Ultralow-Volume Spray Control of Three Apple Diseases

H. L. KEIL, Plant Pathologist, Fruit Laboratory, and H. J. RETZER, Agricultural Engineer, Agricultural Equipment Laboratory, AR-SEA, USDA, Beltsville, MD 20705; R. E. BARRAT, Graduate Student, Department of Plant Pathology, West Virginia University, Morgantown 26506; and J. L. MAAS, Plant Pathologist, Fruit Laboratory, AR-SEA, USDA, Beltsville, MD 20705

ABSTRACT

KEIL, H. L., H. J. RETZER, R. E. BARRAT, and J. L. MAAS. Ultralow-volume spray control of three apple diseases. Plant Disease 64:681-684.

Ultralow-volume (ULV) application of fungicides satisfactorily controlled *Venturia inequalis, Podosphaera leucotricha,* and *Gymnosporangium juniperi-virginianae*. Fungicides were applied with a modified Kinkelder model 3P-50 Pony sprayer at ultralow-volumes on four varieties of full-size apple trees in a seasonal program. Droplet size emitted by the Kinkelder averaged 20 μm. Rates averaged 14 L/ha. No clogging occurred when vacuum jet atomizers were used with combinations of wettable powder and emulsifiable fungicides. A leaf disk bioassay was performed with *Penicillium variabile* as the detector organism to monitor levels of initial and residual benomyl deposits on apple foliage. Concentrations of benomyl were highest on lower leaf surfaces closest to the sprayer and lowest in the tree interior. An average 50% activity of benomyl was lost 1 wk after application to foliage.

The definition of ultralow-volume (ULV) spraying differs. Maas (7) defined ULV as less than 5 L/ha, whereas Bals (1) considered ULV application between 1 and 8 L/ha. Howitt et al (5) defined it as applying the technical liquid or emulsion directly without dilution. All agree, however, that spraying at ULVs depends on whether the equipment can emit uniformly sized droplets and distribute them evenly on the plant surface. Optimum droplet size for control of insects (4,10) and diseases (1,2) is less than 150 μm and probably between 20 and 70 μm. Apple scab and cherry leaf spot have previously been controlled with undiluted liquid fungicides at ULV rates applied with spinning cage nozzles (6).

This study was undertaken to determine if apple scab, powdery mildew, and cedar-apple rust, caused by *Venturia inequalis* (Cke.) Wint., *Podosphaera leucotricha* (Ell. & Ev.) Salm., and *Gymnosporangium juniperi-virginianae* Schw., respectively, could be controlled on four cultivars of apple (*Malus sylvestris* Mill.) in a seasonal program at ULV rates. Formulations and concentrations of pesticides, initial and residual fungicide deposits, droplet sizes, and disease control recordings are reported.

H. L. Keil died before this paper was submitted for publication. This article is the culmination of 8 years of preliminary work by Keil on ultralow-volume control of apple diseases.

This paper reports the results of research involving fungicides and does not contain recommendations for their use or imply that the uses discussed have been registered. All uses of fungicides must be registered by appropriate state or federal agencies before they can be recommended.

Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the USDA and does not imply its approval to the exclusion of other products that may also be suitable.

MATERIALS AND METHODS

Pesticides. The fungicides used in these trials were: benomyl (Benlate 50 WP), dodine 65% WP, captan 50 WP, chlorothalonil (Bravo 6F), glyodin 30% S, and streptomycin sulfate (Agri-Strep 17 WP).

Equipment. A modified 3P-50 Pony Kinkelder sprayer (DeKinkelder, Zevenaar, The Netherlands) was used to apply the fungicides. Desirable features were the sprayer's small size, its three-point hitch mounting, and the insensitivity of the vacuum-jet atomizers to wettable powder spray materials. The sprayer is power take-off (PTO) driven and generates a wind velocity of 314 km/hr at 1.8 m^3/sec at 540 PTO rpm.

Modifications were made because the sprayer is designed to apply more than 225 L/hr. We removed the original spray tank and pump and replaced them with a 10-L stainless steel tank and recirculating pump (Fig. 1). The original tank was too large to be practical for such low volumes, since the pump bypassed so much liquid that it caused excessive foaming. A small 12 Vdc impeller bilge pump was installed to prevent settling of the solids in the spray suspensions. The viscosity of the concentrated fungicide suspension required pressurizing the spray tank to 11 psi with CO_2 to dissolve the liquid. Flow of the fungicide was controlled through the line with a 12 Vdc electric pinch valve and a micrometer-adjustable metering valve. The sprayer was calibrated to 14 L/ha (1.5 gpa) before spraying each treatment, and the fungicide remaining in the tank after spraying was measured to determine the amount applied.

Orchard design. The orchard of Mills cultivars at the Fruit Laboratory at Beltsville, MD, was used for the fungicide trials. The orchard consisted of 56 plots of four trees of each of the cultivars Delicious, Golden Delicious, McIntosh, and Jonathan.

The trees are grown on M7 rootstocks and are semidwarf (about 4 m high) in rows oriented north and south. There were 12 plots per replicate and three replicates per treatment, including an unsprayed check. One unsprayed buffer plot separated each replicate in the row to reduce the effects of drift. Twelve sprays were applied in 1978, at prepink, pink, and petal fall, and nine cover sprays were applied at 7- to 14-day intervals. Insects were controlled with a dormant oil spray followed by uniform insecticide applications at dilute rates throughout the season.

Foliar disease was evaluated by selecting 100 leaves randomly from each

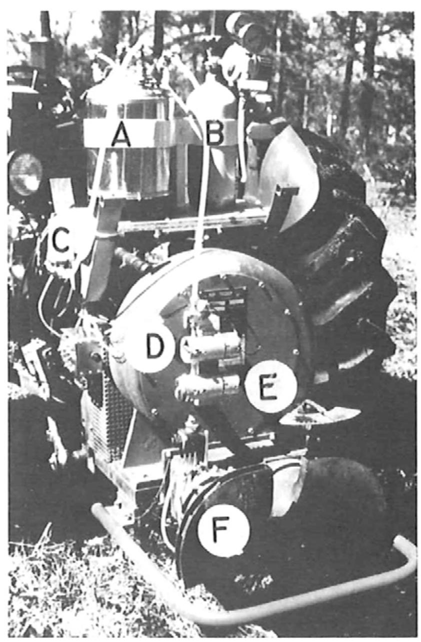

Fig. 1. Modified Kinkelder 3P-50 Pony ultralow-volume sprayer: **(A)** Pesticide tank. **(B)** Compressed CO_2 tank with pressure regulator and gauges. **(C)** Recirculating pump. **(D)** On/off electric pinch valve. **(E)** Metering valve. **(F)** Vacuum jet atomizers (four).

tree in each replicate and scoring for the presence of apple scab, powdery mildew, and cedar-apple rust. Apple scab was also evaluated by randomly selecting and scoring 50 fruits from each McIntosh tree in each replicate.

Bioassay. Foliage from the orchard was bioassayed 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 (11). Leaf disks, 8.0-mm diameter, were cut from either side of the leaf midvein with a cork borer and placed on spore-seeded potato dextrose agar. McIntosh and Delicious trees were sampled at six different dates, three immediately after spraying (18 and 31 July and 16 August).

Leaf samples were taken randomly from the north, south, east, and west sides of trees at heights of 1.2, 2.4, and 3.7 m and from the tree interior. Inhibition zones surrounding leaf disks were measured after a 48-hr incubation at 22–24 C. Inhibition zones from both upper and lower leaf surfaces were recorded.

Serial dilutions of benomyl were assayed for fungicidal activity by the cylinder plate method with *P. variabile* also as the assay organism (3). Standard aqueous solutions of benomyl containing 10, 7.5, 5, 2.5, and 1 mg/L a.i. were included in each assay. Six assays were performed, three on the same day that fungicides were applied and the other three a week after each application, to determine residual amounts of fungicide.

Droplet measurements. A Model OAP-200X optical array spectrometer probe and Model PDS-100 particle data system (Particle Measuring Systems, Inc., Boulder, CO) were used to measure in situ particle sizes emitted from the modified sprayer (9). Droplet sizes of water as well as actual formulations of fungicides used in the field were measured with the spectrometer. Measurements were taken 1.5, 3.0, 4.6, and 6.1 m from the spray nozzle, at a constant height of 1 m.

RESULTS

Equipment. Formulations and amounts of chemicals applied at the rate of 14 L/ha are given in Table 1. Because of variability of pesticide viscosity caused by temperature as well as the metering system, the quantity of pesticide applied varied. The machine was calibrated for 14

Table 1. Fungicide treatments (14 L/ha) of apple trees during 1978 at Beltsville, MD

	Date and amount of fungicide applied (liters)												
	April			May			June			July		August	
	13	20	22	9	17	25	2	12	26	10	24	8	
				Cover sprays									
Formulation	Pre-pink	Pink	Petal fall	1	2	3	4	5	6	7	8	9	Mean[a]
1. Benomyl (340.5 g), glyodin (473 ml), streptomycin (454 g), water (3.40 L)	20.5	12.1	15.4	13.2	13.2	13.8	7.9	10.8	11.9	10.5	6.9	13.7	12.4
2. Captan (1.36 kg), glyodin (473 ml), streptomycin (454 g), water (3.40 L)	35.5	15.8	19.6	13.6	14.0	15.1	13.1	11.2	12.9	18.2	16.8	12.3	16.5
3. Dodine (454 g), glyodin (473 ml), streptomycin (454 g), water (4.3 L)	20.2	10.3	14.6										
followed by: chlorothalonil (1.05 L), glyodin (473 ml), streptomycin (454 g), water (4.3 L)				13.9	9.7	11.7	14.5	10.3	10.6	20.4	9.5	12.2	13.2
4. Unsprayed check													

[a] Means were not significantly different at $P = 0.05$ according to Duncan's multiple range test.

Table 2. Sizes of droplets emitted by an ultralow-volume sprayer, measured in situ at four distances

	Droplet size (μm)[x] at distance (m):									
	1.5		3		4.6		6.1		Mean[y]	
Formulation	MMD	NMD	MMD	NMD	MMD	NMD	MMD	NMD	MMD	NMD
Fenarimol (360 ml),[z] water (4.4 L)	22	13.4	19	11.1	20	10.7	19	9.9	20 b	11.3 b
Thiophanate (454 g),[z] water (4.3 L)	19	11.6	21	12.4	21	10.8	21	10.3	20 b	11.3 b
Captan (1,362 g),[z] water (4.3 L)	18	10.4	18	10.2	18	9.9	16	9.9	18 c	10.1 b
Water	23	17.6	23	16.1	24	17.6	24	17.9	24 a	17.3 a

[x] MMD = mass median diameter, 50% intercept of cumulative volume curve; NMD = numerical mean diameter.
[y] In each class (MMD and NMD), means followed by the same letter are not significantly different at $P = 0.05$, according to Duncan's multiple range test.
[z] Plus streptomycin (454 g) and glyodin (473 ml).

L/ha before spraying each treatment. Equipment problems included failure of the impeller pump on the recirculating system in as little as 6 hr running time with the viscous, abrasive slurries of fungicide used. Also a distinct reduction in flow rate was noticed after several hours of use, because of deposits of solids in the lines. This was overcome by recalibration before applying each treatment. The variation among mean rates of the three treatments was not significant, however.

Droplet measurements. Droplet sizes of three different pesticide formulations and water as emitted from the modified sprayer are given in Table 2. There is no significant variation in the size of the particle as a function of distance of the measuring device from the nozzle, indicating a consistent particle size range at all distances. Water alone emitted from the sprayer produced a significantly larger droplet than the pesticide formulations. This was probably related to surfactant and particle-forming properties of the fungicide mixture.

Bioassays. Inhibition of *P. variabile* by benomyl is directly related to concentration (Fig. 2). Data for initial and residual fungicidal activity on McIntosh and Delicious trees are presented in Table 3. An average of 1.75 mg/L of benomyl was present immediately after spraying and less than 1 mg/L remained after 1 wk. The east and west sides, facing the sprayer, received approximately 3.25–3.5 mg/L initially; the north and south sides received between 1.35 and 1.50 mg/L. The interior leaves received approximately 0.6 mg/L. North, south, and interior samples had the same amount of residue on upper and lower surfaces (Table 4). The east and west sides had significantly more spray deposited on the lower leaf surface (1.5 mg/L of benomyl) than on the upper surface (0.95 mg/L).

Table 3. Concentration of benomyl on leaves of McIntosh and Golden Delicious apple trees sampled immediately after spray application and after 1 wk

Position of sampled leaf on tree	Concentration (mg/L a.i.)	
	Initial[x]	Residual[y]
North	1.4 b	0.5 cd[z]
South	1.5 b	0.4 cd
East	3.2 a	1.8 b
West	3.5 a	1.8 b
Interior	0.6 c	0.1 d
Mean	1.8 a	0.75 b

[x] Each value is the combined upper and lower leaf surface mean of collections immediately after spraying on three dates.
[y] Each value is the combined upper and lower leaf surface mean of collections 1 wk after spraying on three dates.
[z] For location date and mean data separately, values followed by the same letter are not significantly different at $P = 0.05$, according to Duncan's multiple range test.

Table 4. Concentration of benomyl on upper and lower leaf surfaces of McIntosh and Golden Delicious apple trees

Position of sampled leaf on tree	Concentration (mg/L a.i.)	
	Upper surface	Lower surface
North	0.8 c[y]	1.0 c[z]
South	0.8 c	0.9 c
East	1.6 b	2.8 a
West	1.6 b	3.8 a
Interior	0.3 d	0.3 d
Mean	1.0 b	1.8 a

[y] All values are the mean of six assays, three immediately after spraying and three 1 wk after spraying.
[z] For location data and mean data separately, values followed by the same letter are not significantly different at $P = 0.05$, according to Duncan's multiple range test.

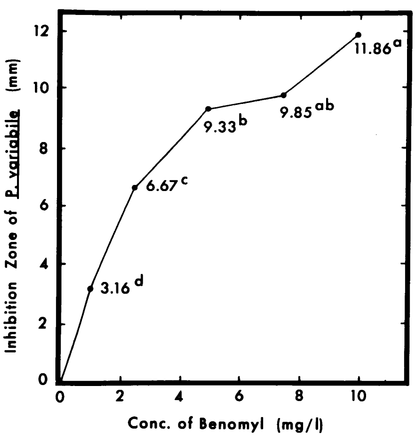

Fig. 2. Inhibition of *Penicillium variabile* (Poland Strain no. 2) by benomyl at 1, 2.5, 5, 7.5, and 10 mg/L. Values not followed by the same letter are significantly different at $P = 0.05$, according to Duncan's multiple range test.

Disease control. Control of apple scab did not differ significantly among the fungicide treatments (Table 5). Cedar-apple rust on Jonathan was best controlled by the captan treatment. McIntosh and Delicious are not susceptible to cedar-apple rust. Powdery mildew was not severe on Delicious.

No phytotoxicity appeared on apple foliage at any time throughout the season.

DISCUSSION

The highest concentration of benomyl was deposited on the lower leaf surfaces closest to the sprayer, and the lowest concentration was deposited on foliage in the center of the tree. The test orchard rows extend north and south, explaining increased deposit on east and west sides. Similar distribution occurs with high-volume sprays (8). The activity of benomyl residue was decreased approximately 50% after 1 wk.

Success of ULV spraying depends on breaking the pesticide suspension into very fine droplets and depositing them adequately on the tree. Apple scab, powdery mildew, and cedar-apple rust were controlled to an acceptable economic level in these trials. Droplet sizes of about 20 μm and low volumes (14 L/ha) were used.

The vacuum jet atomizers used in this study do not have orifices to control the flow or atomize the spray mixture. Instead they shear the pesticide liquid along an edge exposed to the airstream, breaking the stream into small, uniform particles. No clogging occurred at any time in these trials. Because the atomizers are stationary, no auxillary motors or bearings are needed to spin or propel them. Future improvements of the sprayer should include a positive displacement metering pump, so that the flow rate does not change with time or

Table 5. Apple scab, cedar-apple rust, and powdery mildew on four apple cultivars after fungicide applications at ultralow-volume rates

Disease	Treatment[y]	Percent infection[x]			
		Jonathan	McIntosh	Golden Delicious	Delicious
Apple scab	1	0.4 b[z]	12.9 b	6.2 b	14.3 b
	2	0.0 b	8.1 b	3.8 b	9.3 b
	3	0.6 b	16.3 b	4.5 b	17.6 b
	4	1.5 a	69.4 a	66.0 a	34.2 a
Cedar-apple rust	1	14.3 b	0.0 a	8.1 a	0.0 a
	2	6.1 c	0.0 a	4.7 b	0.0 a
	3	10.0 bc	0.0 a	3.5 b	0.0 a
	4	20.0 a	0.0 a	9.1 a	0.0 a
Powdery mildew	1	3.4 c	1.3 c	1.4 c	2.0 b
	2	10.4 b	4.7 b	5.9 b	2.3 a
	3	7.7 bc	3.0 bc	2.4 c	0.5 b
	4	18.3 a	16.3 a	13.8 a	0.2 b

[x] Data are the mean number of foliar infections per 100 leaves per replicate, three replicates per treatment.
[y] Treatments are formulations in Table 1.
[z] Within each cultivar and disease, means followed by the same letter are not significantly different at $P = 0.05$, according to Duncan's multiple range test.

with changes in viscosity of the spray suspension.

Potentially, ULV spray methodology can reduce pesticide amounts to 50% of current recommendations and virtually eliminate water used in application. Reduced ULV sprayer size permits using smaller tractors for application and eliminates the need for a separate sprayer engine, thus reducing fuel requirements. Soil compaction of orchard floors is lessened as a result of smaller spray equipment and less water being transported. An important feature of the ULV technique is that it provides the possibility of attaching small, returnable tanks of custom-mixed pesticides prepared at chemical plants directly to the sprayer. This would eliminate on-site pesticide mixing, orchard storage facilities, and container disposal problems and, correspondingly, would increase applicator safety.

Much work remains to establish ULV application as an alternative commercial orchard pest control technique. Research combining both fungicides and insecticides in a seasonal program with emphasis on formulation, compatibility, and phytotoxicity is necessary. Also, combining reduced rates of pesticides applied with the ULV technique, biological control practices, and disease and insect forecast systems has potential as a valuable tool for integrated pest management. The ULV technique of pest control should be particularly advantageous when used with semidwarf, dwarf, and trellised high-density planting schemes. Studies are in progress to examine several of these implications of ULV technology.

LITERATURE CITED

1. BALS, E. J. 1970. Ultra low volume and ultra low dosage spraying. Cotton Growing Rev. 47:217-221.
2. FULTON, R. H. 1965. Low volume spraying. Annu. Rev. Phytopathol. 3:175-196.
3. GROVE, D. C., and W. A. RANDALL. 1955. Assay methods of antibiotics. Laboratory Manual. Medical Encyclopedia Inc., New York.
4. HIMEL, C. M., J. P. KEATHLEY, and M. C. MILLER. 1971. The case for finely atomized sprays for maximum efficiency in insect control. ASAE Paper 71-660, Am. Soc. Agric. Eng., St. Joseph, MI 49085.
5. HOWITT, A. J., E. J. KLOS, P. CORBETT, and A. PSHEA. 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.
6. KLOS, E. J., A. J. HOWITT, and A. PSHEA. 1966. The control of diseases and insects attacking apples and cherries using ultra low volume ground sprayer in seasonal programs. Mich. Agric. Exp. Stn. Q. Bull. 49:229-236.
7. MAAS, W. J. 1971. ULV Application and Formulation Techniques. N.V. Philips-Duphar, The Netherlands. 164 pp.
8. PIELOU, D. P., K. WILLIAMS, and F. E. BRINTON. 1962. Differences in the deposition and persistence of pesticides on the upper and lower surfaces of leaves. Nature 195:256-257.
9. REICHARD, D. L., H. J. RETZER, L. A. LILJEDAHL, and F. R. HALL. 1977. Spray droplet size distributions delivered by air blast orchard sprayers. Trans. Am. Soc. Agric. Eng. 20:232-242.
10. SMITH, D. B., E. C. BURT, and E. P. LLOYD. 1975. Selection of optimum spray droplet sizes for boll weevil and drift control. J. Econ. Entomol. 68:415-417.
11. THORNBERRY, H. H. 1950. A paper-disk plate method for the quantitative evaluation of fungicides and bactericides. Phytopathology 40:419-429.