02	2.76	2.04	2.08	1.0	5.8	45.4
17	411	15.05	1.83	1.91	0.86	3.0	13.8	16.7
Nelson F32 — Flow Control, 4-5 gpm								
18	206	3.83	2.76	1.76	0.98	1.6	8.2	45.1
19	411	3.43	1.45	1.69	1.02	4.5	21.8	10.0
20	206	4.19	2.90	1.94	3.03	1.8	8.9	51.0
21	274	4.07	2.30	1.81	1.57	2.7	12.1	34.8
22	411	3.80	1.25	1.98	0.64	5.3	25.1	2.5
Rainbird 30 — CD (square)								
23	206	3.44	1.54	1.47	2.67	3.9	18.1	16.3
24	137	3.81	1.89	1.31	5.57	4.9	12.8	32.9
25	206	3.84	1.97	1.54	1.12	2.5	14.9	27.3
26	274	3.87	1.51	1.56	1.87	3.3	19.6	14.6
27	206	4.17	2.03	1.59	1.95	2.5	14	30.2

Table 3. Laser drop size distribution test results for spray heads, by sprinkler and nozzle type

Test	Pressure (kPa)	Nozzle (mm)	d_{50} (mm)	n	Error (%)	<0.5 mm (% vol)	<1 mm (% vol)	>3 mm (% vol)
Senninger Wobbler— 6 Groove High Angle								
28	69	3.12	1.77	1.69	1.47	1.9	16.8	18.5
29	137	3.16	1.21	1.75	1.16	5.8	29.9	2.7
30	274	3.16	0.86	2.05	0.87	11.3	46.8	0.0
31	69	6.24	2.34	1.48	2.51	2.7	14.1	37.6
32	137	6.22	1.60	1.75	1.15	3.7	19.7	12.2
33	274	6.24	1.18	2.25	0.58	3.6	25.3	0.4
Senninger Wobbler— 9 Groove Low Angle								
34	69	3.13	1.55	1.64	1.85	2.5	21.8	13.8
35	137	3.13	1.47	1.45	2.26	4.4	26.7	15.9
36	274	3.12	0.86	2.27	0.59	9.6	45.4	0.0
37	69	6.30	2.53	1.71	3.66	1.8	10.7	43.7
38	137	6.37	1.55	1.81	1.01	2.8	18.9	10.6
39	274	6.30	1.27	2.19	1.38	2.5	20.3	2.1
Nelson Rotator D4 — 4 Groove Plate								
40	108	4.62	3.07	1.35	4.57	1.4	8.7	52.9
41	206	4.63	2.02	1.39	1.96	3.3	17.3	32.2
42	108	6.16	2.48	1.25	3.09	2.1	13.1	39.3
43	206	6.22	2.00	1.51	1.98	4.1	17.7	30.2
44	313	6.22	1.26	1.63	1.03	6.9	30	5.1
Nelson Rotator D6 — 6 Groove Plate								
45	108	4.63	1.83	1.45	2.39	1.8	15.7	27.7
46	206	4.63	1.18	1.41	2.53	6.8	33.2	9.4
47	108	6.16	1.63	1.26	3.05	4.1	21.5	25.2
48	206	6.22	1.23	1.39	2.59	5.6	31.3	11.8
49	206	9.24	1.38	1.62	1.20	4.8	25.8	8.9
Nelson Rotator D6S — 6 Groove Spinning Plate								
50	108	4.62	1.32	1.62	4.35	5.1	21.7	7.8
51	206	4.63	1.15	2.29	2.10	7.9	24	2.3
52	108	6.12	1.55	1.47	2.34	3.4	23.8	19.7
53	206	6.16	1.05	1.82	1.61	6.9	35.9	2.5
Nelson Spray I — Concave, Medium (30) Groove								
54	69	3.09	0.85	3.26	1.13	5.3	48.7	0.0
55	206	3.12	0.76	2.76	0.67	8.9	56.8	0.0
56	69	6.12	1.23	2.15	1.56	3.5	24.9	0.0
57	206	6.25	1.16	1.99	1.52	4.7	31	0.0
58	69	8.10	1.61	1.68	2.63	2.5	18	20.2
59	206	8.19	1.38	1.76	1.47	3.7	23.2	5.1
Senninger LDN — Single (36) Groove Plate								
60	69	3.09	1.19	6.30	1.74	3.2	8.7	0.0
61	206	3.13	1.09	3.96	0.51	2.2	17.2	0.0
Senninger LDN — Double (36) Groove Plates								
62	69	6.16	1.68	3.23	2.89	4.2	8.8	4.6
63	206	6.25	1.98	2.18	2.62	2.3	6.9	19.7
Senninger LDN — Triple (36) Groove Plates								
64	69	7.76	2.34	2.20	1.93	1.4	4.3	28.3
65	206	7.85	2.03	1.80	1.98	2.9	8.3	26.0
Nelson Spray I — Flat, Smooth Plate								
66	69	2.98	0.70	3.35	0.89	12.7	68	0.0
67	108	3.06	0.70	2.68	0.79	11.5	64.6	0.0
68	206	3.07	0.68	2.73	0.92	12.5	69	0.0
69	69	4.57	0.94	2.11	1.60	4.3	38.2	0.3
70	206	4.61	0.86	2.59	0.87	6.3	43.4	0.2
71	69	6.12	1.08	1.98	1.57	4.0	32.7	1.4
72	108	6.12	1.21	1.85	1.73	4.2	30.3	2.3
73	206	6.22	1.03	2.01	1.31	5.5	35.3	0.5
74	69	9.06	1.63	1.61	1.88	2.3	19.5	16.8
75	206	9.15	1.31	1.72	1.21	4.5	25.8	6.0

compares calculated and measured values of percent volume for the three size ranges in tables 2 and 3, for each test using the listed values for d_{50} and n. Equation 2 overestimates the percent volume in drops smaller than 0.5 and 1 mm by factors of about 2 and 1.3, respectively. The model predicts the volume in large (> 3 mm) drops accurately.

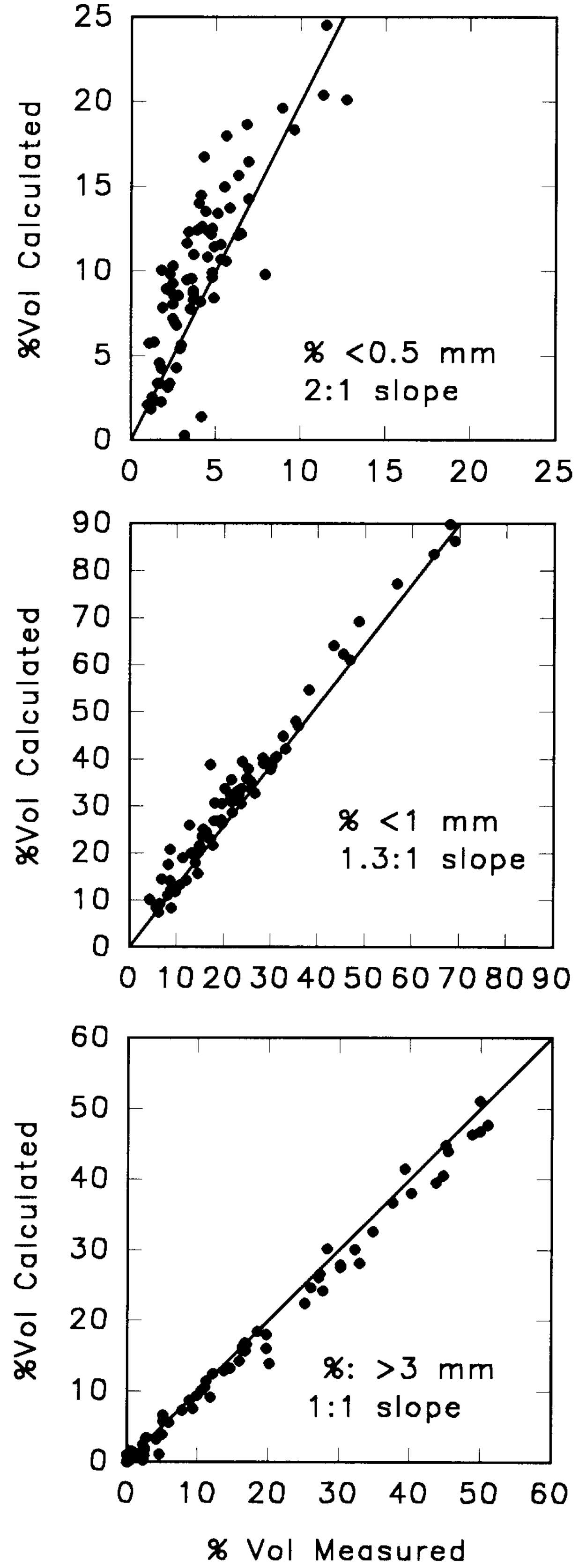

Figure 8–Measured and calculated (eq. 2, tables 2 and 3) percent volume in three drop size categories.

For any given type of sprinkler and nozzle or spray plate, the drop size distribution is affected by the nozzle size and pressure. With impact sprinklers, nozzle pressure has more influence on drop sizes than nozzle size, while nozzle size appears to have more influence with spray heads where the jet is deflected and divided by a specially shaped plate. We found the ratio of nozzle size to pressure head, here denoted by R, to be a useful parameter in characterizing drop size distributions for the various sprinkler types. Parameters d_{50} and n are related to R in figures 9 and 10. As R increases, d_{50} and percent large drops increase, the percent small drops decreases, and the value of n tends to decrease slightly. The values of d_{50} and n can be estimated by:

$$d_{50} = a_d + b_d R \tag{3}$$

and

$$n = a_n + b_n R \tag{4}$$

where a_d, b_d, a_n, and b_n are regression coefficients.

The tests were grouped into seven distinct types in which the parameters d_{50} and n were well correlated with R. The impact sprinklers were separated into two types, with small and large nozzles, since the correlations were significantly different with these two groups. Table 4 lists values of the coefficients for the seven types, and r_d and r_n are correlation coefficients for d_{50} and n, respectively. The r_d values are higher for the impact sprinklers than for the spray heads (except the Wobbler) because, for nondeflected jet sprinklers, drop sizes are highly influenced by the nozzle size and pressure, whereas for the sprayheads, drop

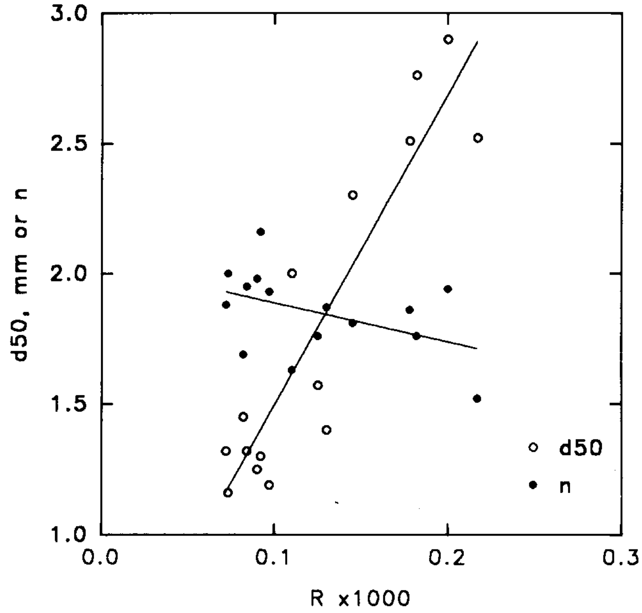

Figure 9–Effect of nozzle-head ratio on value of d50 and exponent n for impact sprinklers with small (3 to 6 mm) round nozzles.

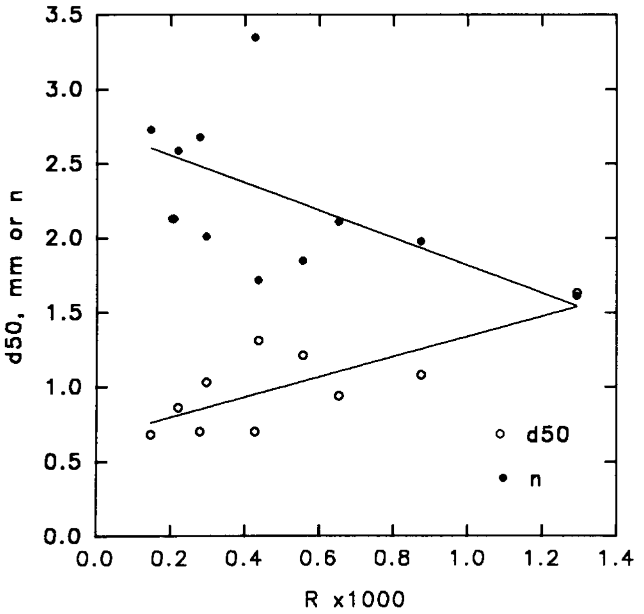

Figure 10–Effect of nozzle-head ratio on value of d50 and exponent n for flat plate spray heads.

sizes are influenced by the plate shape. The r_n values are generally lower because the value of n does not change drastically.

CONCLUSIONS AND RECOMMENDATIONS

The comparisons between the laser and photographic methods indicate that the laser method, as modified to minimize distortions in the data, is reliable. Data from the pellet method compared well with the laser method, while the stain method tends to underestimate the percent volume in small drops. The exponential model gives a good overall fit to the cumulative percent volume with drop size, but overestimates the percent volume in very small (< 1 mm) drops. The suggested adjustment factors should therefore be used with this model in the small drop size ranges. The coefficients in table 4, used with equations 2, 3, and 4 should give reasonable predictions of the drop size distributions for the stated ranges of R. The distributions should prove useful in modeling spray drift and evaporation and impact energy for the range of sprinklers tested. Drop size distribution parameters for other nozzle sizes and pressures can be estimated by interpolation from tables 2 and 3, and distributions for sprinkler types similar to those tested could be estimated by use of the nozzle/pressure ratio and the coefficients from table 4.

Table 4. Coefficients for estimating drop size distribution parameters for seven types of sprinkler or spray heads

Sprinkler type	a_d	b_d	r_d	a_n	b_n	r_n
Impact sprinkler Small (3-6 mm) round nozzle	0.31	11,900	0.92	2.04	-1,500	0.45
Impact sprinkler Large (9-15 mm) round nozzle	1.30	2,400	0.88	1.82	300	0.36
Wobbler	0.78	1,870	0.97	2.08	-630	0.59
Rotator, 4 groove	1.07	3,230	0.74	1.70	-830	0.83
Rotator, 6 groove	0.81	1,480	0.76	2.07	-1,300	0.53
Concave, 30 groove plate	0.82	620	0.74	2.68	-750	0.46
Flat smooth plate	0.66	680	0.77	2.74	-920	0.59

The equations can be used to estimate what type sprinkler and range of pressure and nozzle sizes would be desirable for a particular situation. For example, on a center pivot system, it is desirable to limit the nozzle size range at a given pressure to prevent the drops from getting too large or small, i.e., to minimize wind drift or droplet energy impact on the soil.

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