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EVALUATION OF AERIAL AND GROUND-APPLIED ADULTICIDES AGAINST MOSQUITO SPECIES IN ARKANSAS AND LOUISIANA[1]

R. L. GROVES,[2] J. C. McALLISTAR,[3] C. L. MEEK[3] AND M. V. MEISCH[2]

ABSTRACT. Mosquitoes were subjected to ultra-low volume (ULV) aerial applications of permethrin synergized with piperonyl butoxide (Biomist® 30:30, Biomist 31:66) and Cythion® and ULV ground applications of permethrin synergized with piperonyl butoxide (Biomist 30:30, Biomist 12:60), resmethrin (Scourge®), and sumithrin (Solo® 40-OS and Duets 8.8-OS). Permethrin compounds tested aerially against *Anopheles quadrimaculatus* were not significantly different. Biomist 30:30 tested aerially against *Culex quinquefasciatus* did provide significantly greater mortality compared to Cythion. Biomist 30:30 and Biomist 31:66 tested aerially against *An. quadrimaculatus* at 1 h did not provide a significant difference up to 600 ft. (182.9 m). Both products ground tested at 24 h revealed nonsignificant results. Biomist 30:30 and Biomist 12:60 ground tested against *Cx. quinquefasciatus* at 1 h did not provide a significant difference at 100 ft. (30.5 m) or 200 ft. (61.0 m); however, significantly greater mortality was observed at 300 ft. (61.0 m) and 600 ft. (91.4 m). At 24 h no significant mortality differences were observed at 300 ft. (61.0 m) and 600 ft. (91.4 m). *Anopheles quadrimaculatus* and *Psorophora columbiae* were treated with a 1:1 mixture of Solo 40-OS and Duet 8.8-OS (sumithrin + piperonyl butoxide). Significant mortality differences ($P \leq 0.05$) between species at 1 h posttreatment occurred at 300 ft. (91.4 m).

INTRODUCTION

Pest mosquito management in Arkansas and Louisiana employs aerial and ground application of pyrethroids. Weathersbee et al. (1986) and Efird et al. (1991) demonstrated that pyrethroids alone provided an effective control of riceland mosquito species.

A study was conducted in the summer of 1993 to determine if permethrin and sumithrin synergized with piperonyl butoxide (PBO) at selected dosages proved to be an effective tool in the arsenal of available pesticides against riceland mosquitoes. The specific objectives were to determine if different ratios of synergized permethrin were an effective control measure for mosquito control.

MATERIALS AND METHODS

Louisiana

Adult *Culex quinquefasciatus* Say were collected with hand-held aspirators (Meek et al. 1985) near an open septic ditch within East Baton Rouge Parish, Louisiana. In the laboratory the mosquitoes were anesthetized with CO_2 and transferred to cylindrical screened cages, 5.2 × 8.6 cm (Sandoski et al. 1983). Each test cage contained approximately 20 adult mosquitoes, which were placed in polystyrene insulated chests and held at room temperature until just prior to testing. Aerial and ground tests were conducted on the Louisiana State University Agricultural Center, St. Gabriel Research Station.

Aerial tests: Three aerial test plots consisting of 3 rows of 3 stakes each were located in an open field. Each row and each stake within the row was 30.5 m apart. A single cage of adult mosquitoes was suspended from each stake approximately 1.5 m above ground. Aerial ULV applications of 2 chemicals, Biomist® 30:30 and 95% technical Cythion® (malathion), were replicated 3 times on the evening of June 23, 1993, between 1900 and 2100 h. Biomist 30:30 was mixed 1:19 with Envirotech® 13 oil and applied at 3.0 oz./acre (65.8 ml AI/ha). Cythion was applied at 2.0 oz./acre (137.5 m AI/ha). During each replication, temperatures ranged from 26 to 29°C and wind speed was variable, ranging from 0.6 to 3.1 kph. Applications were conducted using a Micronaire® AV 4000 Rotary Atomizer suspended from a twin-engine Islander® aircraft flying at an altitude of 45.7 m and at an airspeed of 93.2 kph.

Ground tests: A single test plot in an open fallow field consisting of 3 rows of 4 stakes/row was used at the St. Gabriel Research Station. Each row was separated by 30.5 m and each of the 4 stakes within the row was 30.5, 61.0, 91.4, and 182.9 m downwind from and perpendicular to the spray path. A single cage of adult mosquitoes was suspended from each stake approximately 1.5 m above ground. Ground ULV applications of 3 chemicals, Biomist 12:60, Biomist 30:30, and Scourge® (resmethrin), were replicated 3 times on the evenings of June 22 and 23, 1993, between 1900 and 2300 h. Each of the 3 chemicals was mixed 1:13 with Envirotech 13 oil. Biomist 12:60 was applied at 10.8 oz./min

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[2] Department of Entomology, University of Arkansas, Fayetteville, AR 72701.

[3] Department of Entomology, Louisiana State University, Baton Rouge, LA 70803.

(0.6 ml AI/sec) with a mean droplet size of 17.7 μm. Biomist 30:30 was applied at 10.8 oz./min (1.6 ml AI/sec) with a mean droplet size of 17.7 μm, and Scourge was applied at 10.8 oz./min (2.1 ml AI/sec) with a mean droplet size of 17.9 μm. During each replication, temperatures ranged from 23 to 27°C and wind speed ranged from 0.6 to 6.2 kph. Applications were conducted using a Leco® Model 1600 HD cold aerosol generator driven at 9.3 kph with a nozzle pressure of 5.5 psi (330.1 g/cm^2) for all treatments.

Treatment cages containing adult mosquitoes were placed in the test plots just prior to exposure and remained there for 15 min posttreatment in both the aerial and ground tests. After each test, exposed cages were immediately transported to a holding facility on the St. Gabriel Research Station where the mosquitoes were anesthetized with CO_2 and transferred to 237-ml paper cups with screened lids. A solution of 10% sugar and water was offered in cotton placed on the surface of each screened lid. Percent mortality was observed at 1 and 24 h posttreatment.

Arkansas

Adult *Anopheles quadrimaculatus* Say were collected from a livestock barn within the city limits of Humphrey, AR, with a backpack aspirator developed by USDA, Medical and Veterinary Entomology Research Laboratory, Gainesville, Florida. Adult mosquitoes were handled and caged in a similar fashion as those in the Louisiana tests with each test cage containing approximately 20 adult mosquitoes. Both aerial and ground tests were conducted over fallow fields near the Stuttgart, AR, airport located 7.5 km north of the city.

Aerial tests: Three aerial test plots were established in the same design as those in Louisiana. Aerial ULV applications of 2 chemicals, Biomist 30:30 and Biomist 31:66, were replicated 3 times on the evenings of July 14 and 16, 1993, between 2000 and 2200 h. Biomist 30:30 was mixed 1:19 with Envirotech 13 oil and applied at 2.0 oz./acre (43.9 ml AI/ha) and a higher concentration at 2.25 oz./acre (49.4 ml AI/ha). Only the Biomist 30:30 compound at 2.0 oz./acre produced valid results. Biomist 31:66 was mixed 1:19 with Envirotech 13 oil and applied at 2.0 oz./acre (45.5 ml AI/ha).

During each replication, temperatures ranged from 26 to 27°C and wind speed ranged from 1.9 to 5.0 kph. Applications were conducted using a Beecomist® Rotary Atomizer with 40 μm sleeves at 10,000 rpm. A twin-engine Piper Aztec® aircraft flew at an altitude of 45.7 m during the application of Biomist 31:66 on July 14, 1993, and at an airspeed of 93.2 kph. Applications conducted using both concentrations of Biomist 30:30 were flown at an altitude of approximately 30.5 m at an airspeed of 93.2 kph on July 16, 1993.

A second, repeated aerial test was conducted using Biomist 30:30 at the higher rate 49.4 ml AI/ha as well as Biomist 31:66 45.4 ml AI/ha. Invalid results were caused by wind change and the chemical(s) did not sufficiently contact the test cages. This test was conducted August 11, 1993, under similar circumstances with temperatures ranging from 29 to 30°C and wind speed ranging from 3.7 to 5.0 kph.

Ground tests (permethrin): A single test plot was constructed in the same design as in the Louisiana ground tests. Ground ULV applications of 3 chemicals, Biomist 12:60, Biomist 30:30, and Scourge, were replicated 3 times on the evenings of July 14 and 15, 1993, between 2000 and 2200 h. Each of the 3 chemicals was mixed 1:14 with Envirotech 13 oil. Biomist 12:60 had a mean droplet size of 16.9 μm and was applied at 12.0 oz./min (0.7 ml AI/ha). Biomist 30:30 had a mean droplet size of 16.9 μm and was applied at 12.0 oz./min (1.8 ml AI/ha). Scourge had a mean droplet size of 18.4 μm and was applied at 12.0 oz./min (2.4 ml AI/ha). During each replication, temperatures ranged from 26 to 30°C and wind speed ranged from 2.5 to 5.0 kph. Applications were conducted using a Leco Model 1600 HD cold aerosol generator driven at 9.3 kph with a nozzle pressure of 5.5 psi (316.1 g/cm^2) for all chemicals.

Treatment cages containing adult mosquitoes were placed in the test plots just prior to exposure and allowed to stand for 10 min posttreatment in both the aerial and the ground tests. After each replication of each test, exposed cages were immediately transported to a holding facility at the University of Arkansas Rice Branch Experiment Station. The adult mosquitoes were anesthetized with CO_2 and transferred to 237-ml paper cups with screened lids. A solution of 10% sugar water was offered in cotton placed on the surface of each screened lid. Percent mortality was observed at 1 and 24 h posttreatment.

Ground tests (sumithrin): Adult *An. quadrimaculatus* were collected as previously described within the city limits of Humphrey, AR, with a backpack aspirator (Sandoski et al. 1983). Adult mosquitoes were handled and caged in a similar fashion as those in the Louisiana tests. Adult *Psorophora columbiae* (Dyar and Knab) were collected with a backpack aspirator approximately 1.2 km west of Stuttgart, AR, near rice fields. The test cages of adult *Ps. columbiae* contained approximately 10 individuals.

A single test plot in an open fallow field consisting of 3 rows of 3 stakes/row was used near

Table 1. Mean percentage mortality of adult mosquitoes exposed to aerial applications of permethrin (Biomist®) compounds alongside a malathion (Cythion®) standard.

Location	Species	Chemical	Application rate ml AI/ha	Mean percentage mortality[1] 1-h reading	24-h reading
Baton Rouge, LA	*Culex quinquefasciatus*	Biomist 30:30	65.8	76.6a	86.8a
		Cythion	137.5	3.0b	33.7b
		Control		3.1b	5.8c
Stuttgart, AR	*Anopheles quadrimaculatus*	Biomist 30:30	43.9	89.9a	87.6a
		Biomist 30:30[2]	49.4	78.1a	81.3a
		Biomist 31:66[2]	45.4	82.5a	92.0a
		Control		7.2b	4.8b

[1] Means reported from retransformed data analyzed by GLM. Means not followed by the same letter within columns are significantly different ($\alpha = 0.05$), by Duncan's multiple range test.

[2] Chemicals did not appear to strike the target areas in original test. Reported are data from a repeat of the test at a later date.

the Stuttgart, AR, airport grounds. Each row was separated by 30.5 m and each of the 3 stakes within the rows was 30.5, 61.0, and 91.4 m downwind from and perpendicular to the spray path. A single cage of adult *An. quadrimaculatus* and a cage of adult *Ps. columbiae* were suspended from each stake within the test plot approximately 1.5 m above ground. Ground ULV applications of a 1:1 mixture of Solo® 40-OS and Duet® 8.8-OS at 1.51 lb/gal (0.15 mg/L) were replicated 3 times on the evening of August 11, 1993, between 1900 and 2100 h. The insecticide mixture was mixed 1:14 with Envirotech 13 oil. The chemical was applied at 14.0 oz./min (3.5 ml AI/sec), and mean droplet size was measured as 10.24 μm. During each of the 3 replications, temperatures ranged from 26 to 27°C and wind speed did not vary from 3.7 kph, and wind direction changed from 140 to 160° azimuth. Applications were conducted using an 18 Hp Vectec Grizzly® Model cold aerosol generator driven at 9.3 kph with a nozzle pressure of 5.2 psi (300.3 g/cm^2) for all replications.

Separate treatment cages containing both species of adult mosquitoes were placed 2/stake in the test plots just prior to exposure and allowed to remain there for 10 min posttreatment. Twelve control cages containing the same number of adult mosquitoes were allowed to stand for 10 min prior to the test. After each replication, exposed cages were immediately transported to a holding facility at the University of Arkansas Rice Research and Extension Center where the mosquitoes were held and observed as in the permethrin ground tests.

Percent mortality data were subjected to an arcsine transformation and a subsequent analysis of variance (General Linear Models). Means were corrected by Abbott's formula (Abbott 1925) and mean separation was subsequently conducted using Duncan's multiple range test (SAS Institute 1985).

RESULTS AND DISCUSSION

Louisiana

Aerial tests: Results for 1- and 24-h mortality are presented in Table 1. The Cythion 1-h mortality was very low and did not significantly differ ($P > 0.05$) from control mortality. The greatest mortality for the Cythion treatment was reached at 24 h with 33.7%. Biomist 30:30 treatment mortality ranged from 76.6% at 1 h to 86.8% at 24 h, significantly greater ($P < 0.05$) than either control or Cythion mortality at both the 1-h and the 24-h readings. Mean percent mortality for Cythion does not appear to have a significant detrimental effect upon the caged population.

Ground tests: Results for the 1-h mortality are presented in Table 2. The only significant difference ($P \leq 0.05$) occurred at both 61.0 and 91.4 m where Biomist 30:30 was significantly higher than Biomist 12:60. At this distance, Biomist 30:30 was not significantly different ($P > 0.05$) than Scourge. No other significant differences were observed at any distance.

Results for the 24-h mortality are presented in Table 3. Significant mortality differences ($P \leq 0.05$) occurred at both 61.0 and 91.4 m distances. At 61.0 m, Biomist 30:30 was significantly greater ($P \leq 0.05$) than either of the other 2 treatments. At 91.4 m, Biomist 30:30 was again significantly greater ($P \leq 0.05$) than Biomist 12:60, but it was not significantly greater ($P > 0.05$) than Scourge. No other significant differences (*P*

Table 2. Mean percentage mortality of adult mosquitoes after 1-h exposure to ULV ground-applied permethrin (Biomist®) and sumithrin (Solo® and Duet®) adulticides alongside a resmethrin (Scourge®) standard.

Location	Species	Chemical	Application rate ml AI/sec
Baton Rouge, LA	*Culex quinquefasciatus*	Biomist 12:60	0.6
		Biomist 30:30	1.6
		Scourge	2.1
Stuttgart, AR	*Anopheles quadrimaculatus*	Biomist 12:60	0.7
		Biomist 30:30	1.8
		Scourge	2.4
Stuttgart, AR	*An. quadrimaculatus*	Solo 40-OS	
	Psorophora columbiae[2]	Duet 8.8-OS	3.5
		Solo 40-OS	
		Duet 8.8-OS	3.5

[1] Means reported from retransformed data analyzed by GLM. Means not followed by the same letter within columns are significantly different ($\alpha = 0.05$), by Duncan's multiple range test.
[2] Means have been corrected for control mortality according to Abbott (1925).

≤ 0.05) were observed at any distance. Some recovery occurred with Scourge at both the 61.0- and 91.4-m swaths. Such recovery was not shown with the other compounds tested.

The experiments conducted with *Cx. quinquefasciatus,* both aerially and ground, proved to challenge all compounds. Although submarginal control was obtained, effective comparisons were achieved. The *Culex* species in question likely represent one of the most insecticide-tolerant species in the southern USA and most certainly in the Baton Rouge area. Dosages were increased for the Arkansas trials against *An. quadrimaculatus* and greater effectiveness was obtained.

Arkansas

Aerial tests: Results for 1- and 24-h mortality are presented in Table 1. Only the Biomist 30:30 compound at 43.9 ml AI/ha appeared to strike the target cages on the first aerial test date and resulted in the only conclusive data obtained from this test. The test of the remaining 2 compounds was repeated at a later date.

Results for all valid tests of Biomist 30:30 and

Table 3. Mean percentage mortality of adult mosquitoes after 24-h exposure to ULV ground-applied permethrin (Biomist®) and sumithrin (Solo® and Duet®) adulticides alongside a resmethrin (Scourge®) standard.

Location	Species	Chemical	Application rate ml AI/sec
Baton Rouge, LA	*Culex quinquefasciatus*	Biomist 12:60	0.6
		Biomist 30:30	1.6
		Scourge	2.1
Stuttgart, AR	*Anopheles quadrimaculatus*	Biomist 12:60	0.7
		Biomist 30:30	1.8
		Scourge	2.4
Stuttgart, AR	*An. quadrimaculatus*	Solo 40-OS	
		Duet 8.8-OS	3.5
	Psorophora columbiae[2]	Solo 40-OS	
		Duet 8.8-OS	3.5

[1] Means reported from retransformed data analyzed by GLM. Means not followed by the same letter within columns are significantly different ($\alpha = 0.05$), by Duncan's multiple range test.
[2] Means have been corrected for control mortality according to Abbott (1925).

Table 2. Extended.

Mean percentage morality[1]				
Control	30.5 m	61.0 m	91.4 m	182.9 m
1.6a	58.0a	7.2a	5.0a	4.8a
2.4a	27.3a	26.7b	43.8b	8.5a
3.3a	53.0a	31.0b	34.2b	3.2a
3.7a	93.5a	89.4a	79.1a	55.6a
5.6a	91.7a	91.2a	87.1a	78.3a
7.9a	91.4a	92.2a	84.5a	62.6a
2.2a	86.9a	74.3a	82.6a	—
19.4b	81.5a	82.8a	67.4b	—

Biomist 31:66 at both 1 and 24 h are presented in Table 1. At both 1 and 24 h, the 43.9 ml AI/ha rate of Biomist 30:30 (low), the 49.4 ml AI/ha rate of Biomist 30:30 (high), and Biomist 31:66 mortality were not significantly different from each other. Theoretically, the Biomist 30:30 at the higher rate (49.4 ml AI/ha) should have had a greater mortality than the Biomist 30:30 at the lower rate (43.9 ml AI/ha); however, the data do not agree with this assumption. Possibly 5.5 ml AI/ha is not a significant enough rate increase to give a discriminating dosage.

Ground tests (permethrin): Results for the 1-h mortality are presented in Table 2. No significant mortality differences were observed between any of the treatments at any distance. Mortality at 30.5 m was consistently high for all treatments, ranging from 91.4 to 93.5%. At 61.0 m, all treatment mortality was still high, ranging from 89.4 to 92.2%. Treatment mortality at 91.4 m was still relatively high, ranging from 79.1 to 87.1% for all 3 treatments. Treatment mortality at 182.9 m never dropped below 55.6% for any treatment and control mortality never exceeded 7.9% for any of the 3 treatments.

Table 3. Extended.

Mean percentage mortality[1]				
Control	30.5 m	61.0 m	91.4 m	182.9 m
5.5a	58.1a	14.9a	18.9a	9.7a
6.8a	31.4a	32.9b	48.2b	16.0a
4.5a	38.0a	13.3a	23.3ab	5.2a
4.9a	93.2a	88.7a	78.9a	69.9a
4.3a	95.3a	93.9a	90.5a	76.6a
9.6a	96.0a	97.6a	88.4a	49.0a
7.3a	99.6a	88.0a	90.3a	—
≥20.0b	98.0a	100.0b	93.3a	—

Results for the 24-h mortality are presented in Table 3. No significant mortality differences were observed among any of the treatments at any distance. Mortality at 30.5 m remained high for all treatments, ranging from 93.2 to 96.0%. At 61.0 m, all treatment mortality remained high, ranging from 88.7 to 97.6%. Treatment mortality at 91.4 m was, again, relatively high, ranging from 78.9 to 90.5% for all 3 treatments. Treatment mortality at 182.9 m never dropped below 49.0% for any treatment and control mortality did not exceed 7.9% for any of the 3 treatments. At the 24 h reading, some recovery was observed at 182.9 m for individuals treated with Scourge.

Ground tests (sumithrin): There appeared to be little difference in susceptibility among the species tested. Results for 1-h mortality are presented in Table 2. The only significant difference ($P \leq 0.05$) among mosquito species occurred at the 91.4-m distance, at which the percent mortality of *An. quadrimaculatus* was greater than that of the *Ps. columbiae.* At the 30.5- and 61.0-m distances the chemical did not impart any significantly different control among species. The compound did prove effective at 1 h posttreatment and provided excellent control at 24 h posttreatment.

Results illustrating the 24-h mortality are presented in Table 3. The only significant ($P \leq 0.05$) mortality difference between species occurred at 61.0 m at which the percent mortality of *Ps. columbiae* was significantly greater than that of *An. quadrimaculatus.* However, due to high control mortality within *Ps. columbiae,* valid comparisons are questionable. It should be noted that *Ps. columbiae* is a cage-intolerant species. Also, the biting collection method of collecting individuals is quite stressful, particularly if mosquito numbers are scarce. The chemical did, however, impart a high level of control against the *An. quadrimaculatus* tested at the 24-h reading at which mean mortality did not fall below 88.0% at any distance.

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