Comparison of Spray Droplet Size, Pesticide Deposition, and Drift with Ultralow-Volume, Low-Volume, and Dilute Pesticide Application on Apple

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ABSTRACT

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Fifteen-year-old trees of four apple cultivars were sprayed at rates of 9.4 L/ha (1 gal/A) for ultralow-volume (ULV) pesticide treatment, 190 L/ha (20 gal/A) for low-volume (LV) treatment, and 1,900 L/ha (200 gal/A) for dilute treatment. Thirteen sprays were applied, the first five following bud phenology and the rest as cover sprays. Fungicide deposits were monitored biologically with *Penicillium variabile*, and insecticide deposits were monitored analytically with high-pressure liquid chromatography. The ULV technique deposited at least as much pesticide on leaves as the other techniques, with less drift. Differences among arithmetic means at 2 and 4 m of the mass median and numerical mean diameters of spray droplets were 64.5 and 42.7 μm for ULV, 248 and 96.1 μm for LV, and 333 and 146.9 μm for dilute treatments. All treatments controlled *Venturia inaequalis* and *Aphis pomi* equally well at economically acceptable levels.

Ultralow-volume (ULV) pesticide spraying is the generation and distribution of small, evenly sized pesticide droplets on plant foliage (2). By contrast, in the dilute method of applying pesticides, the foliage is drenched until runoff occurs. Low-volume (LV) or concentrate spraying, a modification of the dilute technique, is the application of pesticides to cover the foliage without runoff (5,8). Dilute spraying ranges from about 1,870 to 5,610 L/ha (200–600 gal/A); low-volume spraying ranges between 93 and 935 L/ha (10–100 gal/A); and ULV spraying is generally considered less than 47 L/ha (5 gal/A), varying with planting scheme.

Although ULV rates have been demonstrated to give satisfactory control of insects and diseases on fruit trees (9,10), the effectiveness of the ULV pesticide application technique compared with the commercial standard LV and dilute techniques is still questioned. This study was undertaken to evaluate the performance of the three techniques in controlling apple scab, caused by *Venturia inaequalis* (Cke.) Wint., and green apple aphids, *Aphis pomi* DeGeer, on four apple (*Malus sylvestris* Mill.) cultivars in a seasonal program. We compared spray equipment, formulations and concentrations of pesticides, initial and residual pesticide deposits, drift, droplet sizes, and insect and disease control.

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MATERIALS AND METHODS

Orchard design. The orchard, located at Beltsville, MD, consisted of 56 plots, each containing one tree of each of the apple cultivars Delicious, Golden Delicious, McIntosh, and Jonathan. The trees were budded onto M7 rootstocks and were about 4 m tall. A uniform dormant oil spray was initially applied to the orchard to control European mites and scale insects.

Four pesticide treatments were applied, with three replicates per treatment randomized in a split-plot design. One unsprayed buffer block separated each replicate in the row to reduce the effects of drift and to serve as a disease reservoir and control. Thirteen sprays were applied in 1979: one at each of delayed dormant, tight cluster, open cluster, bloom, and petal fall stages and eight cover sprays at 7- to 14-day intervals.

Equipment. A modified 3P-50 Pony Kinkelder sprayer (DeKinkelder, Zevenaar, The Netherlands) was used to apply the ULV treatments. The Pony is driven by power take-off and generates 1.8 m^3 of air per second at a velocity of 89 m/sec. Modifications included replacing the original 190-L tank with a 10-L stainless steel tank and replacing the original pump with a variable-speed transmission (Graham Series 20; Graham Transmissions Co., Menomonee Falls, WI 53051) and peristaltic rotor pump (Randolph Model 500; The Randolph Co., Houston, TX 77019) for precise metering of pesticides. Flow of liquid to the nozzles was controlled by a three-way valve (Imperial no. 108-HD; Gould Inc., Valve & Fittings Div., Chicago, IL 60648), so that when not being sprayed, the liquid was recirculated to agitate the material in the tank. The Pony was calibrated before every treatment to apply 9.4 L/ha (1 gal/A).

A Kinkelder Royal concentrate sprayer was used for LV applications. The Royal has two air outlets at the rear, each containing six vacuum-jet atomizers, and is driven by power take-off at 540 rpm, which propels the fan and circulation pump. The Royal emits about 7 m^3/sec of air at 49.2 m/sec velocity. Both the Royal and the Pony sprayer use a triangular wedge that shears the pesticide material along an edge into a high-velocity airstream (11). The Royal was calibrated to apply 190 L/ha (20 gal/A) at 9.57 L/min.

A John Bean Speed Sprayer model 495CP (FMC Corporation, Agricultural Machinery Division, Jonesboro, AR 72401) was used for dilute pesticide applications. This sprayer emits about 33 m^3/sec of air at 31 m/sec and uses hydraulic, high-pressure, hollow-cone nozzles located in the airstream to break up and disperse the spray material. The sprayer was calibrated to apply 1,900 L/ha (200 gal/A) at 95.7 L/min.

Pesticides. Four treatments were applied to the orchard during the 1979 growing season. The 1979 West Virginia Spray Bulletin for Commercial Tree Fruit Growers (1) was used as the standard reference for the recommended concentrate and dilute pesticide rates. Equivalent pesticide rates were used with three different sprayers in order to compare application techniques.

The full recommended dilute rate for all pesticides used was applied at 1,900

L/ha with the dilute sprayer. The full rate of pesticide concentrate was applied with both the LV sprayer at 190 L/ha and the ULV sprayer calibrated at 9.4 L/ha. For the fourth treatment, pesticide concentrate was applied at 75% of the ULV rate at 9.4 L/ha.

The following fungicides were used in the trials: benomyl, glyodin, coordination product of zinc ion and manganese ethylene bisdithiocarbamate (Dithane M-45, 80% W), and a mixture of streptomycin and oxytetracycline (Agri-Strep 19 WP). Azinphos-methyl, cyhexatin, and phosalone insecticides were used. Triton B-1956 was used as a surfactant for the dilute treatment, Triton CS-7 for the LV and ULV treatments.

Fungicide bioassay. Foliage from treated Golden Delicious trees was assayed microbiologically for initial and residual fungicidal activity of benomyl by a leaf disk method with *Penicillium variabile* Sopp (Poland strain no. 2) as the assay organism, as adapted from Bera (4). Leaf disks (8.0 mm in diameter) were cut from either side of the leaf midvein with a cork borer and placed on spore-seeded potato-dextrose agar. Samples were taken on four different dates, two immediately after spraying (13 and 29 June) and two 1 wk later (20 June and 5 July). Leaf samples were taken at random from the east and west sides of Golden Delicious trees, and the lower leaf surfaces were exposed to the agar. Ten leaf disks were used per replicate, for a total of 30 leaf disks per treatment. Inhibition zones surrrounding leaf disks were measured after a 48-hr incubation.

Serial aqueous dilutions of benomyl (10, 7.5, 5, 2.5, and 1 mg of active ingredient per liter) were assayed with *P. variabile* for fungicidal activity by a paper disk method and were included with each leaf disk assay to measure residual amounts of fungicide. Analysis of variance and Duncan's multiple range test were performed on all measurements.

Insecticide analytical assay. High-pressure liquid chromatography (HPLC) was used to analytically determine initial and residual concentrations of azinphos-methyl and phosalone insecticides deposited on the foliage by the three application techniques. Thirty leaves per treatment were collected randomly from treated trees twice immediately after spraying (26 July and 20 August) and once 1 wk after spraying (2 August). Leaves were put in 2-L glass jars with 200 ml of methanol and water (1:1) solvent. The jars were shaken by hand for 30 sec to remove insecticide deposits from the foliage. A 10-ml aliquot of the solvent was then filtered and injected into the chromatograph.

Samples of technical grade azinphos-methyl and phosalone were diluted to 10 and 20 μg/ml and injected into the chromatograph before and after leaf extracts were injected to serve as reference concentrations.

Insecticide drift. HPLC was also used to monitor the azinphos-methyl and phosalone drift associated with the three application techniques. A wooden frame 3 m tall was constructed with a wide screen across the center. Four paper towels (each 27.9 cm^2) were hung on the screen, and the frame was positioned to face representative trees in the row along which the sprayer would pass. Pesticide that was not deposited on the foliage and that was blown through the tree canopy adhered to the paper towels.

Drift was measured twice (27 July and 17 August) for each treatment. The towels were removed from the screen and placed separately in 1-L jars. Solvent, 200 ml of methanol and water (1:1), was added, and the jars were shaken by hand for 20 sec to remove the insecticide. Ten milliliters of the rinse solvent was then filtered and injected into the chromatograph. Standards of azinphos-methyl and phosalone at 20 μg/ml were also injected to serve as reference concentrations.

Droplet size. An optical array spectrometer probe (model OAP-200X) and particle data system (model PDS-100) (both by Particle Measuring Systems, Inc., Boulder, CO) were used to measure in situ droplets emitted from the three sprayers. Benomyl (225 g) and glyodin (1,500 ml) were added to 3.7, 76, and 760 L of water in the ULV, LV, and dilute sprayers, respectively. Droplets were measured 2 and 4 m from the sprayer nozzles, with the spectrometer probe 1 m from ground level.

Insect and disease control. Incidence and severity of *A. pomi* and *V. inaequalis* were monitored to compare pest control obtained with the three pesticide application techniques. Aphid populations were determined on five randomly selected terminal shoots of Golden Delicious per replicate. Three measures of apple scab severity were recorded. Primary foliar scab was measured by counting the number of scab lesions per rosette cluster on 10 randomly selected rosettes per tree, one tree per replicate. Secondary foliar scab was measured by randomly selecting 50 leaves per tree per replicate of all four cultivars. And scab that developed on the fruit was monitored by recording the number of infected McIntosh fruit in 100 randomly selected fruit per tree replicate. Untreated control trees were included in all counts.

RESULTS

Fungicide bioassay. The fungicide bioassay showed that more benomyl was deposited on the foliage of Golden Delicious trees at the full rate both initially and residually with the ULV method than with either the LV or the dilute application method (Fig. 1 and Table 1). At the 75% ULV pesticide rate, deposits were greater than or equal to LV and dilute benomyl deposits. Deposits from the LV and dilute application techniques were not significantly different (5% level) either immediately after application or 1 wk later.

Insecticide residues. HPLC foliage residue analysis showed that the full ULV rate deposited more azinphos-methyl and phosalone on the foliage than any other treatment (Table 2). The LV treatment deposited the next highest concentration, followed by the 75% ULV reduction treatment. The dilute treatment deposited the least pesticide on the foliage, although it did not appear to differ significantly from the 75% ULV treatment. Pesticide runoff was observed in the field only on trees sprayed with the dilute application

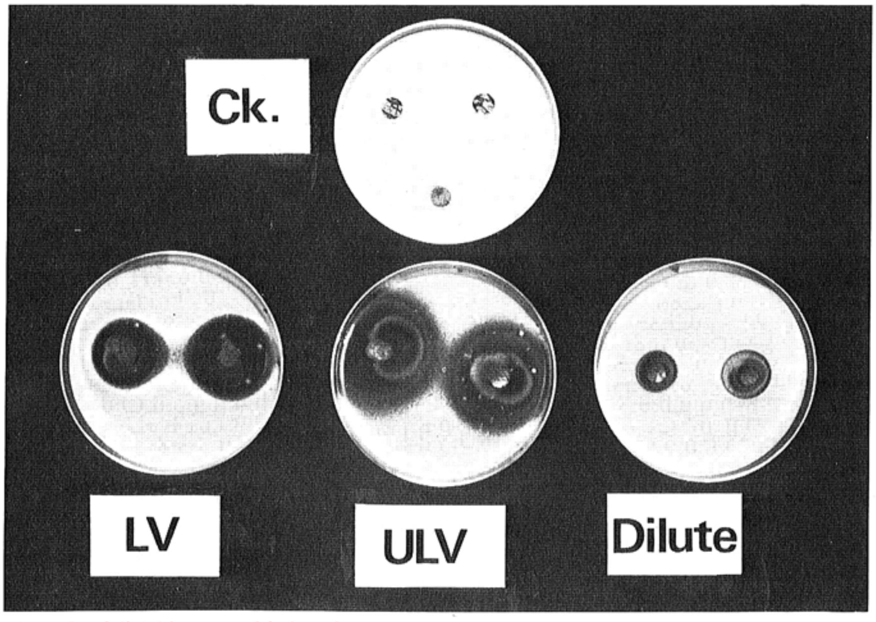

Fig. 1. Leaf disk bioassay of foliage from trees treated with benomyl at ultralow-volume (ULV), low-volume (LV), dilute, and control rates, showing zones of growth inhibition. *Penicillium variabile* was used as the indicator organism.

treatment, which may partially account for the comparatively low concentrations of pesticide deposited on the foliage of these trees. There were no clear indications that pesticide residues present on leaf samples taken immediately after pesticide application were greater than those on samples taken 1 wk later.

Insecticide drift. Significantly less (about 90%) drift of azinphos-methyl and phosalone was detected at the full ULV rate of application than with the other two treatments (Table 3). No significant differences were found between the LV and dilute techniques in pesticide drift.

Droplet size. Both the mass median diameter (MMD), which represents the intercept at 50% of the cumulative volume curve of the droplets, and the numerical mean diameter (NMD) were measured (Table 4). Differences among arithmetic means of the diameters of droplets at 2 and 4 m were significant (5% level) for each sprayer.

Both the MMD and the NMD of the droplets were significantly different at the 5% level among the three sprayers (Table 4). The ULV sprayer generated the smallest droplets, with a much narrower range of sizes than the other sprayers (Fig. 2 and Table 4). The LV sprayer produced the widest range (18–500 μm) of droplet sizes of the three sprayers. Even though the ULV and LV sprayers use the same vacuum-jet atomizer, the droplet size range was increased as more pesticide passed through the nozzle.

Aphid control. All treatments controlled the green apple aphid. Although differences in the degree of control obtained were not significant, the lowest aphid count (13.3 per terminal shoot) was obtained with the full ULV treatment, compared with 37.7, 26.7, and 26 aphids per terminal for the 75% ULV, LV, and dilute treatments, respectively. Aphids on untreated terminals were too numerous to count when measured on June 1.

Primary apple scab. McIntosh was the most susceptible to apple scab of the four cultivars. Dilute application controlled primary apple scab significantly better than the full ULV application rate (Table 5). No significant (5% level) differences in number of lesions were observed between the LV and dilute treatments or between the LV and either ULV treatment. All treatments were significantly different from the unsprayed check.

Secondary scab. The full ULV treatment controlled secondary foliar scab on McIntosh significantly better than the LV treatment (Table 5). Control of secondary scab lesions with the 75% ULV rate did not differ significantly from either LV or dilute rates.

Secondary scab on Delicious and Golden Delicious leaves was controlled best by the 75% ULV rate (data not shown). On Delicious leaves, the LV treatment controlled scab better than the full ULV rate treatment. In general, however, the full ULV treatment gave best control of secondary scab for all cultivars, followed by the dilute treatment (which gave the best control of both primary and fruit infections), the 75% ULV, and the LV treatments.

Fruit scab. The four treatments did not differ significantly in controlling apple scab affecting the fruit of McIntosh trees (Table 5). Sixty-five percent of fruit on unsprayed trees was infected, indicating a high level of inoculum caused by

Table 1. Zones of inhibition from leaf disk bioassay of foliage of Golden Delicious trees sprayed with benomyl, with *Penicillium variabile* (Poland strain no. 2) as the indicator organism[x]

Application rate (L/ha)	Sampling date			
	13 June		29 June	
	Initial[y]	Residual[z]	Initial[y]	Residual[z]
9.4 (75% ULV)	16.0 b	11.87 b	12.27 b	12.10 ab
9.4 (ULV)	16.7 b	13.43 c	13.07 b	15.00 b
190 (LV)	10.87 a	10.37 a	10.47 ab	8.03 ab
1,900 (dilute)	13.40 ab	10.47 a	6.93 a	6.90 a

[x] Each figure represents the diameter of the inhibition zone (measured in millimeters). Within each column, values followed by the same letter are not significantly different at the 5% level, according to Duncan's multiple range test.

[y] Initial bioassay performed immediately after spraying on each date.

[z] Residual bioassay performed 1 wk after spraying on each date.

Table 2. Initial and residual deposits of azinphos-methyl (A) and phosalone (P) on foliage, as monitored with high-pressure liquid chromatography (HPLC)[a]

Application rate (L/ha)	Sampling date[b]					
	26 July		20 August		2 August	
	A	P	A	P	A	P
9.4 (75% ULV)	12.0	9.2	10.0	6.8	6.9	9.9
9.4 (ULV)	21.5	14.2	16.6	9.5	9.8	15.7
190 (LV)	9.8	7.9	15.5	9.6	10.1	15.9
1,900 (dilute)	9.3	6.0	13.5	8.4	5.1	5.6

[a] Figures represent HPLC peak heights, measured in centimeters.

[b] Samples of 30 leaves each were taken twice immediately after pesticide application to measure initial deposits (26 July and 20 August) and once 1 wk after application to measure residual deposits (2 August).

Table 3. Drift of azinphos-methyl (A) and phosalone (P) from ultralow-volume (ULV), low-volume (LV), and dilute sprayers, as monitored with high-pressure liquid chromatography (HPLC)[y]

Application rate (L/ha)	Sampling date					
	27 July		17 August		Mean[z]	
	A	P	A	P	A	P
9.4 (ULV)	0.65	1.05	0.47	0.55	0.56 a	0.80 a
190 (LV)	4.42	4.57	2.60	1.60	3.51 b	3.09 b
1,900 (dilute)	4.32	3.50	2.40	1.67	3.36 b	2.59 b

[y] Each figure represents the mean amount of pesticide deposited on four paper towels, as measured in centimeters from HPLC peaks.

[z] Means in each column not followed by the same letter are significantly different at the 5% level, according to Duncan's multiple range test.

Table 4. Sizes of droplets emitted by ultralow-volume (ULV), low-volume (LV), and dilute sprayers[w]

Sprayer	MMD[x] (μm)			NMD[y] (μm)		
	2 m	4 m	Mean[z]	2 m	4 m	Mean[z]
ULV	65	64	64.5 a	43.7	41.8	42.7 a
LV	248	248	248 b	119.5	72.7	96.1 b
Dilute	325	341	333 c	147.9	146	146.9 c

[w] All measurements in micrometers. Fungicide combinations of 225 g of benomyl and 1,500 ml of glyodin per 3.7, 76, and 760 L of water for ULV, LV, and dilute sprayers, respectively, were used.

[x] Mass median diameter (50% intercept of cumulative volume curve) of droplets measured 2 and 4 m from nozzle of sprayer.

[y] Numerical mean diameter measured in situ 2 and 4 m from nozzle of sprayer with an optical array spectrometer.

[z] Means in a column not followed by the same letter are significantly different at the 5% level, according to Duncan's multiple range test.

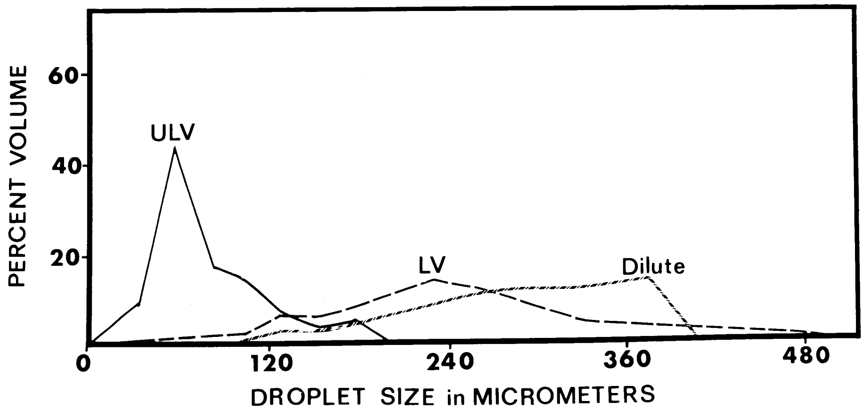

Fig. 2. Cumulative volume curves for droplets emitted by ultralow-volume (ULV), low-volume (LV), and dilute sprayers.

Table 5. Primary, secondary, and fruit apple scab lesions on McIntosh apple trees

Application rate (L/ha)	Number of lesions[w]		
	Primary[x]	Secondary[y]	Fruit[z]
9.4 (75% ULV)	6.67 b	10.00 ab	5.00 a
9.4 (ULV)	5.33 b	7.33 a	3.33 a
190 (LV)	4.67 ab	14.33 b	8.33 a
1,900 (dilute)	2.67 a	12.66 ab	2.33 a
Control	19.33 c	42.66 c	65.00 b

[w] Numbers in each column not followed by the same letter are significantly different at the 5% level, according to Duncan's multiple range test.
[x] Figures represent the number of scab lesions on 10 rosettes per tree (one tree per replicate), counted 8 July 1979.
[y] Figures represent the number of scab lesions on 50 leaves per replicate (three replicates per treatment), counted 24 August.
[z] Figures represent the number of scab lesions on 100 fruit per replicate (three replicates per treatment), counted 23 August.

numerous early wetting and infection periods in the 1979 season.

DISCUSSION

Pesticide residues monitored both biologically and analytically were often greater on foliage sprayed at full or reduced ULV rates than at conventional LV or dilute rates, although deposits varied. This variability may be the result of monitoring methods or techniques more than actual differences among spray systems. HPLC showed that significantly less pesticide drifted through the tree canopy with the ULV machine than with either the LV or dilute sprayers. Hall et al (6), working with sprayers delivering 235 and 1,400 L/ha, also found that concentrate LV techniques deposited more insecticide on apple foliage than dilute application.

Measurements taken with an optical array spectrometer showed that the ULV sprayer emitted droplets with significantly smaller NMD and MMD and with a much narrower size range than either LV or dilute sprayers. Droplet sizes of the ULV sprayer were not significantly different at 2 and 4 m, indicating that size was not a function of distance, which agrees with previous findings (10).

The three sprayers controlled green apple aphids equally well. These results are similar to those obtained by Howitt et al (9) regarding the control of blueberry maggots, apple maggots, and codling moths at ULV rates with malathion applied with double-orifice spinning cage nozzles.

The ULV technique at both full and 75% rates controlled foliar and fruit scab as well as but not significantly better overall than the LV and dilute application methods; all three gave economically acceptable control. Hall et al (7) compared dilute spray rates with up to 33 times concentrate rates and found equal control of aphids, mites, and apple scab at all rates. Howitt et al (9) controlled apple scab at ULV rates with a glyodin-dodine combination, again using spinning cage nozzles. Keil et al (10) obtained satisfactory control of apple scab, powdery mildew, and cedar-apple rust on apple with fungicide combinations at 14 L/ha.

Bals (3) called the ULV pesticide application technique controlled droplet application. The efficacy and success of the ULV techniques in controlling diseases and insects depend on the ability of the spray equipment to generate small, uniformly sized droplets and distribute them evenly on the foliar surface. Smaller droplets have been shown to weather and break down more slowly than larger droplets, and the chemical is redistributed better when foliage is rewetted, such as in early morning dews (5). In this study, however, pesticide breakdown after 1 wk did not unequivocally support this generality.

We found that the ULV technique deposited at least as much pesticide on the foliage of apple trees as standard techniques, and less of the chemicals was blown through the tree canopy. The ULV technique required less water and pesticide, and runoff was eliminated. *A. pomi* and *V. inaequalis* were controlled as well at full and 75% ULV pesticide rates as at standard LV and dilute application rates. Pesticide effectiveness may be interpreted to have increased if less pesticide must be used to obtain the same results as LV and dilute methods. ULV application techniques thus can reduce energy and pesticide requirements in the chemical protection of food and fiber crops, while increasing pesticide efficacy.

LITERATURE CITED

1. Anonymous. 1979. West Virginia spray bulletin for commercial tree fruit growers. Circ. 436. W. Va. Univ., Morgantown. 35 pp.
2. Bals, E. J. 1970. Ultra-low volume and ultra-low dosage spraying. Cotton Grow. Rev. 47:217-221.
3. Bals, E. J. 1975. The importance of controlled droplet application (CDA) in pesticide applications. Pages 153-160 in: Proc. Br. Insectic. Fungic. Conf., 8th.
4. Bera, B. E. 1975. The use of biological tests in the evaluation of the usefulness of various techniques of spraying apple orchards with fungicides. Research Institute of Pomology, Skierniewice, Poland. USDA PL-ARS-45. 59 pp.
5. Fulton, R. H. 1965. Low-volume spraying. Annu. Rev. Phytopathol. 3:175-196.
6. Hall, F. R., Forsythe, H. Y., Jones, B. M., Reichard, D. L., and Fox, R. D. 1975. Comparison of orchard sprayers for insect and disease control on apples, 1966-1969. Ohio Agric. Res. Dev. Cent. Res. Bull. 1078. 23 pp.
7. Hall, F. R., Reichard, D. L., and Krueger, H. R. 1975. Dislodgeable azinphosmethyl residues from airblast spraying of apple foliage in Ohio. Arch. Environ. Contam. Toxicol. 3:352-363.
8. Hough, W. S., and Mason, A. F. 1951. Spraying, Dusting and Fumigating of Plants. The Macmillan Co., New York. 726 pp.
9. Howitt, A. J., Klos, E. J., Corbett, P., and Pshea, A. 1966. Aerial and ground ultra low volume applications in the control of diseases and pests attacking deciduous fruits. Mich. Agric. Exp. Stn. Q. Bull. 49:90-102.
10. Keil, H. L., Retzer, H. J., Barrat, R. E., and Maas, J. L. 1980. Ultralow-volume spray control of three apple diseases. Plant Dis. 64:681-684.
11. Reichard, D. L., Retzer, H. J., Liljedahl, L. A., and Hall, F. R. 1977. Spray droplet size distributions delivered by air blast orchard sprayers. Trans. Am. Soc. Agric. Eng. 20:232-237, 242.