Application Method Effects on Methyl Parathion and Permethrin Deposition and Persistence on Cotton Plants

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Methyl parathion and permethrin were applied by controlled-droplet applicators (CDA), i.e., rotary atomizers, and conventional hydraulic nozzles in either soybean oil, soybean oil plus water, or water to mature cotton plants at ULV (ultralow volume, <5 L ha^{-1}), VLV (very low volume, 5–50 L ha^{-1}), or LV (low volume, 50–200 L ha^{-1}) carrier rates. Under the conditions of this study there were no advantages to using soybean oil or CDA relative to conventional methods.

INTRODUCTION

Effective and efficient pesticide application requires placement of the probit dose on the target plants with as little drift as possible. The degree of target coverage and amount of drift depend on spray droplet size. Small droplets (<100-μm diameter) may provide good target coverage but are susceptible to drift. Large droplets (>200-μm diameter) are not as prone to drift but may result in poor target coverage.

The efficacy of some plant-applied insecticides may be affected by persistence (Wilson et al., 1983) and by canopy penetration and coverage (Wilce et al., 1974). Persistent residues may be desired when repeat pest invasion is likely and where no new surfaces (new plant growth) need protection; nonpersistent residues may be desired to minimize worker exposure, to minimize potential for developing pest resistance, to promote fumigant action, to allow survival or re-establishment of beneficial insects, or to reduce pollution potential (Holoman and Seymour, 1983; Wilson et al., 1983; Willis et al., 1985).

Ultralow-volume (ULV) application (<5 L ha^{-1}) of insecticides in vegetable oil has been of interest in recent years because of several potential advantages: (1) improved spray-droplet stability, resulting in less evaporation and drift; (2) better coverage and plant canopy penetration; (3) longer residual control; and (4) improved application economics. ULV oil applications can be made with conventional hydraulic nozzles or controlled droplet applicators (CDA), i.e., rotary atomizers (McDaniel and Dunbar, 1981; Ware, 1983). ULV application of insecticides in oil has in some cases increased persistence and canopy penetration (McDaniel, 1980; Crumby, 1984). In other cases, no such increases were evident (Clower et al., 1982; Southwick et al., 1983, 1986; Rester, 1984). In some cases, initial deposits were higher with ULV oil than with conventional water application (Southwick et al., 1986) and higher with ULV oil than with ULV water (Sanderson et al., 1986).

Improved insecticide efficacy occurred with ULV oil application of endosulfan (6,7,8,9,10,10-hexachloro-1,5,-5a,6,9,9a-hexahydromethano-2,3,4-benzodioxathiepin 3-oxide) (Wilson, 1989) and permethrin [3-phenoxybenzyl [±]-*cis*,*trans*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropanecarboxylate] (McDaniel, 1980; McDaniel and Dunbar, 1981; Luttrell and Wofford, 1984; Ochou et al., 1986; Wofford et al., 1987) to cotton (*Gossypium hirsutum* L.) The efficacy of ULV oil applied fenvalerate [(*R*,*S*)-α-cyano-3-phenoxybenzyl (*R*,*S*)-2-(4-chlorophenyl)-3-methylbutyrate] was equal to conventional application for insect control in sugarcane (*Saccharum officinarum*.) (Smith et al., 1989).

The purpose of this study was to determine the effect of CDA and conventional hydraulic nozzle application on the initial deposition and persistence of methyl parathion [*O*,*O*-dimethyl *O*-(*p*-nitrophenyl) phosphorothioate] and permethrin applied in vegetable oil, vegetable oil plus water, or water to cotton plants.

MATERIALS AND METHODS

The study was conducted in a 10-ha cotton field on the S. F. Johnson farm near Oxford, MS, in August and early September, 1983. Emulsifiable concentrate (ec) formulations of methyl parathion and permethrin were applied at rates of 0.280 and 0.112 kg of active ingredient (ai) ha^{-1}, respectively, in either soybean oil, soybean oil plus water, or water to cotton plants (1.22-m mean height, 1.0-m wide rows, 5.0 ± 0.7 stalks m^{-1} of row, 100% canopy cover) by an 8-row sprayer equipped with conventional hydraulic nozzles (two per row) and rotary atomizer CDA (one per row). The various treatments/application conditions are given in Table I. Permethrin ec formulated at 480 g of ai L^{-1} for use in oil was used in all treatments except water8. The permethrin was mixed with refined soybean oil (plus emulsifier) for the LoOil and HiOil treatments; in the oil plus water treatments the oil–permethrin mixture was diluted to volume with water. Permethrin ec formulated at 240 g of ai L^{-1} for use in water was used for the water8 treatment. Methyl parathion ec formulated at 480 g of ai L^{-1} for use in water was mixed and diluted the same way as permethrin for all treatments. Carrier flow rates, adjusted to deliver predetermined spray amounts, and CDA speeds resulted in volume median diameter, $D_{v.5}$ (the diameter that divides the droplet spectrum into two equal parts such that half of the volume contains droplets smaller than the $D_{v.5}$ and half contains droplets larger than the $D_{v.5}$), values of 100, 135, and 135 μm, respectively, for the LoOil, HiOil, and LoOilWCDA treatments. Droplet diameters were not measured directly but were estimated from product information tables supplied by the rotary atomizer manufacturer. The spray nozzles/CDA were set at 0.38 m above the mean canopy height.

One each of the six treatments was applied (in random order) on each of six successive days for each of three replicates. Separate areas, 8 rows wide and about 50 m long, were sprayed for each treatment. Each pesticide application was made at 10:00 a.m. (Central Daylight Savings Time) after the dew had dried. Measured windspeeds during the applications were 1.3 ± 0.7 m/s. Weather conditions were generally the same for all three

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Table I. Application Methods and Sprayer Operating Conditions for Methyl Parathion and Permethrin Application to Cotton Plants

treatment	carrier	nozzle[a]	CDA[b] orifice	spray volume,[c] L ha^{-1}	pressure, kPa	applicator ground speed, km h^{-1}
LoOil	oil[d]		14	4.7	69	5.6
HiOil	oil[e]		20	9.4	97	8.1
LoOilWCDA	oil + water[d]		30	21.4	83	8.1
LoOilW2	oil + water[d]	TX2		21.4	276	8.1
LoOilW8	oil + water[d]	TX8		79.5	276	8.1
water8	water	TX8		79.5	276	8.1

[a] Conventional hydraulic hollow cone 80° nozzles. [b] Controlled droplet applicator with rotary atomizers operated at 4000 rpm zero load. [c] Spray volume classes: ultra low volume (ULV), <5 L ha^{-1}; very low volume (VLV), 5–10 L ha^{-1}; low volume (LV), 50–200 L ha^{-1} [on the basis of Matthews (1979)]. [d] Refined soybean oil with emulsifier applied at 3.9 L ha^{-1}. [e] Refined soybean oil with emulsifier applied at 8.5 L ha^{-1}.

replicates. Portable shelters (lightweight tarps stretched over aluminum frames) were placed over plots (1.5-m sections of row) prior to any rain event. The experimental design was treated as a randomized complete block for statistical purposes.

Cotton plants were collected immediately after spraying and 0.25, 0.5, 1, 1.5, 2, 6, 25, and 49 h after application. The plants were cut at the soil surface along a 1.5-m length of a single row and placed in a 114-L steel drum (prerinsed with methanol). Four rows were sampled each time (four drums), providing quadruplicate samples for each sampling time for each replicate. Methanol was immediately added to each drum, and the drum heads were replaced to prevent solvent–pesticide evaporation. Care was taken to ensure that the plant material was completely covered with methanol.

The plants were extracted by allowing them to soak in methanol at ambient temperatures for a minimum of 4 h. The methanol was mixed thoroughly, and a 125-mL aliquot was removed and stored in an amber bottle at 4 °C until analysis. Extraction efficiencies were 96 ± 3 and 95 ± 2% for permethrin and methyl parathion, respectively, as determined from laboratory studies with fortified samples.

The methanol extracts were diluted with benzene to volumes appropriate for gas chromatographic analysis. The gas chromatograph was equipped with a ^{63}Ni electron-capture detector, glass columns (1.8 m long × 2 mm i.d.) packed with 5% SP-2100 (methyl parathion) or 3% SP-2401 (permethrin) on 100/120 Supelcoport, and an electronic integrator to compare sample peaks against standard peaks. General operating conditions were as follows: carrier gas, filter-dried N_2, 99.995% minimum purity; flow rate, 90 mL min^{-1}; inlet temperature, 240 °C; detector temperature, 350 °C; column oven temperatures, 180 (methyl parathion) and 210 °C (permethrin). Under these conditions the lower limits of detection were 0.01 and 0.2 g ha^{-1} for methyl parathion and permethrin, respectively, on cotton plants.

The insecticide load data were analyzed by Lilliefor's test (Conover, 1980) to determine if the distributions were normal. The null hypothesis (the insecticide load distribution functions for the different application treatment sets are not significantly different) was tested by using Student's t-test (Snedecor and Cochran, 1980) for normally distributed data and by using the Kolmogorov–Smirnov test (Conover, 1980) for nonnormally distributed data.

RESULTS AND DISCUSSION

Interception by Plants. The amounts of applied methyl parathion and permethrin intercepted by the cotton plants, determined immediately after application, are given in Table II. The percent of applied pesticide intercepted was least for the LoOil treatment. The low interception is attributed to spray drift, which was noticeable during the application process. The drift resulted from the smaller droplets ($D_{v.5}$ = 100 μm) used in the LoOil treatment. Wind speeds during the application periods were 1.03 ± 0.13 m s^{-1}. Although the $D_{v.5}$ values for the other CDA treatments were only 35% larger, the masses of the 135-m-diameter droplets were 2.5 times greater, resulting in considerably less drift. Comparisons of the mean initial loads of insecticides intercepted by the plants (Tables III and IV) show that the LoOil treatment resulted in significantly less insecticide deposition, while no differences existed among the other treatments. The only treatment other than LoOil to result in substantially less than 100% interception was the conventional hydraulic nozzle application of permethrin with water as the carrier. There was a trend for slightly lower interception percentages for permethrin for most of the treatments (Table II). A recent review showed that pesticide application by ground equipment with conventional hydraulic nozzles resulted in 62 ± 27% interception by plants/targets under a wide range of application conditions (Willis and McDowell, 1987). The results of the current study agree with suggestions that $D_{v.5}$ values of about 150 m result in good interception by target plants (McDaniel, 1982; Rester, 1984).

Table II. Mean Initial Loads of Methyl Parathion and Permethrin Intercepted by Cotton Plants for Different Nozzle/CDA and Carrier Treatments

	methyl parathion		permethrin	
treatment	load,[a] kg ha^{-1}	amount intercepted,[a] %	load,[a] kg ha^{-1}	amount intercepted,[a] %
LoOil	0.16 ± 0.06	59 ± 20	0.05 ± 0.03	43 ± 26
HiOil	0.33 ± 0.18	119 ± 65	0.12 ± 0.05	103 ± 47
LoOilWCDA	0.36 ± 0.09	127 ± 34	0.13 ± 0.08	119 ± 71
LoOilW2	0.35 ± 0.17	125 ± 62	0.11 ± 0.07	98 ± 59
LoOilW8	0.28 ± 0.10	100 ± 37	0.11 ± 0.05	100 ± 43
water8	0.29 ± 0.07	105 ± 24	0.09 ± 0.02	76 ± 21

[a] X ± SD.

Table III. Comparison of Mean Initial Loads of Methyl Parathion Intercepted by Cotton Plants for Different Application Treatments

treatments compared	t[a]	95% confidence limits[b]
LoOil vs HiOil	3.010[c]	−0.168 ± 0.123
LoOil vs LoOilWCDA	5.894[c]	−0.192 ± 0.071
LoOil vs LoOilW2	3.503[c]	−0.186 ± 0.117
LoOil vs LoOilW8	2.830[c]	−0.115 ± 0.089
LoOil vs water8	4.841[c]	−0.129 ± 0.059
HiOil vs LoOilWCDA	0.404	−0.024 ± 0.131
HiOil vs LoOilW2	0.248	−0.018 ± 0.160
HiOil vs LoOilW8	0.826	0.053 ± 0.142
HiOil vs water8	0.692	0.039 ± 0.118
LoOilWCDA vs LoOilW2	0.106	0.006 ± 0.125
LoOilWCDA vs LoOilW8	1.696	0.077 ± 0.099
LoOilWCDA vs water8	1.882	0.063 ± 0.074
LoOilW2 vs LoOilW8	1.149	0.071 ± 0.137
LoOilW2 vs water8	1.062	0.057 ± 0.118
LoOilW8 vs water8	0.338	−0.014 ± 0.091

[a] Calculated t; $t_{0.05}$ = 2.201 (11 df). [b] $\bar{X}_1 - \bar{X}_2 + (t_{0.05})(S_{\bar{X}_1-\bar{X}_2})$. [c] Significantly different at 0.05 level.

Persistence on Plants. Although the interception data were normally distributed and amenable to Student's t analysis, the plant load data for the 0.25–49-h period were not normally distributed. Thus, nonparametric statistics were used to test the null hypothesis. The Kolmogorov–Smirnov two-sample and two-sided test statistic (T_1) is the greatest vertical distance between two empirical cumulative distribution functions and was used to deter-

Table IV. Comparison of Mean Initial Loads of Permethrin Intercepted by Cotton Plants for Different Application Treatments

treatments compared	t^a	95% confidence limits[b]
LoOil vs HiOil	3.756[c]	−0.067 ± 0.040
LoOil vs LoOilWCDA	3.421[c]	−0.085 ± 0.055
LoOil vs LoOilW2	2.932[c]	−0.062 ± 0.047
LoOil vs LoOilW8	3.318[c]	−0.064 ± 0.042
LoOil vs water8	3.218[c]	−0.037 ± 0.025
HiOil vs LoOilWCDA	0.650	−0.018 ± 0.061
HiOil vs LoOilW2	0.205	0.005 ± 0.054
HiOil vs LoOilW8	0.131	0.003 ± 0.050
HiOil va water8	1.786	0.030 ± 0.037
LoOilWCDA vs LoOilW2	0.768	0.023 ± 0.066
LoOilWCDA vs LoOilW8	0.733	0.021 ± 0.063
LoOilWCDA vs water8	1.991	0.048 ± 0.053
LoOilW2 vs LoOilW8	0.078	−0.002 ± 0.056
LoOilW2 vs water8	1.233	0.025 ± 0.045
LoOilW8 vs water8	1.473	0.027 ± 0.040

[a] Calculated t; $t_{0.05}$ = 2.201 (11 df). [b] $\bar{X}_1 - \bar{X}_2 + (t_{0.05})(S_{\bar{X}_1-\bar{X}_2})$. [c] Significantly different at 0.05 level.

Table V. Kolmogorov–Smirnov Two-Sample Test Statistic (T_1) for Methyl Parathion and Permethrin Fractional Loads on Cotton Plants (0.25–49-h Period) for Different Application Treatments

	T_1[a]	
treatments compared	methyl parathion	permethrin
LoOil vs HiOil	−0.241[b]	−0.280[b]
LoOil vs LoOilWCDA	−0.222[b]	−0.280[b]
LoOil vs LoOilW2	−0.272[b]	−0.235[b]
LoOil va LoOilW8	0.160	−0.245[b]
LoOil vs water8	−0.173	−0.174
HiOil vs LoOilWCDA	−0.192[d]	0.096
HiOil vs LoOilW2	−0.178	0.089
HiOil vs LoOilW8	0.235[b]	0.293[b]
HiOil vs water8	0.171	0.180
LoOilWCDA vs LoOilW2	0.123	0.107
LoOilWCDA vs LoOilW8	0.372[b]	0.235[b]
LoOilWCDA vs water8	0.301[b]	0.208[c]
LoOilW2 vs LoOilW8	0.362[b]	0.228[b]
LoOilW2 vs water8	0.282[b]	0.183
LoOilW8 vs water8	−0.098	−0.142

[a] Calculated T_1; $T_{1_{0.5}}$ = 0.185, $T_{1_{0.02}}$ = 0.207, $T_{1_{0.01}}$ = 0.222 (11 df). [b] Significantly different at 0.01 level. [c] Significantly different at 0.02 level. [d] Significantly different at 0.05 level.

mine if any pair of sample populations were governed by the same unknown distribution (Table V). Data from the LoOil treatment were excluded from the following conclusions because of the extensive drift/low interception problems associated with that treatment. In all cases, methyl parathion and permethrin plant loads (0.25–49 h) from application by the TX8 hydraulic nozzle were greater than or equal to loads from the TX2 nozzle or CDA applications. For both insecticides, plant loads from application by the TX2 hydraulic nozzle did not differ from loads applied by CDA. The addition of soybean oil to water or use of CDA-applied oil did not result in insecticide loads (during the 0.25–49-h period) greater than application by water only with the TX8 hydraulic nozzle. Thus, under the conditions of this study, use of oil or CDA application generally did not result in greater initial deposition or greater persistence for either insecticide during the 49 h following application.

The disappearance of surface residues of many pesticides from foliage is usually characterized by very rapid loss rates immediately after application followed by slower asymptotic decreases with time. Equations describing the disappearance of methyl parathion from cotton plants as a function of time for the different application treatments are given in Table VI. The best-fit, hyperbolic equations

Table VI. Equations Describing the Disappearance of Methyl Parathion from Cotton Plants as a Function of Time after Application

treatment	equation[a]	r^2	DT_{50},[b] h	eq no.
LoOil	$F = 1/(0.93 + 0.30t) + 0.06$	0.52	4.5	1
HiOil	$F = 1/(1.09 + 0.79t) + 0.08$	0.60	1.6	2
LoOilWCDA	$F = 1/(1.04 + 1.34t) + 0.04$	0.73	0.9	3
LoOilW2	$F = 1/(1.19 + 1.27t) + 0.10$	0.56	1.0	4
LoOilW8	$F = 1/(0.99 + 0.37t) + 0.06$	0.66	3.5	5
water8	$F = 1/(1.03 + 0.51t) + 0.07$	0.77	2.5	6

[a] Fraction (F) of initial insecticide load remaining on plants with time (t = h); developed by using all measured, nontransformed values from triplicate plots. [b] 50% disappearance time (time required for 50% of the initial load to disappear from plants).

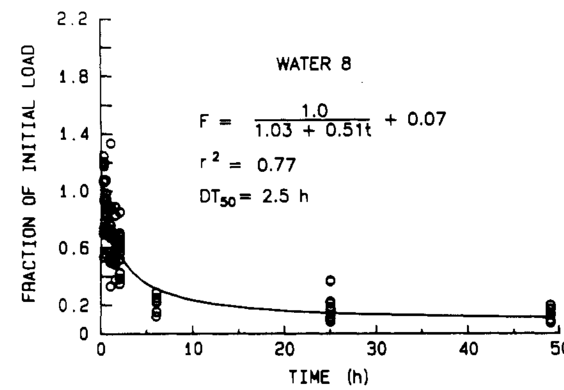

Figure 1. Methyl parathion load on cotton plants as a function of time.

describe the rapid decrease in plant load during the first few hours after application better than other equation forms (exponential, power, etc.). The rapid decrease in methyl parathion load on cotton plants is clearly depicted in Figure 1. The methyl parathion DT_{50} values listed for the LoOilW8 and water8 treatments in Table VI are greater than those for the other treatments except LoOil. Apparently the larger spray volumes for the LoOilW8 and water8 treatments permitted, in this case, greater canopy penetration and resulted in increased protection from dissipation processes. The same factor may explain the apparently anomalous results found when the DT_{50} of the LoOil treatment is compared to that of the other oil and oil plus water low-volume (CDA, TX2 nozzle) treatments; i.e., even though a smaller fraction of the LoOil droplets was intercepted by the plant canopy, the somewhat smaller droplets ($D_{v.5}$ = 100 μm) of the LoOil treatment may have penetrated farther into the canopy and were afforded greater protection from dissipation processes. This illustrates one of the proposed advantages (increased persistence) and one of the observed disadvantages (drift).

The DT_{50} value for the water8 treatment (2.5 h) is similar to the value (2.4 h) determined in 1980 (Willis et al., 1985) but is less than values (5.4 and 4.4 h) determined in 1982 and 1983, respectively (Smith et al., 1987). All studies were done under similar conditions.

The best-fit curves developed from the permethrin data had slopes that were not different from zero. Under the conditions of this study, 49 h was not long enough to measure significant disappearance rates for permethrin.

The results of this study tend to agree with those of Rester (1984) and Southwick et al. (1983, 1986); i.e., the potential advantages of application by ULV oil for insecticides are not always evident. Although there were no apparent deposition or persistence advantages to the use of soybean oil or CDA, there may still be advantages to the applicator accruing from less time required to fill sprayer tanks per unit area sprayed. The economics of time saved versus possible additional equipment requirements and carrier costs should be evaluated.

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Registry No. Methylparathion, 298-00-0; permethrin, 52645-53-1.