# EVALUATION OF EQUIPMENT MODIFICATIONS AND DOSAGE RATES OF GROUND ULV APPLICATIONS OF NALED AGAINST *AEDES TAENIORHYNCHUS* IN A FLORIDA CITRUS GROVE

G. ALAN CURTIS AND JAMES MASON

*Indian River Mosquito Control District, P.O. Box 670, Vero Beach, FL 32961-0670*

ABSTRACT. Efficiency of ground-applied naled (Dibrom 14), based on caged mosquito bioassays in a moderately vegetated coastal southeastern Florida citrus grove, proved to be significantly associated with downwind distance. However, association analysis between wind speed, temperature or relative humidity revealed no correlation between these meteorological factors and mosquito mortality. Tests conducted with 3 of the commonly used ULV machines demonstrated no significant differences in efficiency. Equipment modifications to simulate aerial application by elevating the spray release point proved ineffective. Increasing the dosage of naled to 3 times the labeled rate for ground treatment resulted in greater than 95% mortality.

## INTRODUCTION

Ground ultra low volume (ULV) application of insecticides for adult mosquito control has become the standard of the industry since its introduction by Mount et al. (1968). This method, used by virtually all mosquito control agencies to some extent, is generally considered by the public to be "mosquito control" due to its high visibility. Reluctantly however, it is considered the least effective of the various control methods commonly employed in a progressive mosquito control operation. Operational programs are constantly faced with the erratic results of ground ULV with retreatments to suppress adult mosquito populations being considered the norm. This unpredictability often appears to be most evident when the habitat to be treated is heavily vegetated (Taylor and Schoof 1971), a common condition around salt marshes and agriculturally cultivated locations in coastal southeastern Florida. These areas pose particular problems in that they are prolific producers of mosquitoes, principally floodwater *Aedes* species.

In addition to vegetation, meteorological conditions (e.g., wind speed, wind direction, humidity and temperature) have also been implicated as contributing factors influencing the efficiency of ground ULV treatments (Henderson et al. 1985).

In 1985, we conducted a series of ground ULV tests to identify and quantify some of the important meteorological and physical conditions associated with insecticide induced mosquito mortality in moderate to heavy vegetation. These tests were designed to evaluate the comparative effectiveness of several equipment and technique modifications on the successful insecticide penetration in moderately vegetated areas. Experiments were conducted during what we felt were normal operational situations, those in which spray trucks are commonly deployed for adult mosquito control. The tests were sufficiently replicated to make statistically accurate evaluations of the various parameters believed to influence ULV treatments. This paper is a report on the findings of that investigation.

## MATERIALS AND METHODS

*Study area.* All field tests were conducted in a mature 120 acre (48.6 ha) coastal citrus grove ca 10 miles (16.1 km) north of Vero Beach, Florida, typical to others along coastal southeastern Florida (Curtis 1985). This habitat was selected because it represented the moderate to heavily vegetated areas that are commonly treated. Citrus groves comprise some 65,000 acres of Indian River County.

*Test procedures.* Three to six day old laboratory reared flamingo strain *Aedes taeniorhynchus* (Wiedemann) females were caged (25/cage) in modified WHO cages (Haile et al. 1982). Prior to testing, caged mosquitoes were placed in styrofoam ice chests and provided 10% sucrose. Immediately following insecticide exposure, mosquitoes were mechanically transferred to clean plastic holding cages where the sucrose solution was also available. Additionally, control cages were identically handled but not exposed to the insecticide. These control mosquitoes were used for mortality adjustment. If control mosquitoes exhibited greater than 10% mortality in any test, that particular test was discarded from the data set. Mosquito mortality was assessed 12 hr. post-treatment. Generally, 4 separate tests were conducted nightly with weather conditions usually being the determining factor.

The test plot consisted of 2 parallel transects 50 ft (15.2 m) apart. Mosquito cages were hung at the top of 4 ft (1.2 m) polyvinylchloride stakes spaced at 100 ft (30.5 m) intervals from the application point to 500 ft (152.4 m). Both sets of cages were positioned in the mid-section of the test site. This allowed the spray truck to make a 0.25 mi (0.46 km) pass by the test cages which was sufficient to allow insecticidal drift to the most distant cages even with quartering wind directions. Perimeter roads permitted ground treatments under all wind directions so that insecticidal applications were made nearly perpendicular to the test plot and wind direction.

*Meteorological data collection.* Meteorological data was collected at 1 sec intervals and stored with a recording anemometer (Weather Measure #2010) and recording wind vane (Weather Measure #2005) coupled to a portable IBM PC computer. This data was later analyzed in concert with the mosquito mortality information. Relative humidity was measured at the start of each test and entered into the data storage program. Temperature was measured at 4 and 25 ft (1.2 and 7.6 m) heights for detection of temperature inversions.

*Experimental procedures.* Tests were divided into 3 groups: 1) standard dosage for base line comparisons, 2) modified equipment, and 3) high dosage tests. Baseline tests were conducted for each of the standard machine configurations using the labeled dosage rate before any modifications were attempted. The 3 machines, LECO, London Aire and Curtis-Dyna, were all standard machines with only a variable insecticide flow rate system added, which accurately delivered the proper dosage with changing vehicle speed. Vehicle speed in all tests was approximately 10 mph. Comparisons among the standard machines was primarily to demonstrate that there were no initial biases. The modifications are as follows: 1) The London Aire was adapted to a Buffalo Turbine with the nozzle injected into the upward air flow of the Buffalo Turbine. Tests using this modification were conducted in two phases, the first using only the London Aire ULV machine with the turbine inoperative. This was to verify that the equipment modification had not changed the performance of the ULV machine. 1b) The London Aire ULV was operated with the turbine functioning. 2) The output of the Curtis-Dyna was elevated using manufacturer supplied extension tubes from 4 ft to 13.5 ft (approximately that of the tree canopy). In the tests involving the Buffalo Turbine, the turbine was directed upwards allowing the prevailing wind to disperse the propelled insecticide droplets into the test plot. Both of the modifications were with the intent of simulating an aerial application from the ground. It was hypothesized that with both modifications, descending droplets would be able to drift greater distances not having to penetrate the citrus vegetation.

*Calibration and dosage.* Prior to each test all ULV machines were calibrated to insure proper insecticide output. Droplet analysis (Beidler 1974) was conducted on all 3 machines to assure that they all functioned similarly. Naled (Dibrom 14) was applied at 3.6 fluid oz/min in all but the triple dose tests (10.8 fluid oz/min). The 10.8 fluid oz/min rate was selected as a reference point, we wanted to pick a rate that was sufficiently high to insure optimal lethality, yet one that was operationally possible.

*Statistical methods.* Comparisons between tests were evaluated using a Kruskal-Wallis Multiple Comparison technique (Dunn 1964).

## RESULTS

From May 1985 through December 1985 110 individual tests were conducted. Meteorological conditions varied, as expected, during the course of the investigation. Ambient temperature ranged between 23 and 35°C (mean = 26.5 ± 4.0°), relative humidity between 74 and 100% (mean = 89.0 ± 6.9%) with wind speed between 0.2 and 8.6 mph (mean = 4.1 ± 1.7 mph). Association analysis revealed that mosquito mortality and changes in the various meteorological parameters were independent.

Figures 1, 2 and 3 illustrate the absence of correlation between the various meteorological elements measured and mosquito mortality at the standard Dibrom 14 rate. Figure 1 shows that there was no relationship between wind speed and percent mortality ($r^2 = 0.021$, $P > 0.63$, df = 37). Similarly, temperature and relative humidity (Figs. 2 and 3) demonstrate no significant ($r^2 = 0.002$, $P > 0.1$, df = 37, and $r^2 = 0.002$, $P > 0.22$, df = 37, respectively) trends with increases or decreases in these two meterological parameters.

*Data adjustment.* The test plots were set up so that treatments could be made with any wind direction. However, it is obvious that the spray traveled greater distances to reach a particular cage whenever the wind angle was not exactly perpendicular to the direction of the application truck. For example, for cages at 500 ft; if the wind is exactly parallel to the test plots then the functional distance the droplets travels is 500 ft. However, if the wind is at 45° to the test plot the distance traveled is 707 ft. Figure 4 shows the significant negative relationship ($r^2 = 0.45$, $P < 0.001$, df = 194) between mosquito mortality and the test cage distance from the insecticide output (standard Dibrom 14 rate). To adjust for this condition of varying wind angle, which affects the distance the spray travels, an average angle of wind direction ($V\Theta$) was determined by vector analysis from the continuous meteorological record, velocity (V) and direction ($\Theta$) were used in the following equation:

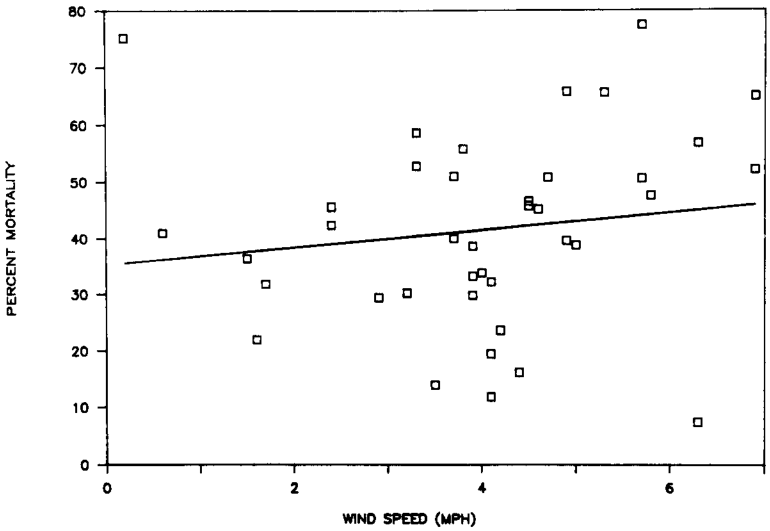


Fig. 1. Relationship between wind speed and caged mosquito mortality evaluated at the labeled dosage rate of Dibrom 14.

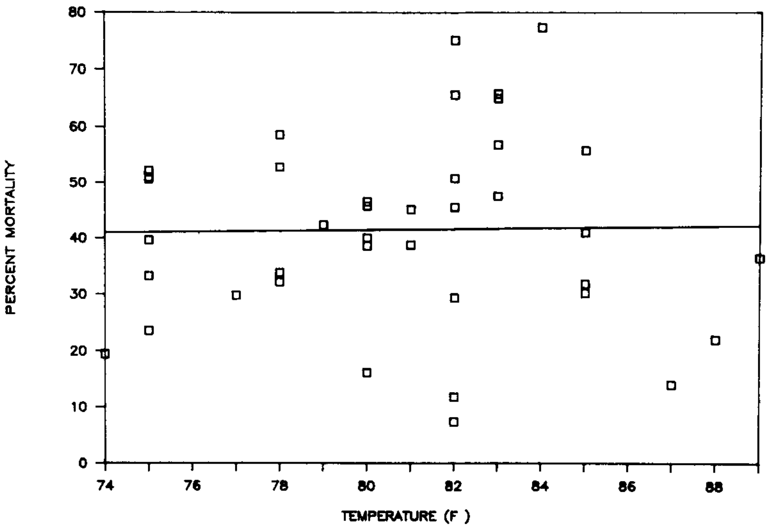


Fig. 2. Relationship between temperature and caged mosquito mortality evaluated at the labeled dosage rate of Dibrom 14.

Where average direction during test = $V\Theta$, X = horizontal vector component and Y = vertical vector component.

$$\Sigma X = V_1 \cos(\Theta_1) + V_2 \cos(\Theta_2) \cdots V_n \cos(\Theta_n)$$

$$\Sigma Y = V_1 \sin(\Theta_1) + V_2 \sin(\Theta_2) \cdots V_n \sin(\Theta_n)$$

$$V\Theta = \tan^{-1}(\Theta) = (\Sigma X)/(\Sigma Y)$$

$V\Theta$ allowed estimation of the actual distance the spray travelled to reach the cages, as follows:

Actual Distance = measured distance/sin($V\Theta$)

Mosquito mortality correction was determined by least squares fitting of the test data for tests where the wind direction was nearly parallel (within 3 degrees) to the test plot. This gave a prediction of what, under the best wind conditions, could be expected given the variances encountered in experimentation. The equation calculated for estimated mortality at a given distance (X) was:

estimated mortality (Y)

$$= 324.65 - 49.25\,(\ln(X))$$

$$r^2 = 0.817,\ n = 80$$

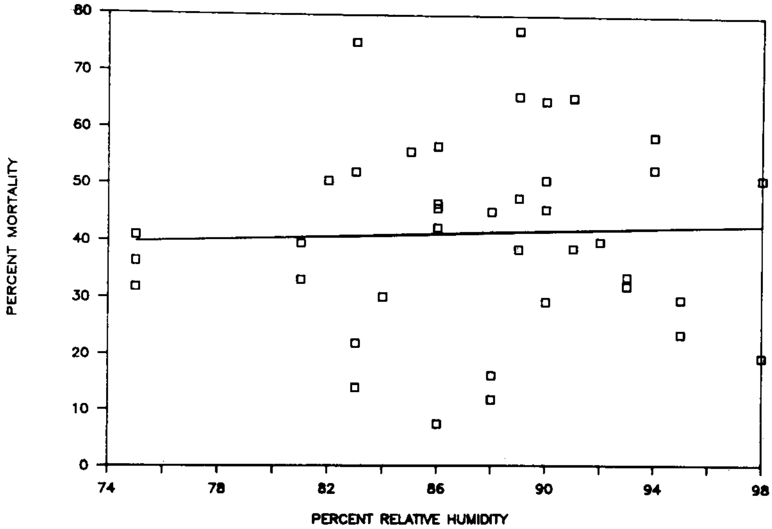


Fig. 3. Relationship between relative humidity and caged mosquito mortality evaluated at the labeled dosage rate of Dibrom 14.

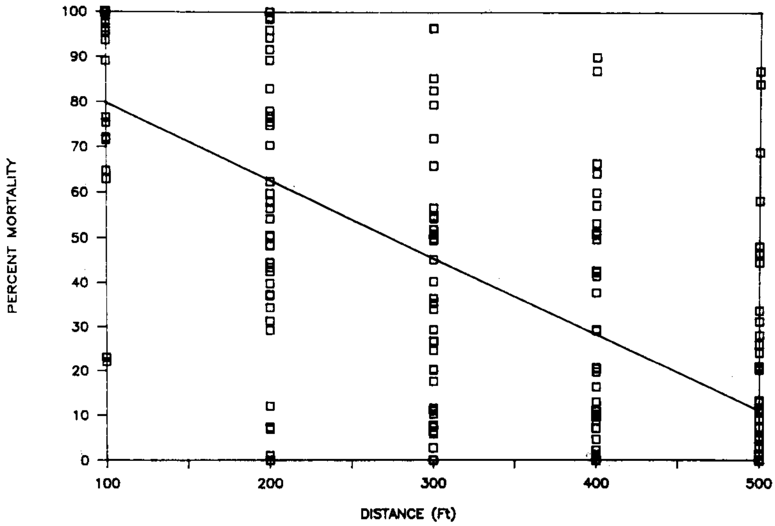


Fig. 4. Relationship between distance and caged mosquito mortality evaluated at the labeled dosage rate of Dibrom 14.

With these equations we could then correct mosquito mortalities at varying wind angles relative to the actual cage placement. This made inter-test comparisons more homogeneous for statistical analysis. Corrections were not necessary for any of the meteorological parameters since they were independent from treatment efficiency. For comparative purposes, all mortality data were adjusted for distance in accordance to the wind direction during that particular experiment. In all cases the adjustment for distance resulted in only a slight increase in percent mortality.

*Standard rate tests.* The first series of trials were baseline tests using naled at the labeled rate (3.6 fluid oz/min). These were used for both comparing the various ULV machines and the varying techniques. Table 1 illustrates the results of the standard tests with the 3 ULV machines (LECO, Curtis-Dyna and London Aire). There was not a significant overall difference (all distances combined) between any of the machines tested ($P \leq 0.35$, n = 49). However, in comparing the various distances, the Curtis-Dyna was significantly better than either of the other 2 machines at 200 ft ($P \leq 0.05$, n = 245).

Although the Curtis-Dyna appears to cause better overall mortality than the LECO or the London Aire (56.5% vs 39.6% and 32.8%, respectively), the difference was not statistically significant.

The droplet analysis revealed that the Volume Median Diameters (VMD) of all machines were not significantly different (Kolmogorov-Smirnov, $P \geq 0.45$).

*Equipment modifications at standard rates.* Table 2 shows the results of elevating the Curtis-Dyna nozzle to tree canopy height. Note that there was only slight improvement at 300–500 ft and a slight deterioration at the 100 and 200 ft placements compared to the standard application. This special configuration resulted in an overall mortality of 32%, not significantly different from the standard procedure. Mortality at individual distances also were not statistically different from the standard.

The London Aire modified Buffalo Turbine, with the turbine inoperative, performed like that of the standard London Aire machine (Table 2). Also in Table 2 are the results of the tests using the turbine assisted ULV. This method killed 33.9% of the mosquitoes, which was not statistically different from conventional methods. This technique resulted in some improvement in mortality at 400 and 500 ft, but not statistically different from the standard. However, there was a marked deterioration in mosquito mortality at 100 ft which was significantly less than normal ($P \leq 0.001$, n = 12).

*High dosage rates.* Twelve tests were executed at 10.8 fluid oz/min (3 × the labeled rate for Dibrom 14). The results, shown in Table 2 depicts the efficiency of this increased rate above that of the standard rate. Treatments at 10.8 fluid oz/min produced greater than 95% mortality through 500 ft in the test plot. This is a highly significant increase over any of the standard application methods ($P \leq 0.001$, n = 12).

The last series of experiments was a variation on the triple rate tests. Three individual passes were made by the test plot at 3.6 fluid oz/min, each made within 1 min of the previous pass. These results seen in Table 2, indicate that there is no significant overall difference ($P < 0.45$, n = 12) between the triple dose single pass method and the triple pass normal dose treatment. Both produced greater than 95% mortality through the 500 ft cages.

## CONCLUSIONS

Results from this investigation indicate that under the conditions of these tests, which included penetration of vegetation in a citrus grove, the standard labeled rate for ground ULV application of naled will only produce about 35%

Table 1. Results of labelled dose rate (3.6 fluid oz/min Dibrom 14) with standard application methods. Mortality is percent mean mortality ± SD.

| Application method and (replicates) | Distances (feet) 100 | 200 | 300 | 400 | 500 | Total |
|---|---|---|---|---|---|---|
| LECO (n = 21) | 94.1 ± 17.1 | 45.2 ± 26.8 | 29.7 ± 22.4 | 14.5 ± 14.5 | 14.6 ± 25.0 | 39.6 ± 36.7 |
| Curtis-Dyna (n = 14) | 86.5 ± 22.5 | 71.0 ± 30.3 | 52.3 ± 29.5 | 47.7 ± 26.3 | 30.2 ± 21.2 | 57.5 ± 32.1 |
| London Aire (n = 12) | 88.0 ± 17.5 | 46.2 ± 30.9 | 17.2 ± 32.5 | 11.2 ± 21.0 | 1.8 ± 3.6 | 32.9 ± 38.3 |

Table 2. Results of experimental application methods and dosage rates. Mortality is percent mean mortality ± SD.

| Application method, dosage rate and (replicates) | Distances (feet) 100 | 200 | 300 | 400 | 500 | Total |
|---|---|---|---|---|---|---|
| Curtis Dyna 3.6 oz/min, nozzle at 13.5′ (n = 15) | 73.1 ± 23.5 | 32.4 ± 21.3 | 34.4 ± 34.4 | 35.3 ± 32.8 | 25.0 ± 25.6 | 40.0 ± 32.1 |
| Buffalo Turbine London Aire ULV only, 3.6 oz/min (n = 12) | 82.5 ± 24.8 | 37.8 ± 36.8 | 19.7 ± 27.3 | 43.2 ± 35.3 | 10.6 ± 15.4 | 38.8 ± 36.9 |
| Buffalo Turbine London Aire ULV and turbine, 3.6 oz/min (n = 12) | 51.9 ± 41.2 | 14.0 ± 26.4 | 30.0 ± 35.7 | 47.2 ± 46.6 | 26.5 ± 38.5 | 33.9 ± 38.2 |
| LECO 10.8 oz/min (n = 12) | 100.0 ± 0.0 | 98.6 ± 4.8 | 88.4 ± 19.3 | 93.0 ± 16.0 | 95.1 ± 11.1 | 95.0 ± 12.7 |
| LECO 3 passes, 10.8 oz/min (n = 12) | 100.0 ± 0.0 | 99.8 ± 0.6 | 97.5 ± 5.3 | 96.0 ± 8.9 | 90.5 ± 17.4 | 96.7 ± 9.3 |

mortality at 500 ft, or 52% at 300 ft. This is inadequate in an operational adulticiding program, especially one directed towards high density mosquito populations. Giglioli et al. (1979) accurately pointed out that if adult mosquito control measures are to be considered effective against high density salt marsh mosquitoes they must provide a higher level of protection (greater than 96% reduction), than that expected for low density or vector mosquitoes. Attempts to overcome the vegetation penetration problem by elevating the spray output either by physically raising the nozzle or propelling the insecticide up in the air with an air blast proved to be futile.

Meteorological conditions were unimportant in this set of tests. No statistical relationship could associate changes in wind speed, wind direction, temperature or humidity and caged mosquito mortality. Mortality was dependent upon dosage rate and the distance the test cages were from the application source.

This study strongly demonstrates that with the methods tried in this study, effective ground adult mosquito control can only be achieved by increasing the dosage rate. This is especially applicable for situations such as coastal southeastern Florida where high density salt marsh mosquitoes (*Ae. taeniorhynchus* and *Ae. sollicitans* (Walker)) and two of the citrus grove mosquitoes *Ae. vexans* (Meigen) and *Psorophora columbiae* (Dyar and Knab) may cause a severe annoyance. The conclusion that increasing the dosage rate is a solution for successful adult mosquito treatment in heavily vegetated habitats has been independently determined by Focks et al. (1987). The highest rate we tested (10.8 fluid oz/min) is still well below that labeled for aerial application.

## ACKNOWLEDGMENTS

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attempt to contain the Asian tiger, or Aedes

## ERRATUM

*Journal of the American Mosquito Control Association*, vol. 4, no. 3

Curtis, G. A. and J. Mason. Evaluation of equipment modifications and dosage rates of ground ULV applications of naled against *Aedes taeniorhynchus* in a Florida citrus grove, pp. 345–350.

All references to the dosage rates for Dibrom 14 should be 1.2 fluid oz/min for labeled rate and 3.6 fluid oz/min for triple dose tests.