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RICE FIELD MOSQUITO CONTROL STUDIES WITH LOW VOLUME DURSBAN® SPRAYS IN COLUSA COUNTY, CALIFORNIA
II. OPERATIONAL PROCEDURES AND DEPOSITION MEASUREMENT

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Mosquito control applications using reduced total applied volumes and finely atomized sprays or coarse aerosols were begun in California several years ago (Burgoyne *et al.*, 1967). Studies were initiated in 1966 under a USDA contract with the University of California at Davis, cooperatively with several mosquito abatement districts, the California Department of Public Health, and other state and federal agencies who aided in setting up extensive low-volume application tests. This work culminated in a large-scale program applying Dursban® and fenthion with both fixed and rotary wing aircraft during the 1967 season in the Colusa Mosquito Abatement District. Several thousand acres of wetlands, planted to rice for waterfowl feed, were sprayed, as were a few hundred acres of rice being grown for seed. Dosage rates were 0.0125 to 0.05 lb/acre for Dursban and 0.075 and 0.1 lb/acre for fenthion. Total volumes varied from 4 to 8 fl oz/acre, with assumed swath widths of 150 ft when using a fixed wing Piper

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Pawnee PA25 and 250 ft with a Bell 47 AG helicopter. These tests showed that with high potency chemicals it is possible to reduce application rates to near technical (undiluted) levels and still obtain good larval control.

Further tests in the Colusa area and at Bakersfield during 1968 demonstrated swath width relationships to spray atomization and to wind velocity and direction and temperature gradient (Akesson *et al.*, 1969). Tests were continued in 1969 and became the basis for the 1970 applications. This report describes the equipment and procedures used in 1970 and gives the results of several studies.

SPRAY EQUIPMENT. A Piper PA25, 150 hp Pawnee Aircraft was used to apply low volumes (1.6 fl oz/acre) of Dursban for larval control during the 1970 mosquito season on large areas of rice within the Colusa Mosquito Abatement District.

The spray gear consisted of a wind-driven Sorenson Model 1000 centrifugal pump, electric solenoid control valve and a separate ½-inch boom attached to the normal high volume boom. Four nozzles, Spraying Systems hollow cone, D2-25, directed downward (producing particles about 150/200 microns VMD) discharged 169 fl oz/min of Dursban at 70 psi.

Assuming a 600-ft swath, at 80 mph the airplane would cover 107 acres for an application rate of 1.6 fl oz/acre. The altitude chosen was 100 feet, lowered some when winds exceeded 7–8 mph.

For "dressing off" the edges of the field the two inboard nozzles were plugged and the two outboard D2–25 nozzles were replaced with Spraying Systems 800067 fan nozzles. This system was used on the margins of the rice area only and operated at a height of 10–15 feet. A swath width of 100 ft was assumed.

In May of 1970 a single pass test was made with the Piper Pawnee aircraft spraying Dursban over a line of cartons each containing 200 ml of water. After being sprayed the cartons were marked and collected and taken to the laboratory where mosquito larvae were placed in the cups and kill times were noted. The technique was described in detail by Gillies *et al.* (1968). The results of this single pass test are noted on Fig. 1. A 5 mph wind at about 60 degrees from the N-S flight of the aircraft caused the spray to be displaced 200 ft while dropping from

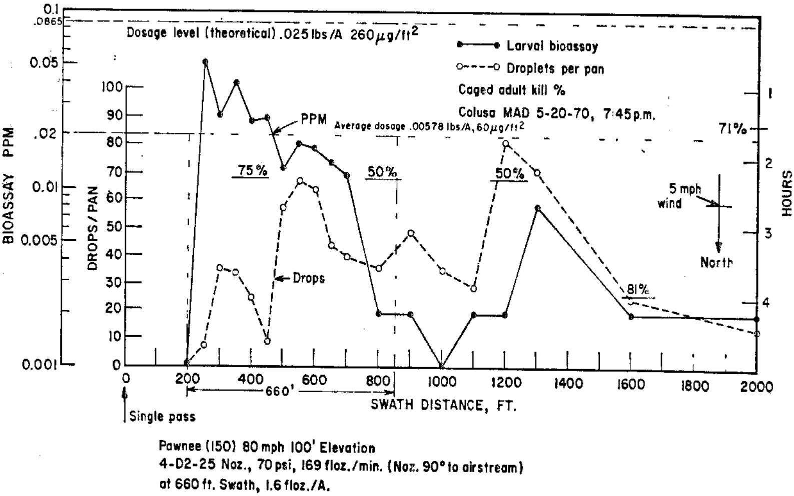

FIG. 1.—Recovery results, single-pass test, Colusa Mosquito Abatement District, May 20, 1970.

the 100-ft altitude. The left-hand scale and the solid line represent the bioassay results as calculated ppm shown across the 1800 foot swath. The second vertical scale on the left is the count of spray drops found on 10-inch diameter aluminum pie plates. The dashed line shows the drop fall-out pattern, related to release height and the gravitational and aerodynamic separation that takes place downwind. The average dose was around 0.02 ppm across a 500-ft swath, but significant drift occurred and a second peak of deposit and numbers of drops showed up at 1,200–1,300 ft, with material still being collected at 2,000 ft from the aircraft path. On the basis of a 660-ft swath the theoretical dosage level (if all the material had fallen in 660 ft only) was 0.0865 ppm for the 0.025 lb/acre application rate, but the spread and transport of the spray reduced this, as can be seen, to an estimated average of .00578 lb/acre.

Caged adult mosquitoes were placed at 400, 800, 1,200, 1,600 and 2,000 feet and the percent of kill is noted at each station. The far right scale is for the hours of exposure of the caged mosquitoes and the percent numbers can be seen at different vertical levels corresponding to the hours of exposure at that station. The high level of adult kill testifies to the high numbers of small drops being transported downwind and to the effectiveness of Dursban as an adulticide.

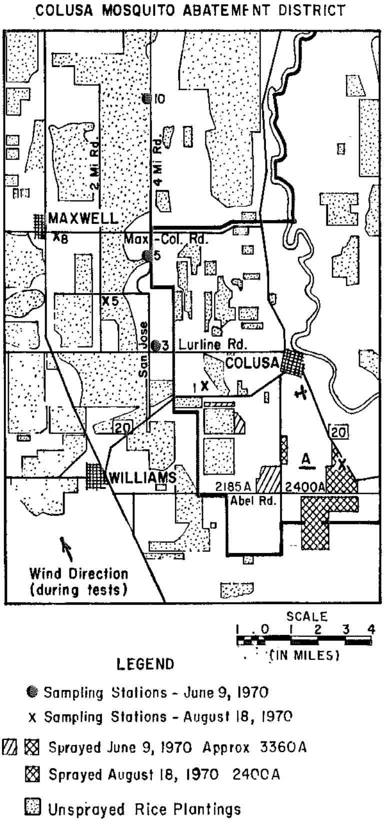

FIG. 2.—Colusa Mosquito Abatement District and environs, showing locations of sampling stations, June–August 1970.

SPRAY PROCEDURES. Figure 2 shows the Colusa area with the boundaries of the Colusa Mosquito Abatement District. Table 1 lists the data on the runs made during June, July and August of 1970. All flights were made from the airport marked by the airplane on Figure 2 just south of Colusa.

The rice grown in the Colusa district is in large blocks and swath lengths up to 5 miles are possible. Since such long distances make it difficult for the pilot to keep on a fixed course, two vehicles equipped with 2-way airground radios were set up on each end of the east-west runs. These vehicles moved forward in swath increments of 660 ft into the wind as the spray progressed. On particularly long passes a third vehicle was located in the center of the pattern, as a further visual and radio guide to aid the pilot in keeping a reasonably uniform swath increment. Stakes which had been placed along the roadway made it easy for the drivers to find the next swath. Other means such as mirrors to reflect the sun or high intensity lights have been used to guide the pilot. However, the pilot reported that the vehicles were easily spotted from the air and that information from the drivers helped to get the proper line on the pattern to be followed. While a high degree of swath width accuracy was probably not obtained with this method, the operation was successful and few skips in the application were found.

The rice fields were not always continuous but were interrupted along the line of flight by fields of other crops. The pilot had no difficulty in turning the system on and off to release spray only over the rice.

SPRAY RECOVERY MEASUREMENTS. The sprayed areas in the southwest portion of the District were monitored for: (1) bio-

TABLE 1.—Weather data for 1970 trials at Colusa, California.

Date	Treated Acres	Wind Direction From	Vel (mph) *	Temperature ** Gradient T_{32}–T_8 degrees F	Notes Wind measured at 16 ft. with vector vane
June runs 0.011 lbs/A					
9	4000	S-SE	12–4 Av. 8	0 to +2	Started 7:30 pm SE corner of SW block Didn't complete block, too dark at 9:30 pm Finished SW block moved to NE started
10	4800	N-NW	10–1 Av. 5	—2 to +10	Approximately 7 pm to 9:30 pm lowered alt. to 25 ft.
11	4800	N	7–3	probable lapse (—)	Broke shock cords on plane before third load
13	9600	SW	12–4	probable inversion (+)	Wind was out of west, variable
15	6000	SE	4–3	probable inversion (+)	Wind steady and light, calm
Total 29,200 acres treated					
July runs 0.0167 lbs/A					
14	9600	SE	8–4	probable inversion	Wind measured at 8 ft. El. Quiet, good spray weather
15	8800	SE	15–4 Av. 8	probable inversion	Quiet, good spray weather
16	8800	N-SE	3–0 Av. 2.5	lapse followed by inversion	Wind dropped by 7:30 pm
17	2400	N	2–1	lapse followed by inversion	Very calm, no spread so stopped
Total 29,600 acres treated					
August runs					
17	2400	SE	6–18 Av. 12	0 to —1	Wind measured 16 ft. vector vane Wind too high, stopped after first load
18	2400	SE	17–5 Av. 10	—1 to +10	Strong inversion and low wind
19	8800	S-SE	15–5 Av. 10	—2 to +1	Somewhat windier, weak inversion, airplane problems
20	12000	S-SE	12–2 Av. 8	—2 to +10	Strong inversion, very good conditions
Total 25,600 acres treated				A grand total of 85,200 acres were sprayed using 42 hours of flying time at $50/hr. for an aircraft cost of $0.0246/acre.	

All runs were with a Piper Pawnee (PA25–150 hp) aircraft
4—D2–25 nozzles, 70 psi for flow rate of 169 fl oz/min, at 660 ft. swath equals 1.6 fl oz/A, altitude 100 ft except as noted

* Generally the wind was highest at 7 pm and gradually decreased as the influx of cold marine air from the south built up and cooled off near the ground, making a stable temperature inversion condition.

** A positive temperature gradient indicates inversion or non-turbulent weather, which is best for mosquito spraying. A negative temperature gradient indicates good vertical mixing weather, which reduces spray deposit.

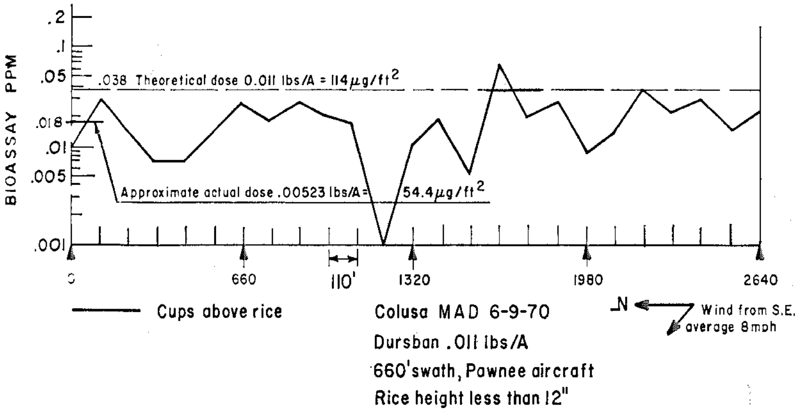

FIG. 3.—Bioassay recovery results, Colusa Mosquito Abatement District, June 9, 1970.

assay of actual material recovered under the aircraft, (2) a gas chromatograph analysis of Dursban from 6 x 18 inch Mylar sheets under the aircraft and (3) residues on Mylar sheets and from air samplers in two lines generally SE to NW (in line with the prevailing wind) downwind from the applications (Yates and Akesson, 1963).

Figs. 3, 4, 5 indicate bioassay tests on several swath passes across a line of water-filled cups spaced at 110-ft intervals. The data in Fig. 3 are from June 9 and show that an 8 mph wind at 16-ft elevation (see Table 1 for details) was moving almost directly across the applied spray swath. The theoretical dosage line is 0.011 lb/acre or a bioassay equivalent dose of 0.038 ppm in the cups. However, as can be seen the approximate actual dose is significantly lower at 0.018 ppm which indicates only a 47 percent recovery of the applied spray, even across a distance of ½ mile. Mosquito control was excellent on this test.

The downwind test stations were located at 1, 3, 5 and 10 miles distance from the northern-most boundary of sprayed fields (June 9) as shown (solid circles) in Fig-

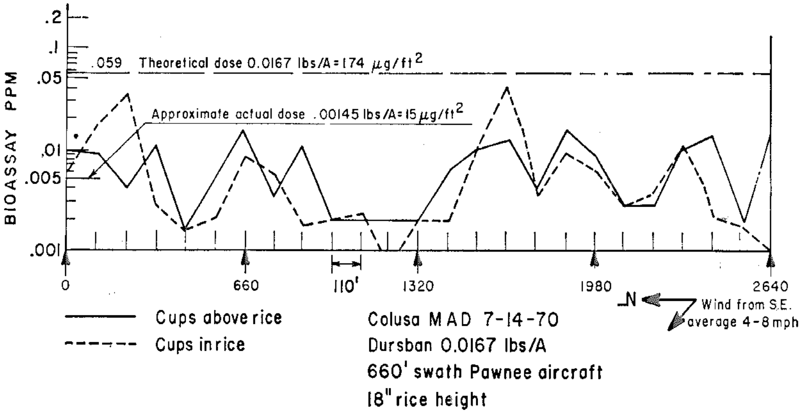

FIG. 4.—Bioassay recovery results, Colusa Mosquito Abatement District, July 14, 1970.

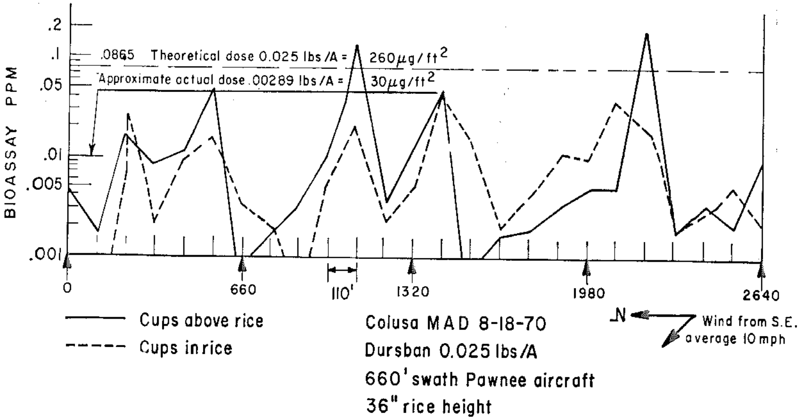

FIG. 5.—Bioassay recovery results, Colusa Mosquito Abatement District, August 18, 1970.

ure 2. Fields in the southeast portion of area *A* (double or cross hatched area) of the District were sprayed first from 7:30 to 8:30 p.m., then the aircraft moved to the west edge of Area *A* but did not complete the west portion, covering only the area as shown by the single hatching. The dosage under the aircraft in $\mu g/ft^2$ actually found by bioassay (Fig. 3) averaged 54.4 $\mu g/ft^2$, with a theoretical level of 114 $\mu g/ft^2$. Mylar plastic fall-out sheets located downwind from the June 9 run and analysed for Uranine fluorescent dye showed a 2 $\mu g/ft^2$ level at 1 mile dropping to 0.2 $\mu g/ft^2$ at 10 miles. The general pattern of this downwind fall-out (for the total spray period) shows the general flattening of the recovery from 5 miles onward. Air-borne recovery for total sample (air devices operated during total spray period) showed 10 μg from air samplers at 1 mile, dropping to 0.8 μg at 10 miles. Air samplers have a 4-inch diameter glass fiber filter capable of extracting 98 percent of all particles above 0.1 μ diameter. The air is drawn through at a rate equal to the prevailing wind velocity so a total of the passing cloud sample is thus found.

Fig. 4 shows the bioassay recovery for the July 14 run. The dosage rate was 0.0167 lb/acre or 174 $\mu g/ft^2$. In ppm this relates to an applied concentration of 0.059 ppm and an average recovery of 0.005 ppm or 8.5 percent. There was little difference to be seen between recovery from cups in the rice or above, but mosquito control was not good and could in part have been related to this evident low recovery.

Fig. 5 shows the August 18 spray trial (see Fig. 2 for areas sprayed, cross hatch only) and again, as in Fig. 4, the difference of collection between cups in the rice and at the top of the rice is not great. Dosage was 0.025 lb/acre or 260 $\mu g/ft^2$, equivalent to 0.0865 ppm. The estimated average recovery was 0.01 ppm or 30 $\mu g/ft^2$ and the percent recovery rose to 11.5 percent. The control of mosquitoes in this 36-inch tall rice was better than with the July runs, but not as good as the June runs, and the rise in Dursban recovery would bear out this field observation.

Downwind sampling to 8 miles north of Road 20 was again taken for the August run on Mylar fall out sheets and glass fiber air filters as for the June 9 runs. In Fig. 1, the southwest Area A (cross hatch only) was sprayed and the crosses mark the 1, 3, 5 and 8 mile downwind stations. While the bioassay indicated a 30 $\mu g/ft^2$ recovery under the airplane, a direct gas chromatograph analysis for Dursban from Mylar strips under the aircraft spray swath indicated a peak recovery of 17.29 $\mu g/ft^2$.

The Mylar strips at the 1 mile station north of Road 20 showed residue levels were down to 0.59 μg/ft² and were less than detectable levels (0.16 μg) at other stations. The air sampler at 3 miles showed a high peak of 0.5 μg for a 12-minute sample period (a sequential sampler was used) and a total collected sample of 1.1–1.5 μg for the total spray time. The air samples at the other stations were below the chromotograph sensitivity of 0.16 μg with the exception of the 1 mile station which showed 0.44 μg, but was turned on too late and appeared to have caught only the tail end of the cloud.

The recoveries both by bioassay (summarized in Table 2) and fall-out on Mylar sheets are unexpectedly low. While the recovery from the June 9 run (47 percent) may be considered as poor for a nonevaporative spray the extremely low recoveries of July (8.5 percent) and August (11.5 percent) are unexplained at this time. In part the tall rice acts to screen out particles, but should not have affected the cups above the rice. The fact that little difference existed between the cups above and below the rice makes it appear that rice filtering was not happening.

The particle size produced by the D2–25 nozzles is about 150 to 200 microns VMD (volume median diameter). This has been shown (Yates and Akesson, 1967) to be highly subject to aerial transport or drift and the downwind sampling of these tests bears this out. However, coarser sprays will not produce the 660-ft swath which is essential to the low aircraft operational cost of 2½ cents per acre. For example, productivity in acres per hour would drop by about 35 percent, and costs increase accordingly when the swath width is reduced to 330 ft.

Studies on the drift of sprays show that the principal loss of spray is in particles of less than 50 μ diameter. Thus, if the drops under 25–50 μ could be significantly reduced, the losses would be reduced accordingly. At this time no practical system exists for controlling these drops, although several research groups are working toward this objective.

Since a certain amount of adult mosquito mortality is taking place in the field being treated the drifting spray (aerosol size or under 50 μ) is not all lost. However, this spray is in droplets much too large for good adult control. If this were the major objective, aerosols of 15 to 25 μ VMD would be used and would be much more effective for contacting flying adults.

It should be obvious that still too little is known of the effects of drop size, wind velocity and temperature gradient, aircraft altitude and spray evaporation on the downwind transport and field recovery for either adulticiding or larviciding. It is generally assumed that a low positive wind not exceeding 6 to 8 mph and with a positive temperature gradient (tempera-

TABLE 2.—Conversion of applied and recovered dosage rates

lbs. AI/A (Active Ingredient)		μg/ft²		Equivalent ppm in 200 ml water cups	
Applied*	Recovered	Applied	Recovered	Applied	Recovered
0.1	....	1040	....	0.346	.....
0.025	0.00289	260	30	0.0865	0.01
0.025	0.00578	260	60	0.0865	0.02
0.0167	0.00145	173.7	15	0.059	0.005
0.0125	....	130	....	0.0433	.....
0.011	0.00523	114.4	54.4	0.038	0.018
0.01	....	104	....	0.0346	.....

* The applied dosage was based on release of 1.6 fl oz/A with AI as noted while recovered was based on ppm equivalent bioassay as demonstrated by exposure of larvae to water from cups placed in the aircraft swath.

ture inversion) or warm air overhead would be optimum for aerosol and fine spray applications. But the proper height to fly along with the spray drop size to use in order to obtain optimum recovery and maximum swath width is not easily found and may as we suspect, vary greatly with the changing weather of early evening spraying.

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RICE FIELD MOSQUITO CONTROL STUDIES WITH LOW VOLUME DURSBAN® SPRAYS IN COLUSA COUNTY, CALIFORNIA. III. EFFECTS UPON THE TARGET ORGANISMS.

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An operational plan for alleviating the mosquito problem associated with rice culture in Colusa County, California, was described by Womeldorf and Whitesell (1972). The following report summarizes the effects of implementing this plan on field populations of the target organisms *Culex tarsalis* and *Anopheles freeborni*. Further evaluation of the low volume applications with caged mosquitoes is reported elsewhere (Akesson *et al.*, 1972).

PROCEDURE. The extent of rice culture within and outside of the treatment area (Mosquito Abatement District boundary) and the major communities that served as mosquito adult sampling sites are shown in Fig. 1. For operational purposes, the rice fields to be treated within the District were grouped into four sub-areas (A, B, C and D). Area A encompassed 4,585 acres of rice in the southwest portion of the District; Area B, 3,564 acres, northwest; Area C, 2,082 acres, southeast; Area D, 7,534 acres, northeast. Within each of the four sub-areas, 10 rice fields were inspected for mosquito larvae at weekly intervals for approximately 15 consecutive weeks from June through August or September when the fields were drained for harvesting. An inspection consisted of 15 dips with an enamel dipper at each permanent station. Six additional rice fields outside the treated area were also inspected weekly.

Four New Jersey light traps were operated 4 nights per week from April through September. Three traps were located within the city limits of Colusa, and the

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