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P. O. BOX 245
BERKELEY, CALIFORNIA 94701

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Log-Normal Spray Drop Distribution...

analyzed by two new computer programs

Gerald S. Walton

ABSTRACT: Results of U.S. Forest Service research on chemical insecticides suggest that large drops are not as effective as small drops in carrying insecticides to target insects. Two new computer programs have been written to analyze size distribution properties of drops from spray nozzles. Coded in Fortran IV, the programs have been tested on both the CDC 6400 and the IBM 7094 computers. Instructions on their use are included.

RETRIEVAL TERMS: insecticide application; insecticide residues; drop size distribution; drops (liquid); spray characteristics; data processing; computer (programing).

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U.S. Forest Service research on improved insecticides and on methods of application has suggested that large drops are not as effective as small ones in carrying chemicals to target insects. This finding has stimulated interest in the properties, including size distribution, of drops produced by spray nozzles. Researchers who need estimates of drop size from limited samples can use two new computer programs developed to help appraise drop size achieved in application of sprays. Coded in Fortran IV, the two programs have been tested on both the CDC 6400 and the IBM 7094 computers.

From the number of distributional forms suggested in the literature, I selected log-normal distribution for use in both programs. This distribution appeared to fit adequately the sample data. The two programs compute:

- Asymptotically unbiased estimates of the parameters of distribution.
- The precession of such estimates.
- Estimates of median diameters for frequency, surface area, and volume.
- Ninety-five percent confidence intervals for such estimates.
- Predicted frequencies, surface areas, and volumes of drops in selected diameter intervals.
- A fit test which measures the adequacy of the log-normal distribution assumption.

The two programs were designed for two different sampling methods. The first program may be used when drop frequencies are

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observed for various drop diameter intervals--as is the usual technique. Because the data are in drop frequency form it uses a minimum chi-square method of estimation. This program will be called the MCS program. The second program is applicable if all drops in a sample are counted, and the largest drops are measured accurately. This method of sampling may save time and effort by eliminating the need to classify each drop by size. Generally, a larger total number of drops must be sampled in order to obtain estimates as precise as those obtained by the first method. Because the data are continuous, this second program uses a maximum likelihood method of estimation. It will be called the MLE program.

INFORMATION PROVIDED

Figures 1 and 2 illustrate the printed results of the MCS and MLE programs. Since the formats are nearly identical and the results analogous, they are discussed simultaneously. The parenthetical numbers on the figures are keys which will be referred to in the text. All dimensions are determined by the data supplied by the program user.

Each printed page is headed by a title (1) provided by the user, and followed by information on the problem being solved (2). U and T (3) are estimates of the parameters Θ_1 Θ_2 in the log-normal probability density function:

$$f_y(\Theta_1,\Theta_2) = \frac{1}{\sqrt{2\pi\Theta_2}} \exp\left[\frac{-(y-\Theta_1)^2}{2\Theta_2}\right]$$

in which y is the natural log of the drop diameter. U and T are asymptotically unbiased and normally distributed with estimable covariance (4). These asymptotic properties hold for "sufficiently large" samples, although it is not possible to say just how large is sufficient. Nevertheless, these properties are used to compute 95-percent confidence intervals for the frequency, surface area, and volume (or mass) median diameters (5).

Item labelled (6) in the printout shows various frequency and volume predictions, based on the estimated values U and T, printed with the values actually observed. The diameter intervals are determined by the user. Estimated frequencies are rounded to the nearest whole number. Volume estimates are printed in 10's exponent form and have the dimensional units of the cube of the diameter measurement units. Item (7) gives the total volume and volume per unit area estimates for the spray sampled.

The last items printed for each problem concern the chi-square fit test. Statistical tests are made by computing a statistic (a function of the observations) whose value is indicative of the reasonableness of the hypothesis. The significance level, α, is a probability statement as to how tenable the hypothesis is in light of the test statistic. The chi-square statistic tends to increase with poor fit. The statement "If the data were truly log-normal, one would expect a larger value of chi-square α percent of the time" indicates that one would err by rejecting the hypothesis of log-normal fit when it is true α percent of the time. To avoid this error, the fit hypothesis is rejected when α is small--usually less than 5 percent. How often a poor fit will or will not be rejected cannot be stated.

Keep these things in mind regarding the fit test: First, lack of fit may be due to departures from proper sampling methods or errors in the data. Second, lack of fit does not necessarily mean that the log-normal assumption is inadequate for the purposes intended. Third, the chi-square test is only one of many possible criteria of fit. Fourth, the test is based on comparing observed and expected frequencies for the diameter intervals specified by the user, and, consequently, may be affected by an unwise choice of intervals.

*** SAMPLE PROBLEM USING SIMULATED DATA, FREQUENCY (4A) CARDS. **(1)**

MINIMUM CHI-SQUARE ESTIMATES OF THE PARAMETERS OF A LOG-NORMAL DROP SIZE DISTRIBUTION ARE PRESENTED, BASED ON **(2)**
A SAMPLE OF 536. DROPS GROUPED INTO 9 INTERVALS BY DIAMETER CLASSES. THE DROPS WERE OBSERVED ON AN AREA OF
SIZE 18.20, OR 29.45 DROPS PER UNIT AREA.

(3) **(4)**

```
MEAN (LOG BASE E) OF LOG-NORMAL = U = 3.65101  *   COVARIANCE  (  0.0029613, -0.0003066 )
                                               *   MATRIX OF = (                        )
VARIANCE OF LOG-NORMAL          = T = 1.50550  *   U AND T     ( -0.0003066,  0.0120235 )
```

ESTIMATES AND APPROXIMATE 95 PER-CENT CONFIDENCE LIMITS FOR THE DROP DIAMETERS AT WHICH MEDIANS OCCUR

	LOWER LIMIT	ESTIMATE	UPPER LIMIT	
FREQUENCY (NMD)	34.62	38.51	42.85	
SURFACE AREA (SMD)	504.97	782.12	1211.40	SMD/NMD = 20.30784
VOLUME OR MASS (MMD)	1843.52	3524.58	6738.58	MMD/NMD = 91.51567

(5)

THE ESTIMATED PARAMETERS LEAD TO THE PREDICTED VALUES FOR THE INTERVALS AS SHOWN BELOW. THE OBSERVED FREQUENCIES ARE PRINTED BELOW THE PREDICTIONS AND ARE FOLLOWED BY AN ASTERISK. **(6)**

DIAMETER INTERVAL	DROP FREQ.	PCT. DROP FREQ	ACC. PCT. FREQ	DROPS/ AREA	MEAN DROP VOLUME	TOTAL CLASS VOLUME	PERCENT CLASS VOLUME	ACCUM. PRCNT VOLUME	CLASS VOLUME/ AREA
0.0 TO 10.0	73.	13.589	13.589	4.00	0.17581E 03	0.128055E 05	0.000	0.000	0.70360E 03
	75.*	13.993*	13.993*	4.12*					
10.0 TO 20.0	86.	16.076	29.665	4.73	0.19898E 04	0.171455E 06	0.001	0.001	0.94206E 04
	78.*	14.552*	28.545*	4.29*					
20.0 TO 40.0	116.	21.566	51.231	6.35	0.14655E 05	0.169403E 07	0.012	0.013	0.93079E 05
	121.*	22.575*	51.119*	6.65*					
40.0 TO 60.0	69.	12.876	64.107	3.79	0.65912E 05	0.454885E 07	0.032	0.046	0.24994E 06
	74.*	13.806*	64.925*	4.07*					

*** SAMPLE PROBLEM USING SIMULATED DATA, FREQUENCY (4A) CARDS.

DIAMETER INTERVAL	DROP FREQ.	PCT. DROP FREQ	ACC. PCT. FREQ	DROPS/ AREA	MEAN DROP VOLUME	TOTAL CLASS VOLUME	PERCENT CLASS VOLUME	ACCUM. PRCNT VOLUME	CLASS VOLUME/ AREA
60.0 TO 100.0	75.	14.054	78.161	4.14	0.25883E 06	0.194979E 08	0.139	0.185	0.10713E 07
	71.*	13.246*	78.172*	3.90*					
100.0 TO 150.0	45.	8.448	86.609	2.49	0.99080E 06	0.448645E 08	0.320	0.504	0.24651E 07
	47.*	8.769*	86.940*	2.58*					
150.0 TO 200.0	24.	4.420	91.029	1.30	0.27490E 07	0.651306E 08	0.464	0.968	0.35786E 07
	22.*	4.104*	91.045*	1.21*					
200.0 TO 250.0	14.	2.601	93.630	0.77	0.58792E 07	0.819511E 08	0.584	1.552	0.45028E 07
	13.*	2.425*	93.470*	0.71*					
250.0 TO 9999.9	34.	6.370	100.000	1.88	0.40470E 09	0.138181E 11	98.448	100.000	0.75924E 09
	35.*	6.530*	100.000*	1.92*					

THE TOTAL PREDICTED VOLUME IS 0.14036E 11 SO THE PREDICTED VOLUME PER UNIT AREA IS 0.77121E 09 **(7)**

THE CHI-SQUARED STATISTIC, BASED ON 6. DEGREES OF FREEDOM IS 1.97
IF THE DATA WERE TRULY LOG-NORMAL, ONE WOULD EXPECT A LARGER VALUE OF CHI-SQUARED 92.24 PERCENT OF THE TIME. **(8)**

Figure 1.--*Example of computer output from minimum chi-square program.*

*** FIRST SAMPLE MLE PROBLEM, USING SIMULATED DATA. (1)

MAXIMUM LIKELIHOOD ESTIMATES OF THE PARAMETERS OF A LOG-NORMAL DROP SIZE DISTRIBUTION ARE PRESENTED, BASED ON (2)
MEASUREMENTS OF ALL DROPS WITH DIAMETERS OF 75.0 OR MORE. ON AN AREA OF SIZE 16.400, A TOTAL OF 623 DROPS
WERE FOUND, OF WHICH 83 QUALIFIED FOR MEASUREMENT.

(3) (4)

MEAN (LOG BASE E) OF LOG-NORMAL = U = 2.98270 * COVARIANCE (0.0253619, -0.0375590)
* MATRIX OF = ( )
VARIANCE OF LOG-NORMAL = T = 1.42600 * U AND T (-0.0375590, 0.0706599)

ESTIMATES AND APPROXIMATE 95 PER-CENT CONFIDENCE LIMITS FOR THE DROP DIAMETERS AT WHICH MEDIANS OCCUR

	LOWER LIMIT	ESTIMATE	UPPER LIMIT		
FREQUENCY (NMD)	14.45	19.74	26.97		(5)
SURFACE AREA (SMD)	156.99	341.96	744.86	SMD/NMD =	17.32234
VOLUME OR MASS (MMD)	390.17	1423.24	5191.65	MMD/NMD =	72.09580

THE ESTIMATED PARAMETERS LEAD TO THE PREDICTED VALUES FOR THE DIAMETER INTERVALS SHOWN BELOW. WHERE POSSIBLE,
OBSERVED VALUES ARE PRINTED BELOW THE PREDICTED VALUES, AND FOLLOWED BY AN ASTERISK. (6)

DIAMETER INTERVAL	DROP FREQ.	PCT. DROP FREQ	ACC. PCT. FREQ	DROPS/ AREA	MEAN DROP VOLUME	TOTAL CLASS VOLUME	PERCENT CLASS VOLUME	ACCUM. PRCNT VOLUME	CLASS VOLUME/ AREA
0.0 TO 25.0	360.	57.839	57.839	21.972	0.15250E 04	0.54950E 06	0.036	0.036	0.33506E 05
25.0 TO 50.0	127.	20.339	78.178	7.726	0.26293E 05	0.33317E 07	0.217	0.253	0.20315E 06
50.0 TO 75.0	54.	8.638	86.817	3.282	0.12367E 06	0.66555E 07	0.433	0.686	0.40583E 06
75.0 TO 100.0	28.	4.471	91.288	1.698	0.34343E 06	0.95654E 07	0.623	1.309	0.58326E 06
	34.*			2.073*		0.10851E 08*			0.66166E 06*
100.0 TO 125.0	16.	2.602	93.889	0.988	0.73405E 06	0.11898E 08	0.774	2.083	0.72548E 06
	14.*			0.854*		0.10759E 08*			0.65602E 06*

*** FIRST SAMPLE MLE PROBLEM, USING SIMULATED DATA.

THE ESTIMATED PARAMETERS LEAD TO THE PREDICTED VALUES FOR THE DIAMETER INTERVALS SHOWN BELOW. WHERE POSSIBLE,
OBSERVED VALUES ARE PRINTED BELOW THE PREDICTED VALUES, AND FOLLOWED BY AN ASTERISK.

DIAMETER INTERVAL	DROP FREQ.	PCT. DROP FREQ	ACC. PCT. FREQ	DROPS/ AREA	MEAN DROP VOLUME	TOTAL CLASS VOLUME	PERCENT CLASS VOLUME	ACCUM. PRCNT VOLUME	CLASS VOLUME/ AREA
125.0 TO 175.0	17.	2.728	96.617	1.036	0.16983E 07	0.28863E 08	1.879	3.962	0.17599E 07
	14.*			0.854*		0.25163E 08*			0.15343E 07*
175.0 TO 250.0	11.	1.707	98.325	0.649	0.47680E 07	0.50721E 08	3.302	7.263	0.30927E 07
	10.*			0.610*		0.42550E 08*			0.25945E 07*
250.0 TO 9999.9	10.	1.675	100.000	0.636	0.13650E 09	0.14247E 10	92.737	100.000	0.86869E 08
	11.*			0.671*		0.94879E 09*			0.57853E 08*

THE TOTAL PREDICTED VOLUME IS 0.1536234E 10 SO THE PREDICTED VOLUME PER UNIT AREA IS 0.9367282E 08. (7)

THE CHI-SQUARED STATISTIC, BASED ON 3. DEGREES OF FREEDOM IS 2.26
IF THE DATA WERE TRULY LOG-NORMAL, ONE WOULD EXPECT A LARGER VALUE OF CHI-SQUARED 52.120 PERCENT OF THE TIME. (8)

Figure 2.--*Example of computer output from maximum likelihood estimation program.*

MINIMUM CHI-SQUARE PROGRAM

DATA REQUIREMENTS

In the minimum chi-square method of estimation (MCS), all drops on a known area are assumed to have been observed. They are classed into NLIM diameter size intervals where 5≤ NLIM ≤99. The intervals need not be of equal length. The Ith interval is defined by lower and upper limits X(I) and X(I+1). This information determines one problem. If more than one problem uses the first N of these limits, the limits only need be punched once. The computer automatically sets X(1) = 0 and X(N+1) = ∞ for each problem. It is a good practice to have at least five drops in each interval. The program will accept either data on drop frequency for each interval or data on each drop, giving the interval in which it falls. This information is then punched into cards.

DATA CARD PREPARATION

Each 80-column card is broken into fields. A field is a fixed number of contiguous columns. Each field contains a number adjusted to the right-most column, or alphanumeric information adjusted to the left-most column. Decimals should not be punched unless specified. The cards described are broken into five types for each problem, and presented in the order of their occurrence in the data deck. Any number of problems may be processed in sequence in a computer run.

Card type 1, consisting of one card, is the first card for each problem. The first two columns hold the number of intervals (NLIM) defined on card type 3. If the intervals defined in a previous run are to be used, punch 01 in this field. Columns 3-10 are for the area on which the drops were observed and must be greater than zero. The decimal, if not punched, is assumed to follow the digit in column 10. The field in columns 11-13 should contain 1.0 if drop frequency information (card type 4A) is used and 0.0 if drop interval numbers (card type 4B) are used for the problem.

Card type 2 is a single card with alphanumeric title information in columns 1-72. The title will be printed at the top of each page of printed output (see item (1) in fig. 1).

Card type 3 records the upper limits for all but the last of the NLIM drop-diameter intervals, punched in order of increasing size. Use eight-column fields, 10 fields per card, for as many cards as needed. If no decimal is punched, it is assumed to precede the last two digits in the field. The values of NLIM and all limits are available, unchanged, to any succeeding problems until reset by other cards of this type. The predicted and observed frequencies and volumes will be printed according to these intervals (see item (6) in fig. 1).

Card type 4A is used only if columns 11-13 on card type 1 contains 1.0. They contain the drop frequencies, in order of increasing diameters, for each of the NLIM intervals. These are punched in five-column fields, 16 fields per card for as many cards as needed. The computer automatically collapses the last intervals if they contain only zeros, even for the problem in which the limits are defined.

Card type 4B is used in place of 4A if 0.0 is punched in columns 11-13 of card type 1. Here, each drop is assigned the number of the interval into which it falls and these numbers are punched, in any order, in two-column fields, 40 fields per card. The numbers must be greater than 0 and less than or equal to NLIM. Because the last such number must be followed by two blank columns, an extra card may be required. Use as many cards as necessary.

The cards following the last card type 4A or 4B must either be two blank cards signaling the end of a computer run or a card type 1 for the next problem. Sample data for two identical problems are shown in figure 3. The results are given in figure 1.

```
******* THE NEXT LINE REPRESENTS THE FIRST CARD IN THE SAMPLE DATA DECK ********
 9      18.21.0
SAMPLE PROBLEM USING SIMULATED DATA, FREQUENCY (4A) CARDS.
     10.      20.      40.      60.   100.     150.     200.     250.
   75    78  121    74    71    47    22    13    35
 1      18.20.0
SAMPLE PROBLEM USING INTERVAL CODE FOR EACH DROP, PREVIOUS INTERVALS.
 2 5 1 3 3 8 1 6 5 1 3 3 4 2 1 6 5 5 1 2 9 2 5 3 2 1 2 4 2 3 3 5 7 1 5 6 3 1 1 5
 9 1 5 5 3 4 3 5 2 6 3 9 7 2 6 1 3 1 8 6 7 7 5 6 1 2 4 3 3 2 4 9 9 2 9 5 9 4 6 5
 1 9 2 5 5 1 5 3 3 2 2 2 3 4 1 3 5 1 5 4 9 5 6 1 3 5 4 2 3 3 2 3 2 9 8 4 6 9 1 3
 3 2 3 9 6 1 1 3 9 5 8 5 1 4 3 3 1 9 3 9 5 3 4 2 3 3 7 3 5 2 4 9 6 4 9 5 6 1 2 1
 5 6 5 3 8 9 4 1 5 3 4 1 7 3 9 1 1 4 4 2 6 5 2 1 8 6 1 2 4 1 2 6 4 1 3 5 2 1 5 5
 1 7 2 3 4 2 6 5 3 5 1 9 3 2 1 3 4 3 3 5 2 2 4 3 4 6 5 5 3 4 1 5 3 3 3 3 3 6 5 4
 3 2 2 4 4 1 8 2 8 5 3 4 2 2 2 2 4 9 5 1 3 2 7 3 3 3 9 7 8 7 4 2 3 4 4 4 3 4 1 3
 6 2 4 4 1 5 2 6 6 4 3 3 2 5 6 3 6 2 3 1 6 9 6 1 5 3 5 9 1 1 7 7 1 4 3 5 9 4 2 5
 3 1 2 4 5 2 6 3 4 3 4 3 3 3 1 1 7 1 4 4 4 6 1 5 3 2 6 3 5 5 8 1 7 6 4 6 4 2 3 3
 2 4 2 2 7 9 3 3 3 4 6 2 1 4 3 3 4 6 4 1 7 3 9 2 8 7 3 1 1 2 2 5 1 4 3 1 4 3 5 4
 8 2 1 3 3 2 3 9 9 6 1 2 4 7 2 6 4 3 4 1 3 3 7 3 6 4 7 6 3 4 5 4 3 6 9 3 3 2 1 3
 5 2 3 6 5 3 2 4 3 4 2 3 1 1 5 1 9 5 5 5 2 2 5 3 5 2 3 9 3 1 2 6 4 6 2 4 6 9 3 6
 1 2 2 5 3 2 2 7 3 1 3 9 2 3 3 4 6 3 1 1 3 4 9 5 3 3 3 3 5 8 1 6 3 5 4 5 4 4 2 6
 5 4 5 3 4 3 1 3 5 3 3 7 1 2 1 4

***** THE PREVIOUS LINE REPRESENTED THE LAST CARD IN THE SAMPLE DATA DECK ******
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Figure 3.--*Sample input data cards for two minimum chi-square problem analyses.*

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****** THE NEXT LINE REPRESENTS THE FIRST CARD IN THE SAMPLE DATA DECK ********
  623   83      75.00      16.4       25
FIRST SAMPLE MLE PROBLEM, USING SIMULATED DATA.
(10F8.2)
  288.47   77.25  122.25  182.33  107.35  127.32  343.47  130.57  109.87  153.01
  148.67   75.55  182.10  143.48   82.74  170.15  114.48   90.73  400.21  159.46
  120.44   75.10   95.86   75.01   91.35  303.38  472.59  182.12  237.54  116.77
   76.63   79.54  120.61  170.86   86.18  287.23   98.48  830.67   96.72  165.74
  120.98   83.96   76.10  202.32   76.62  184.75  239.01   86.58   93.15  177.32
   78.73   86.36  102.89   76.37   97.57   76.67  826.00  122.68   85.93   84.88
   77.39   79.49  129.21  103.12  177.61  165.14   92.45  272.71  146.80   95.72
  112.50  151.96   76.75  108.82  217.59   76.91   77.48  127.88  461.65  101.57
  647.01   80.48   96.82
  384   87      75.00      17.3       50
SECOND SAMPLE MLE PROBLEM.
(10F8.2)
   84.93  194.89   75.59  165.72  112.73  112.75  106.85   86.89  282.09  102.57
  242.26  119.49  311.69  230.48  227.41  137.90  226.35  172.35  361.29  157.33
  198.04  184.32  255.52  389.45  155.39  134.67   76.18   84.74   89.97  113.64
  305.30  257.57  976.33  143.85  110.06   75.37   95.99  207.16  119.42   90.92
  136.95   99.36   79.78  817.04   85.70  545.94  201.22   86.10  225.87   80.12
  146.51  148.94  256.23   98.47  159.76  220.05   75.03  379.68   84.01   94.99
   83.71  842.42  137.76  159.14  109.63  109.52  165.69  155.14  187.71  660.35
  206.42  281.19 1134.06  184.54  101.15  106.40  113.17   97.79  156.67 1098.94
  115.64  136.75  720.15  101.95  180.02  198.13  114.35

***** THE PREVIOUS LINE REPRESENTED THE LAST CARD IN THE SAMPLE DATA DECK ******
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Figure 4.--*Sample input data cards for two maximum likelihood estimation problem analyses.*

MAXIMUM LIKELIHOOD ESTIMATION PROGRAM

PROGRAM DATA REQUIREMENTS

For the MLE program, all drops on a known area are counted. The diameter of the K largest drops are measured, and the diameter of the smallest of these drops designated as DMIN. The diameter measurements should be accurate to ± 0.1 percent of DMIN. This method of collecting data may be less costly than that for the MCS method, given the same reliability of results. Thus the superiority of one method over the other can only be determined relative to cost of data collection. With the MLE method, however, the validity of the log-normal distribution assumption may be verified by tests of fit only for drops of diameter DMIN or greater.

The program will handle problems for which K, the number of measured drops, is < 1500. The precision of the estimates decreases as K decreases. For this reason, K < 30 is to be discouraged. The limit on the total number of drops observed, N, is K < N < 99,999. Any number of problems may be processed in a computer run.

DATA CARD PREPARATION

Four types of data cards are required by the MLE program. Each type is described, in order of appearance in the data deck, for a single problem.

Card type 1 has the total number of drops, N, observed in the sample in columns 1-5. The number of drops measured, K, which must be <1500, is punched in columns 6-10. DMIN, the diameter of the smallest drop measured, is punched in columns 11-20; AREA, the area on which the sample is taken, is punched in columns 21-30 and must be greater than zero; DELT, the length of the intervals for which predicted and observed frequencies and volumes are printed is punched in columns 31-40 (see item (6) in fig. 2). If no decimal is punched in the fields containing DMIN, AREA, and DELT, it is assumed to follow the digit in the last column of the field, The intervals for which predictions are made break at DMIN and are collapsed before printing so that no interval contains less than 10 drops. The chi-square fit test is based on the printed frequencies (except that the predicted frequencies are not rounded to the nearest whole number).

Card type 2 holds, in columns 1-72, the alphanumeric title information printed on each page of problem results (see item (1) in fig. 2).

Card type 3 records the alphanumeric format specification for drop diameter measurements punched in card type 4. A simple form of the specification is (nFw.d); n is the number of diameters appearing on each card type 4, and w is the number of columns in each field of the card for n successive fields. The last d columns in each field are assumed to follow the decimal point unless it is punched in the data read according to the format. Since there are only 80 columns in a card, n times w should be less than 80. Also, d must be less than or equal w. The parentheses, F, and the decimal point are punched literally. Sample data are shown in figure 4. Or for more sophisticated format specifications, see a Fortran programing manual.

Card type 4 includes the diameters of the K measured drops, punched consecutively in any order according to the format specification in card type 3, for as many cards as required. The card after the last card type 4 must be either card type 1 for a succeeding problem, or two blank cards signaling the end of a computer run. Figures 3 and 4 illustrate sample sets of data cards for a computer run containing two problems. Figure 2 shows the results of the first problem.

Source decks for MCS and MLE programs are available as inter-library loan, from: Computer Services Librarian, Pacific Southwest Forest and Range Experiment Station, P.O. Box 245, Berkeley, California 94701.

The Author

GERALD S. WALTON has been a digital computer programer on the Station's insecticide evaluation research staff since 1966. He was born in Leadville, Colo., received a B.A. degree in mathematics (1960) at the University of California, and a M.F.S. degree (1965) from Harvard University.

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