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OPTIMIZING AN AERIAL SPRAY FOR MOSQUITO CONTROL[1]

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ABSTRACT. The role of proper flight line positioning was demonstrated to be critical for maximizing product efficacy when spraying in crosswinds by small-droplet spray strategies. Characterization studies indicated clearly that aircraft height, small drop emission distribution, and the ambient winds combine to dilute the spray cloud before impacting surface targets. A 5-fold increase in mortality was achieved when we used optimization techniques to position the aircraft during a crosswind treatment test.

KEY WORDS Aqua-Reslin®, aerial spray, model

INTRODUCTION

Mathematical modeling to predict the dispersion, evaporation, and deposition of spray material through the atmosphere, within the canopy, and upon the ground is aimed at simplifying and improving the efficacy and safety of pesticide application. Several models available for the end-user are described in Thistle et al. (1998) and Teske et al. (1998).

After several decades of work by the United States Department of Agriculture Forest Service (USDA-FS) and other organizations, mathematical models for aerosol dispersion have come to compare favorably with verifying empirical field studies. As a result, application techniques have been improved, and confidence in the use of the mathematical models, now known as "computer models," has grown. Brown and Mickle (1999) offered a thorough description of how several popular models work, the inputs required, and outputs available.

Although management of spray drift to optimize insecticide use and achieve application goals has always been a mosquito control industry goal, the use of predictive models has not been a priority as it has been with the USDA-FS. Given this background, we have attempted to bring about a technology transfer during the past 3 years and initiate the use of a predictive spray model in the mosquito control industry. The purpose of this work was to apply a version of the Forest Service Cramer Barry Grimm model (FSCBG) to the aerial application of Aqua-Reslin® adulticide (Bayer Environmental Science, Montvale, NJ) and use its predictive power to document aerosol droplet fate.

MATERIALS AND METHODS

In preparation for this field trial, a series of wind tunnel tests were completed at New Mexico State University for a Tee Jet 8003 hydraulic nozzle and a Micronair AU4000 rotary atomizer. The 8003, oriented at 45° forward, was characterized at 175 and 230 kph with a Malvern spectrometer. An AU4000 rotary atomizer was characterized at the rotational speeds of 7500 and 9000 rpm. An Aqua-Reslin (Aventis Environmental Science, Montvale, NJ) formulation was used at the following dilution rates with water: neat, 1:4.5, and 1:8.

The field study was conducted in November 1999 with the East Baton Rouge, LA, Islander aircraft with an AU4000 mounted between each wing-tank pod. Atomizer blade angle was adjusted to provide a rotational speed of 9000–9500 rpm at 190 kph aircraft speed. A tank mix of 1:4.5 was used during the trials and flows were adjusted to provide an application rate of 1.59 g permethrin per acre (43.8 ml tank mix per acre). With an aircraft speed of 190 kph and a swath width of 152.4 m, a flow rate of 2649.7 ml/min per atomizer (2.65 liters/min per atomizer) was used during the characterization and optimization trials.

For the characterization portion of the trial, sample stations were placed crosswind out to distances of 152.4 m on either side of an into-wind flight line. Characterization flights at 15.2, 30.5, and 60.9 m above ground level (AGL) were conducted. Meteorology at each spray height was monitored and recorded with an ADAPCO, Inc. kitoon. Wind speed, wind direction, and ground and spray height temperatures were recorded continuously during the trials. Surface layer relative humidity was manually recorded during each spray run.

Cloud density was characterized with an array of impingers ranging in width from 2 to 25.4 mm in order to investigate the collection efficiencies of different sampling devices. One set of impingers, located at sampling stations every 15.2 m and out to 152.4 m crosswind to the flight line, included 25.4-mm slides with magnesium oxide (MgO) and Teflon® coatings spinning at 450 rpm. A second set of impingers, also rotating at 450 rpm, located at 30.5-m intervals held a 6-mm MgO-coated slide and a 6-mm Kromekote strip. Rotorods spinning at

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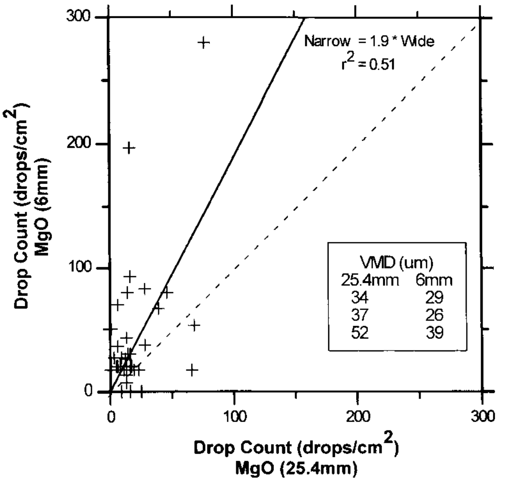

Fig. 1. Comparison of drop densities measured with 6-mm and 25.4-mm MgO slides. Insert compares volume median diameter (VMD) with 2 slide widths.

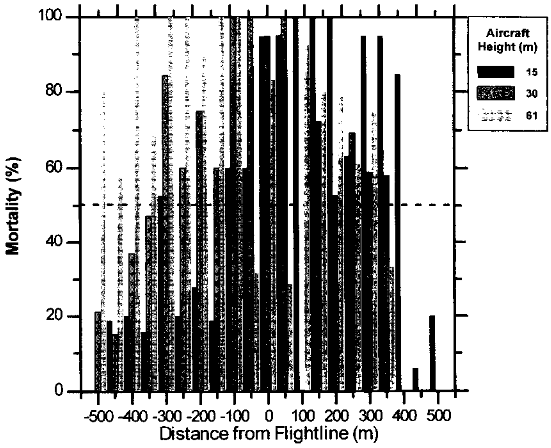

Fig. 3. Mortality results from characterization trials.

2,400 rpm and placed every 60.9 m utilized a U-shaped rod whose surface had been covered with 2-mm strips of Kromekote card. Colocated at each 15.2-m sampling station was a 20.3 × 27.9-cm Kromekote deposit sheet lying flat on the ground surface.

Culex quinquefasciatus (L.) egg rafts were gathered from septic locations outside East Baton Rouge Parish where mosquito control was not present. Ten rafts of eggs were placed in a 91.4 × 45.7-cm pan with 2.54 cm of tap water. Upon hatching, larvae were fed a diet of ground beef liver and yeast. Larvae were separated by ice baths and placed in separate rearing cages. Pupae were subsequently placed inside 30.5 × 15.2-cm pans with tap water and placed inside a humidified 91.4 × 91.4 × 91.4-cm cage. Adults were fed a sugar and water solution. Humidity was kept at 78% and temperature at 26.7°C.

Adults were aspirated with a reverse polarity Black and Decker leaf blower and placed in 0.47-liter ice cream jars. Each ice cream jar had been modified with screening on the lid and bottom. Approximately 100 mosquitoes were placed in a jar. The jars were then placed into a freezer at −2.2°C for 1 min. The mosquitoes were then placed on a chill table. Adults were placed 20 to a test cage. Cages measured 15.2 × 3.8 cm with 0.5-mm-mesh screen on both sides. Cages were then placed into a 121.1-liter cooler, and the mosquitoes were provided sugar water on dental cotton balls 2 times per day. Humidity was provided with water-soaked paper placed in the cooler in an additional container.

Mosquitoes were taken to the field in lots of 21 cages with a strap attached to each for hanging onto poles 1.5 m above ground. These mosquito cages were colocated at each of the 15.2-m sampling sta-

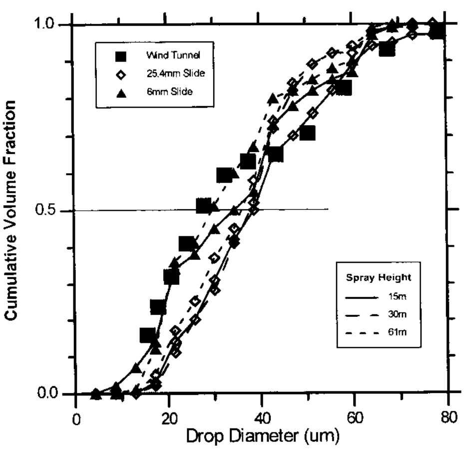

Fig. 2. Drop size distribution from bulked impinger slides compared with AU4000 emission distribution.

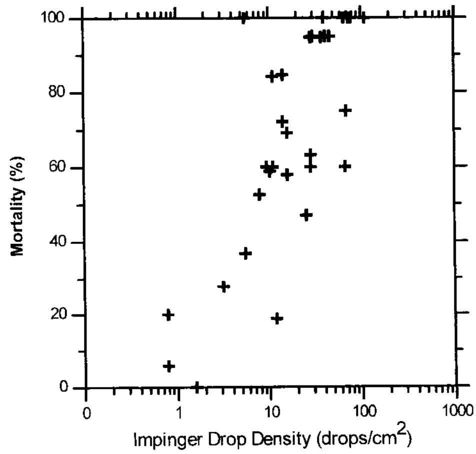

Fig. 4. Relationship between mortality and drop density on 25.4-mm MgO slides for characterization sprays.

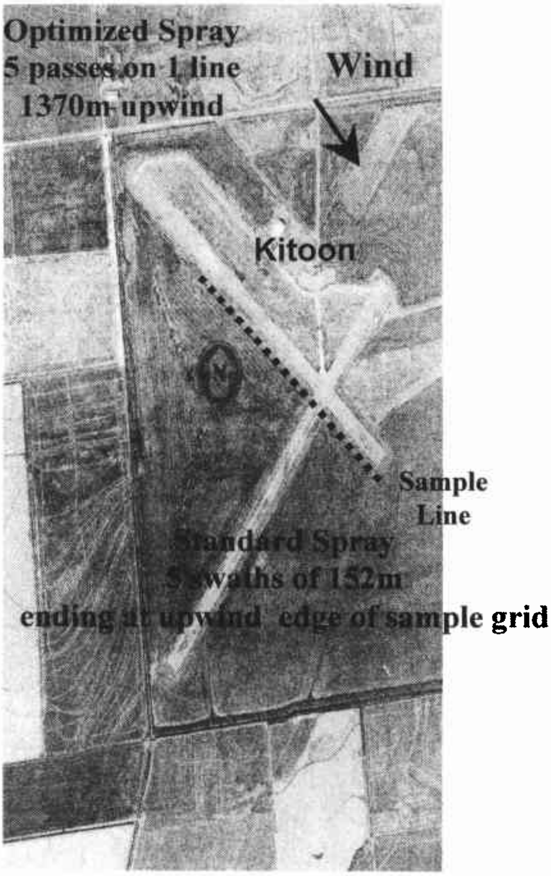

Fig. 5. Overview of experimental design for comparison of standard and optimized block spraying. Aqua-Reslin® was sprayed at 3.9 g/ha (0.0035 lb/acre).

tions described above. Prior to each spray run, mosquito mortality was recorded at each sample cage. At a location removed from the test area, 4 control cages were deployed to record natural mortality in an untreated area.

Cages were recovered approximately 15–30 min after the spray had been completed. Cages were placed into CO_2-filled jars 1 at a time for 5 sec. The mosquitoes were then removed and transferred to a clean cage. Cages were placed into a clean cooler and mosquitoes were fed and humidified. Each cage was labeled with prespray mortality. Mortality was recorded at 1 and 24 h. Final mortality was corrected for prespray mortality by Abbot's formula (Abbot 1925). Control mortality ranged from 0 to 10% for the characterization trials.

RESULTS

During the characterization trials at midafternoon, humidity was relatively low (60–70%) with temperatures at spray height approaching 15.6°C. Surface layer temperatures were nearly 5.5°C warmer until 1600 h, at which time surface cooling quickly commenced. Winds at spray height remained brisk (13–22 kph) from the northwest during the 3 characterization spray runs. Spray flight lines were extended upwind of the sampling line to distances of 20× spray height in order to maximize the probability of small droplets reaching the impingers.

Volume median diameter (VMD) determined from 25.4-mm Teflon slides was about 50% of that determined with the MgO-coated slides. VMDs on Teflon/MgO for 15.2, 30.5, and 60.9 m were 17.9/34, 18.7/36.7, and 19.7/34.8, respectively. Droplet densities on 6-mm MgO slides were typically higher than on the 25.4-mm MgO slides (Fig. 1).

Combining MgO slides for each characterization trial provides an overall drop size distribution at ground level (Fig. 2). Measured drop size distribution with 6-mm slides resulted in a lower VMD than for 25.4-mm slides. The 6-mm slides produced a VMD of 32.5 μm, in good agreement with wind tunnel results of 28 μm. The use of the 25.4-mm slides resulted in a VMD of 40 μm due in part to the lower collection efficiency for very small drops. Despite the reduction in drop density for greater spray heights (Fig. 1), little difference was observed with release height. This result suggests that extending the flight line well upwind of the sample grid resulted in the smaller drops reaching the surface by the time they passed through the sampling grid. No deposit was found on the Kromekote cards at each 15.2-m sampling station or on the 6-mm Kromkote strips, probably due to the small drops being produced at the atomizer. Given the small droplets and the consequent low dye content, no stains were observed.

Efficacy results from the characterization trials are presented in Fig. 3. With the use of Abbot's formula, mortality reflects total cage mortality adjusted by prespray cage mortality. At all spray heights, mortality consistently surpassed 80% over the central portion of the swath. With increased height, resultant swath (in terms of mortality) widened.

Combining drop density data for each sampling site with mortality begins to define efficacy curves for Aqua-Reslin when sprayed from AU4000s spinning at 9,000 rpm. In Fig. 4, mortality has been plotted against drop density on 25.4-mm MgO slides. Over a 2-order magnitude range in measured drop density, mortality increases from near 0 to 100%. Drop densities above 30–40 droplets/cm^{-2} were consistent with high mortality. If drop density is combined with drop size, mortality can be expressed in terms of quantity of permethrin available at each sampling location. That calculation is not provided in this work. The above data were generated to "characterize" the aircraft as to its droplet spectra distribution.

After the characterization of the aircraft/nozzle combination available for the test, a comparison be-

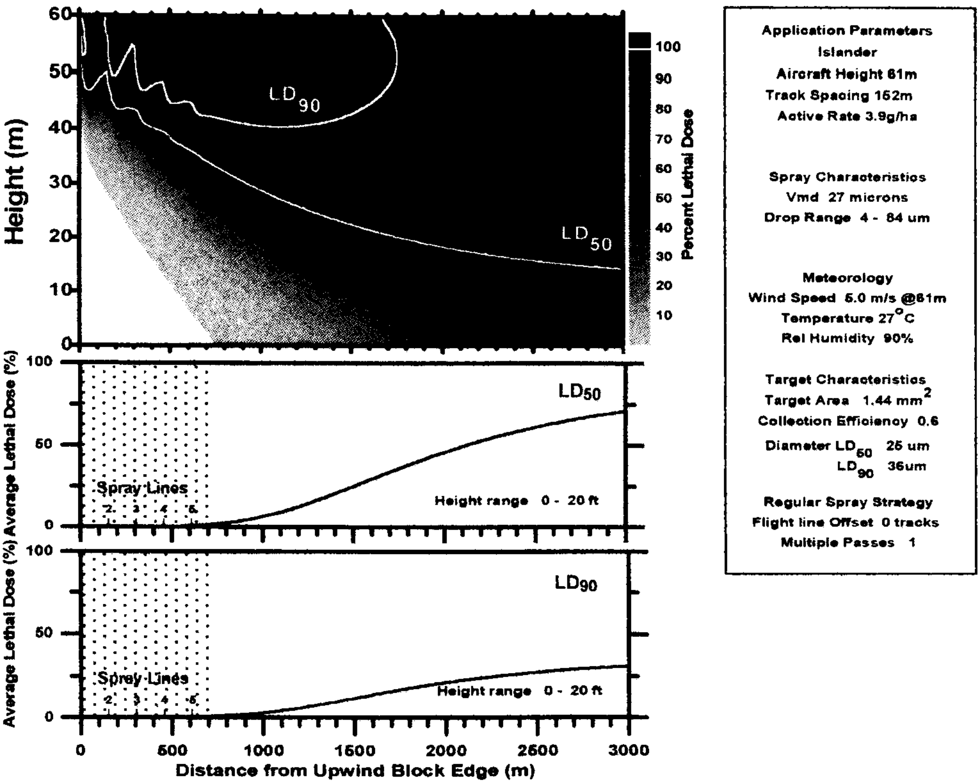

Fig. 6. Predicted mortality along sampling grid from standard spray at 61-m height. LD_{50}, average lethal dose; LD_{90}, lethal dose at 90% mortality; vmd, volume median diameter.

tween a standard (=label recommendation) and an optimization spray scenario was conducted. A sampling line containing 25.4- and 6-mm MgO slides was established parallel to the predominant wind direction (Fig. 5). Impinger stations (=sampling points) were placed 30.5 m apart over a distance of 701 m. A cage containing 20 mosquitoes was also hung at 1.2 m above the ground at each sampling point.

These trials took place after sunset when temperatures had cooled to 10°C at the surface with humidity near 90%. Winds remained brisk at 19 kph from the northwest.

The standard spray consisted of 5 swaths commencing downwind and progressing in 91.4-m (300 ft) increments to the upwind end of the sample grid. This treatment is similar to that conducted for virtually every aerially delivered adulticide in the industry. Aircraft height was maintained at 60.9 m AGL. Efficacy (Fig. 6) was predicted to be negligible across the sampling grid because of the combination of high aircraft height, small emitted droplet size distribution, and strong wind (Mickle and Brown 2001). The highest 50% lethal dose probability peaked in the vicinity of 3,048 m downwind from the last spray line. The importance of proper flight line offset when spraying very small droplets would then be clearly demonstrated. Spraying too close to a target zone will ultimately result in less than desirable efficacy results because the small droplets would overshoot the target.

An optimization trial was conducted in meteorological conditions similar to those for the standard spray. In order to increase drop density and efficacy down the sampling line, flight paths were moved 9 swaths (1,371.6 m) upwind of the initial sample point (Fig. 7). As a result, the model predicted droplet density and hence efficacy to be substantially greater than the standard sprays. Model predictions suggested that down the sampling line, 50% mortality should be observed at least 50% of the time. Higher mortalities have been predicted with other optimization studies. The fact that higher mortality was not predicted in this study was due to the limited number of spray lines. When small droplet spraying is coupled with high release heights, diffusion of the spray cloud plays a significant role in determining cloud density and hence product efficacy for a target near the ground.

Impinger data confirmed that droplet densities down the sample line were significantly greater from the optimized spray as compared with the standard spray runs. Average drop densities on 25.4-mm MgO slides from the optimized sprays

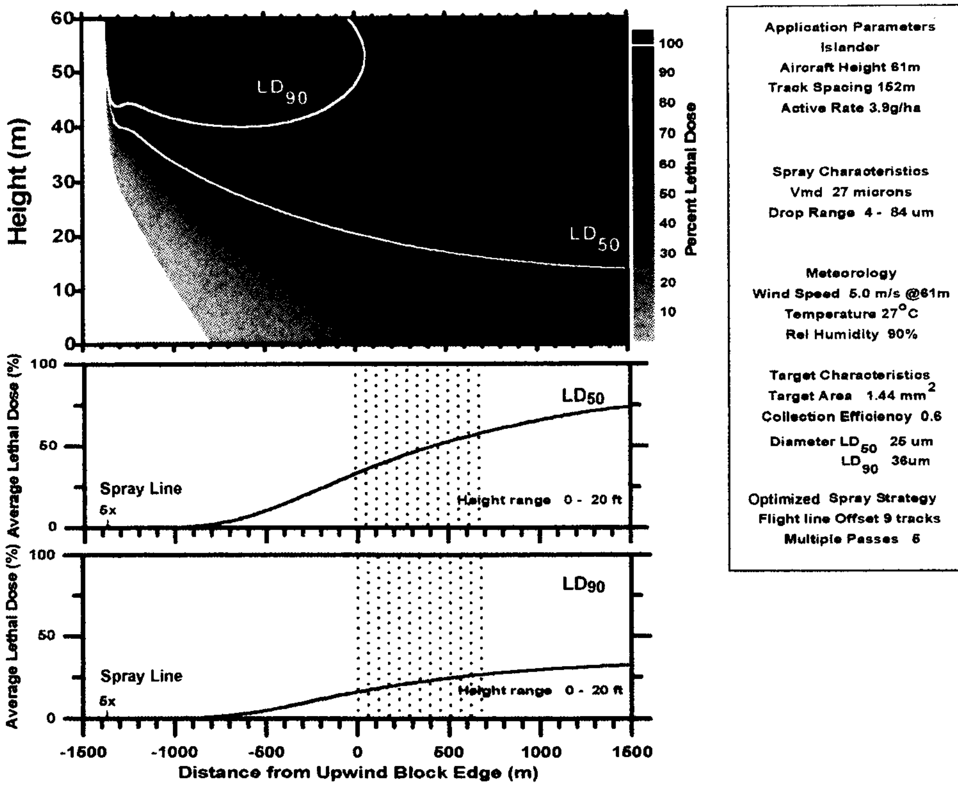

Fig. 7. Predicted mortality along sampling grid for optimized spray at 61-m height. LD_{50}, average lethal dose; LD_{90}, lethal dose at 90% mortality; vmd, volume median diameter.

were 12 droplets/cm^{-2} compared with the standard spray of <1 droplet/cm^{-2}. The 6-mm MgO slides resulted in 22 droplets/cm^{-2} for the optimized trial. Limited droplet counts (<1 droplet/cm^{-2}) precluded further analysis of the 6-mm slides from the standard spray method.

For the optimized spray, little variation in drop count or size was found along the 710-m sampling line of 25.4-mm slides (Fig. 8). Droplets with diameters ranging from 40 to 60 μm were most commonly observed over the sampling distance. The absence of small droplets in comparison with the earlier characterization flights may suggest the developing nocturnal inversion may have retarded their movement to the surface. Combining data from all stations provides spatial maps of changes within the cloud as it moved along the sampling line. Over the length of the sampling line, the drift cloud (Fig. 9) was dominated by 40-μm droplets, markedly different from the characterization spray for the 60.9-m AGL flight. There was no significant change in cloud density or droplet size with downwind distance. This is characteristic of small-droplet clouds when sampled at a significant distance from the source. When droplet density is converted to volume (Fig. 10), the majority of pesticide mass is confined to 40–65-μm droplets. Again little variation was noted with downwind distance along the sampling line.

Combining data from each slide results in drop distributions with VMDs that are larger than both the wind tunnel characterization and the earlier 60.9-m AGL characterization flight (Fig. 11). Few droplets smaller than 20 μm were observed along the sample line. The VMDs were 41 and 52 μm for the 6- and 25.4-mm slides, respectively. Although a portion of the VMD shift from wind tunnel results is due to sampling inefficiency of the rotary slides, the VMD shifts of both 6- and 25.4-mm slides compared with the characterization spray for the 60.9-m AGL flight may indicate the potential influence of stable air limiting the downward displacement of small droplets during these evening trials.

Measured drop densities on the 25.4-mm slides (12 droplets/cm^{-2}) were consistent with model predictions of 50% mortality for the optimized spray (Fig. 11). The mortality–drop relationship for the optimization trials was consistent with the characterization trial (Fig. 12).

Efficacy results (Fig. 13) also tended to confirm model predictions of differences between the standard and optimized sprays. Unfortunately, prespray mortality counts were not made on the caged mosquitoes prior to the standard spray run. It is worth

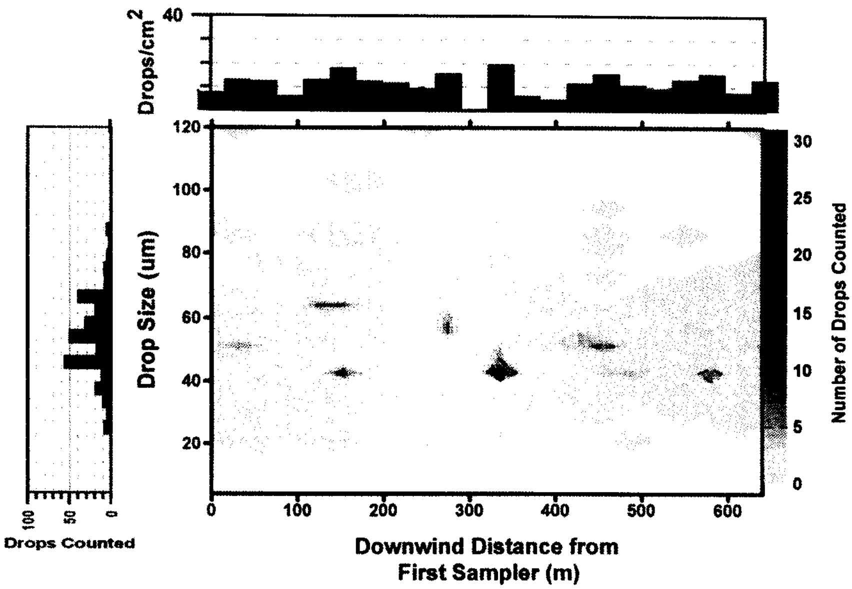

Fig. 8. Spatial variation of drop counts on 25.4-mm MgO slides from optimized spray.

noting that average prespray mortality for the optimized spray was 1.4 mosquitoes per cage, in close agreement with the control population mortality (1.5 mosquitoes per cage) during the standard spray. Given this low control mortality, the impact of flight line offset and multiple-pass spraying is clearly evident in the significant increase in mortality for the optimization spray. Average mortality along the sample line is consistent with model predictions, ranging from 40% to 60%. There was an apparent tendency for increased mortality downwind to 518.2 m from the first sampling point (Fig. 12) as predicted (Fig. 7). Mortality beyond 518.2 m decreased sharply. This decrease may be attributed to the overall dilution of the aerosol cloud spreading out as it moved downwind.

CONCLUSIONS

This field trial was designed to characterize the efficacy of Aqua-Reslin with the use of small droplet aerial technologies. Teflon slides (25.4 mm) pro-

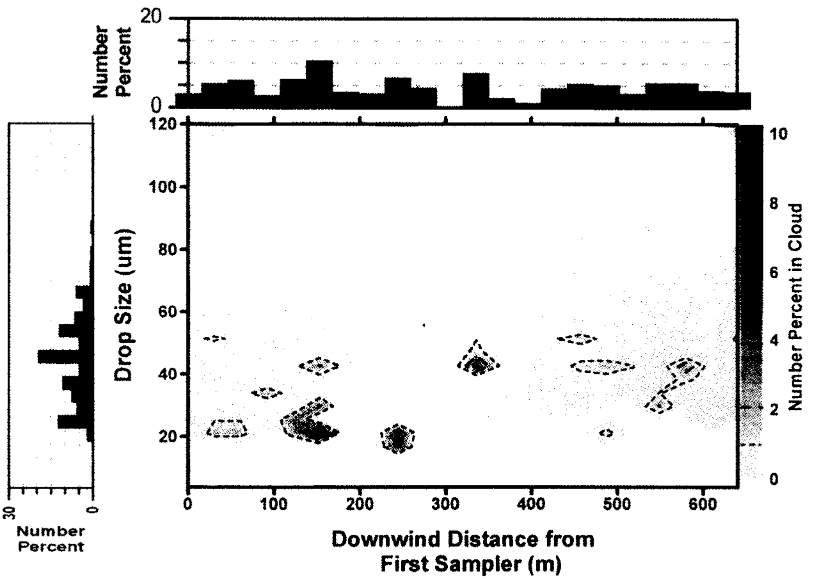

Fig. 9. Number–size distribution of spray cloud along the sampling line for optimized spray.

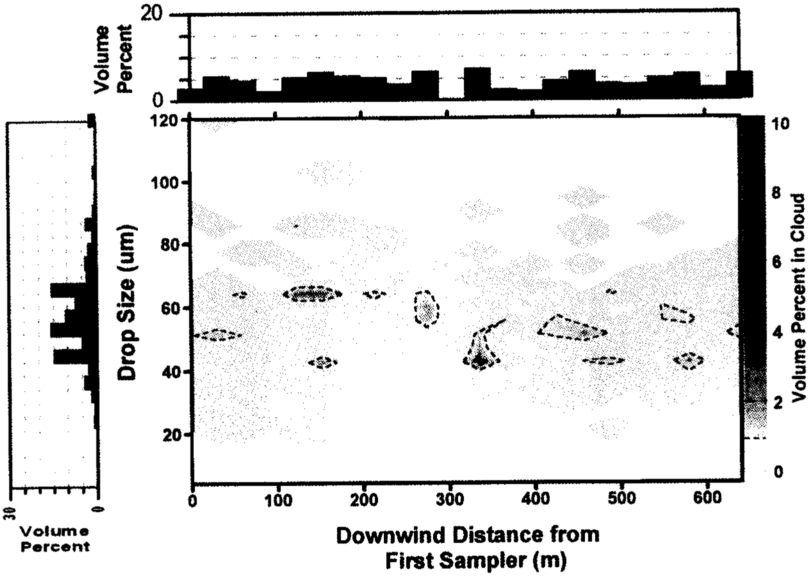

Fig. 10. Volume–size distribution of spray cloud along the sampling line for optimized spray.

duced a measured VMD that was about one-half the measured VMD with 25.4-mm MgO slides. The reason for this inconsistency is not clear although forced evaporation of the aqueous formulation cannot be ruled out.

The collection efficiency for 6-mm MgO slides was significantly higher than for the 25.4-mm MgO slides. The 6-mm MgO slides resulted in nearly a factor of 2× the increase in calculated drop density and corresponding reduction in VMD.

Characterization sprays provided detailed spatial information on cloud structure along the crosswind sample line. At all spray heights, 20-μm droplets dominated the overall cloud structure during afternoon unstable spray conditions. Maximum cloud density tended to span an area up to 121.9 m wide. However, high mosquito mortality was observed for swath widths ranging 121.9–243.8 m depending on aircraft height. Comparison of mosquito mortality with slide density indicated that high mortality was achieved with drop densities approaching 20–30 droplets/cm^{-2}. These studies also show 100% mortality can be achieved when applying Aqua-Reslin in moderate winds that are parallel to the flight line and using small droplet (VMD <30 μm) technologies at spray heights up to 60.9 m AGL.

The role of proper flight line positioning was demonstrated to be critical for maximizing product efficacy when spraying in crosswinds by small-

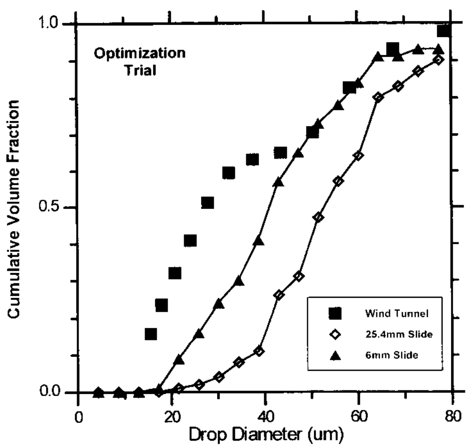

Fig. 11. Composite drop size distribution from 6- and 25.4-mm slide arrays.

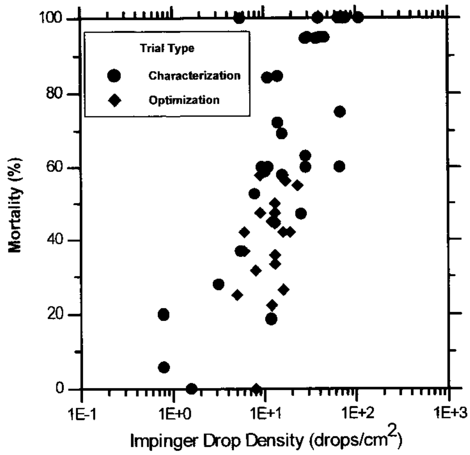

Fig. 12. Comparison of mosquito mortality and drop density for the characterization and optimization trials.

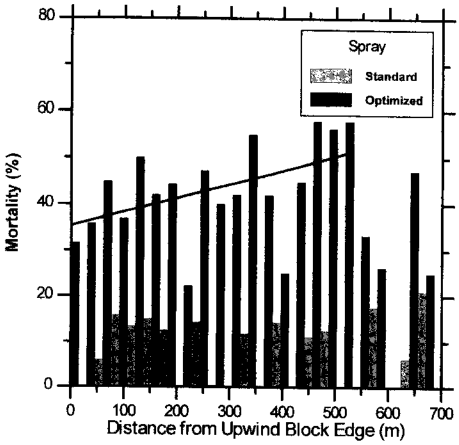

Fig. 13. Comparison of caged mosquito mortality from standard and optimized sprays when Aqua-Reslin® was applied at 3.9 g ai/ha.

droplet strategies. Aircraft height, small drop emission distribution, and winds combine to dilute the spray cloud before impacting near-surface targets. A 5-fold increase in mortality resulted when optimization techniques were used to position the aircraft during crosswind treatment programs (Fig. 13). Less than 100% mortality was accurately predicted for the optimization spray because of a limited number of spray lines. Block size dictates operational factors that are required to achieve high mosquito mortality in this scenario. Aircraft height will have to be lowered below 60.9 m when targeting small areas with small-droplet sprays.

ACKNOWLEDGMENTS

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