ticular, have a greater tendency to impinge into water, rather than onto a solid surface; it is quite apparent that further and more basic research should be conducted to ascertain the cause of this relationship.

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# EVALUATION OF THE ULTRA-LOW VOLUME AERIAL SPRAY TECHNIQUE BY USE OF CAGED ADULT MOSQUITOES

CARLISLE B. RATHBURN, JR., ANDREW J. ROGERS, ARTHUR H. BOIKE, JR. AND ROBERT M. LEE

West Florida Arthropod Research Laboratory, Florida State Board of Health, Panama City, Florida

Since the introduction of the ultra-low volume (ULV) aerial spray technique (Messenger, 1963), a number of reports have been published on the effectiveness of this procedure against natural populations of mosquitoes, evaluation being by pre- and posttreatment landing rate counts in most instances. (Stevens and Stroud, 1966, 1967; Glancy *et al.*, 1965, 1966; Mount and Lofgren, 1967; Knapp and Pass, 1966a, b; Knapp and Roberts, 1965; Knapp and Gayle, 1967; Knapp and Rogers, 1968.)

Early trials by this research group, using caged mosquitoes to evaluate results in two different habitats, were disappointing (Rathburn *et al.*, 1968). It was felt that distribution and behavior of the small droplets produced by this technique were the important factors affecting results. Rogers *et al.* (1965) gave some insight into the problem when they demonstrated the effect of habitat on the penetration of spray droplets and subsequent kill of mosquitoes. Cutkomp *et al.* (1950) also realized the importance of a study of factors contributing to the successful control of insects by aerial sprays when they demonstrated the effect of air temperature, spray density, flight altitude and droplet size on the deposition of spray droplets from aircraft. Probably the most comprehensive single treatment of the behavior of aerial sprays is offered by Johnston *et al.* (1947), who list droplet spectrum and the number of droplets reaching the mosquito habitat, the type and height of vegetation and meteorological conditions as some of the more important considerations in the aerial dispersion of insecticides. Many other research workers also have added to our knowledge in this area; however, much of this research is agriculturally oriented and therefore the problems are not necessarily the same as those encountered in vector control.

The objective of the study reported here was to evaluate the ULV technique with special emphasis on size, number and distribution of droplets in the target area, using caged adult mosquitoes as the principal means of evaluation.

METHODS. All tests were conducted with

a 220 h.p. Stearman airplane flown at 80 miles per hour. Flat fan nozzles positioned at a 45 degree forward angle were used in all tests. The treatment area consisted of fairly level land covered with small planted pines and scrub oak (Fig. 1). The cages were used in each exposure cage. After treatment the mosquitoes were transferred to clean cages and held with access to sugar solution at room temperature for 12 hours, at which time mortality counts were made. Cages of mosquitoes placed

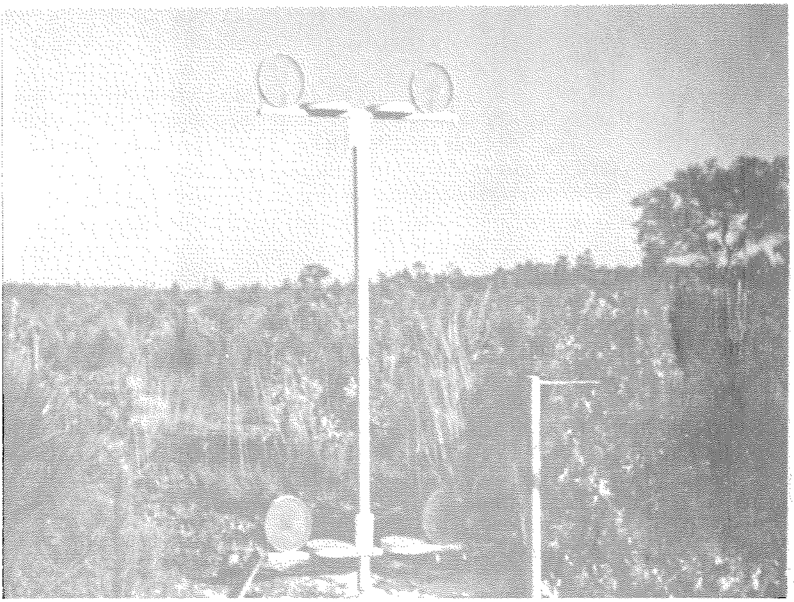

FIG. 1.—The test area showing cages and cards positioned vertically and horizontally at ground level and at 6 feet.

of mosquitoes were placed 50 feet apart in a line perpendicular to the flight line and in the center of the sprayed area. Depending on the test objective, from 4 to 8 cages were used in each of 1 to 3 lines or a total of 4 to 24 cages per test. The lines of cages were approximately 200 feet apart. Total area sprayed was 83 to 238 acres, depending upon the type of test being conducted. All tests were conducted either at sunrise or in late afternoon. Wind velocity was recorded in the test area at altitudes of 1, 5, 10, 20 and 40 feet, and humidity and temperature were recorded at 6 feet above ground level during each test.

The mosquitoes used in the tests were from laboratory colonies and were from 2 to 8 days old; approximately 25 females in an adjacent untreated area were used as checks. Check mortality for all tests averaged 2.6 percent.

Flat cages were used except where otherwise indicated. These were 8 inches in diameter and 1 inch thick with 14 x 18 mesh screen on both sides. Cylindrical cages used in some tests were 6 inches high and 3 inches in diameter. All cages except where otherwise indicated were placed 1 to 2 inches above the ground in a way that prevented ants from entering cages and destroying the mosquitoes.

Droplet data were obtained by use of oil-sensitive dyed cards or microscope slides coated with magnesium oxide. The cards were 3 by 5 inch Kromkote Cover glossy paper (65 lb.) dyed with duPont oil red dye dissolved in acetone at a rate of 0.4

g. per liter. The number of droplets per 2 square inches on each dye card was counted with the aid of a microscope at 10 times magnification. The number of droplets per five to ten 50 mm. traverses on 4 to 8 magnesium oxide coated slides was counted and measured at 100 times magnification. Where average or mass median diameters (mmd) are recorded a minimum of 200 droplets were measured for each determination.

Insecticides used were malathion and naled. Malathion was applied only as technical (95%). Naled at volumes of one ounce or less per acre, was applied as technical (Dibrom 14), but where the volume was more than one ounce per acre a formulation of one part Dibrom 14 to two parts of Ortho Additive in diesel oil was used.

RESULTS. Of prime importance in the evaluation of sprays using caged mosquitoes is the amount of protection the cage offers the mosquito or the penetration of the spray droplets through the cage. Since the results obtained may vary with the type of cage used, it was necessary to determine the type of cage that gave the best droplet penetration. Shown in Table 1 are results obtained using 2 types of cages placed at ground level and 3 feet above the ground. In these tests, 8 cages of each type were placed in a single line in the center of an 83-acre plot of planted pine and scrub oak 3 to 4 feet high. Results (Table 1) show that there was no significant difference between the types of cage used. There was, however, a very significant increase in mortality with

TABLE 1.—Effect of cage type and elevation on mosquito kill using ULV aerial spray of naled.[1]

| | Percent kill | |
|---|---|---|
| Cage type | At ground level | 3 feet above ground |
| Flat | 80 | 91 |
| Cylinder | 77* | 95 |

[1] Four or five fl. oz. per acre (.09–.1 lb./a.); 8002 or 8003 nozzles; 200 ft. swath, 100 ft. altitude.

* Three replications, four all other data.

height above ground. This would indicate that spray droplets were moving horizontally more than vertically.

This difference is also apparent in the data from the next series of tests, which was designed to test effects of elevation as well as orientation of cages and drift beyond the plot. The sprayed area was square in shape and 108 acres in size. Data in Table 2 show that a significantly higher mortality occurred in cages placed 6 feet above the ground than at ground level (Fig. 1). It also was at this height that the maximum number of droplets was deposited on the cards. A greater number of droplets and a higher mosquito mortality were obtained when cards and cages were placed vertically as compared to those laid horizontally. This indicates a horizontal movement of droplets at this height. On the ground or below the top of the low vegetation the number of droplets on the cards and the mosquito mortality decreased significantly and there appears to be little or no difference between those placed horizontally or vertically. Thus it may be assumed that a large portion of the droplets remained in the horizontal air currents above the vegetation.

Also shown in Table 2 are the mortality of caged mosquitoes and the number of droplets collected on dyed cards at 1,000 and 2,000 feet downwind of the treated area. It is evident from these data that the small droplets of low volume sprays are carried for a considerable distance and in sufficient numbers to kill mosquitoes, provided the mosquitoes are well above the ground at the time of spraying. This is only at night for many important species. As in the sprayed area, a greater number of droplets and a higher mosquito mortality were obtained above the vegetation than at ground level. In view of the mosquito kill and the number of droplets collected at these distances downwind, it is evident that many small droplets must have been present which were too small to deposit on the cards. The wind velocity in miles per hour averaged 1.3, 2.5, 3.4, 4.1, and 5.0 at 1, 5, 10, 20 and 40 feet above ground, respectively, for the five tests.

TABLE 2.—The effect of cage position, elevation, and distance downwind of treated area on the mortality of adult mosquitoes and the number of droplets depositing on dyed cards, using ULV aerial spray of malathion.[1]

| Distance downwind | Cage or card Height position | No. tests | % Mort. *Culex*[2] | No. drops per sq. in. | No. tests | % Mort. *Aedes*[2] | No. drops per sq. in. |
|---|---|---|---|---|---|---|---|
| In sprayed area | ground flat | 5 | 16 | 8.7 | 1 | 64 | 2.9 |
| | ground vertical | 5 | 34 | 6.5 | 1 | 54 | 0.4 |
| | 6 feet flat | 5 | 23 | 3.2 | 1 | 69 | 2.8 |
| | 6 feet vertical | 5 | 87 | 25.0 | 1 | 97 | 1.9 |
| 1,000 feet | ground flat | 2 | 0 | 2.3 | .. | .. | ... |
| | ground vertical | 3 | 3 | 0.3 | 1 | 24 | 0 |
| | 6 feet vertical | 2 | .. | 3.8 | .. | .. | ... |
| | 15 feet vertical | 3 | 56 | 9.4 | 1 | 97 | 4.3 |
| 2,000 feet | ground flat | 2 | 0 | 0.5 | .. | .. | ... |
| | ground vertical | 3 | 2 | 0.6 | 1 | 5 | 0.3 |
| | 6 feet vertical | 2 | .. | 1.7 | .. | .. | ... |
| | 15 feet vertical | 3 | 34 | 3.4 | 1 | 77 | 0.8 |

[1] Applied at 3.2 fl. oz./a. (0.24 lb./a.); five 8001 nozzles; 100 ft. swath and 50 ft. altitude.
[2] *Culex*=*Culex nigripalpus*; *Aedes*=*Aedes taeniorhynchus*.

Shown in Table 3 are the number of droplets per square inch obtained on cards placed on the ground next to cylindrical cages containing adult mosquitoes in the center of a 238-acre square plot. These data show that the presence or absence of droplets on cards is no sure criterion of the mosquito mortality to be expected since there was 100 percent mortality of caged mosquitoes adjacent to some cards on which there were no visible droplets. Nevertheless, within the limits of the test, good mortality was obtained in all tests where there were more than 30 droplets per square inch on the cards. It should be understood, however, that the number of droplets in relation to mosquito mortality is dependent on many factors, the more obvious of which are kind of insecticide, dosage and volume used, and droplet size.

TABLE 3.—The percent mortality of caged adult *Aedes taeniorhynchus* compared to the number of droplets per square inch depositing on adjacent dyed cards, using ULV aerial sprays of naled.[1]

| No. droplets per sq. in. | Number of determinations | Percent mosquito mortality Average | Range |
|---|---|---|---|
| 0 | 10 | 64.6 | 32–100 |
| 1–5 | 12 | 68.2 | 24–100 |
| 6–10 | 12 | 89.7 | 13–100 |
| 11–15 | 13 | 91.2 | 62–100 |
| 16–20 | 12 | 94.5 | 59–100 |
| 21–30 | 17 | 97.4 | 76–100 |
| 31–50 | 13 | 98.8 | 89–100 |
| >50 | 7 | 100 | all 100 |

[1] Applied at 16 fl. oz./a. (0.105 lb./a.); ten 6508 nozzles; 200–400 ft. swaths, 100 ft. altitude.

The average diameter of the droplets obtained on the cards in these tests (Table 3) was 76 microns (average of two determinations of 79 and 73 microns—spread factor 1:7). The smallest droplet observed on the cards was about 30 microns and the largest 250 microns.

Shown in Table 4 are the size and number of droplets collected on magnesium oxide coated slides at various discharge volumes in the center of an 83-acre square plot. Although there appears to be an increase in average diameter, mmd, number of droplets per square inch and mosquito mortality with an increase in discharge volume, the differences are small and questionable. Of importance, however, are the rather small average droplet diameters and large number of droplets per square inch compared to those obtained in similar tests using dyed cards.

DISCUSSION. One important factor and one that must be considered is the fact that adult mosquitoes of many species rest

TABLE 4.—Effects of volume on size and number of droplets and mosquito mortality using ULV aerial sprays of naled.[1]

| Volume fl. oz./a. | Dosage lb./a. | Nozzle Tip Size[1] | Alt. feet | Wind @ 40 ft. m.p.h. | Droplet data: Avg. dia. μ | mmd μ | Avg. no. per sq. in. | Percent mosquito mortality |
|---|---|---|---|---|---|---|---|---|
| 1 | .11 | 8002 | 50 | 4 | 28 | 84 | 34 | 61 |
| 4 | .09 | 8003 | 100 | 4 | 34 | 105 | 53 | 79 |
| 4 | .08 | 8003 | 50 | 5 | 32 | 125 | 61 | 83 |
| 5 | .10 | 8002 | 100 | 1 | 41 | 340 | 120 | 87 |

[1] Flight centers 200 ft.; altitude 50 or 100 ft.; 1 replicate each test.

on or near the ground during daylight hours—the time at which these and most aerial tests or spray applications against natural populations are conducted. Therefore, for data to be representative, cages of adult mosquitoes must be placed as close to the ground as possible.

In regard to research on droplet size and number, dyed cards do not adequately sample the small droplets produced by ultra-low volume sprays. This is mainly because of two factors. First, it is impossible to distinguish droplets less than 30 microns in diameter from irregularities of the dyed card even under magnification and second, the efficiency of deposit of horizontally moving droplets below 10 microns in diameter on flat, vertical sampling surfaces is very poor. With the very small droplets present in ultra-low volume sprays a high droplet velocity is necessary for deposition. Although coated glass slides offer good definition of droplets 5 microns in diameter or even smaller, they are still affected by the laws of deposition and also may not give a true representation of droplet size and numbers.

Because of their extremely slow settling velocity, most of the very small droplets are carried by the air currents above the vegetation and do not settle to the ground in appreciable numbers within the treatment area. In this respect ULV aerial sprays behave very much like aerosols, which they undoubtedly are to a large extent. Therefore, it would seem wise to consider this fact in the use of ULV sprays for mosquito control.

Applying volumes of ½ to 3.2 fluid ounces per acre over wooded terrain for mosquito control is quite different from applying 8 fluid ounces or more per acre to open range lands for grasshopper control, yet both operations are classed as ULV. It is evident that much research remains to be done with ULV aerial sprays applied by small aircraft to small target areas.

SUMMARY. The foregoing research has demonstrated that less kill of caged adult mosquitoes is obtained close to the ground than above vegetation only 3–4 feet high when using ULV aerial sprays. In general, fewer droplets are deposited on dyed cards placed horizontally than those placed vertically above the vegetation. This indicates a more horizontal movement of spray droplets above the vegetation, which is a characteristic behavior of aerosol-size droplets. It is evident that the small droplets in the spray are carried for considerable distances even at low wind velocities and are in sufficient numbers to give good mortality of caged mosquitoes 1,000 to 2,000 feet downwind at positions several feet above ground level; however, many species rest at ground level during the daytime when aerial sprays are normally applied. The absence of droplets on dyed cards was no criterion of the kill obtained of caged mosquitoes, although there was a number above which good mortality was always obtained.

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