OPTIMUM DROPLET SIZE FOR ADULT MOSQUITO CONTROL WITH SPACE SPRAYS OR AEROSOLS OF INSECTICIDES[1]

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Droplet size is one of the principal factors affecting the efficiency of insecticide space sprays or aerosols for the control of adult mosquitoes since size is directly related to the transport of droplets and their ability to impinge on the target insects. Unfortunately, after years of extensive work with organic insecticides, there has been only limited research relating the efficiency of dispersal equipment to droplet size. This paper provides a critical review of literature pertaining to the optimum droplet size of insecticides dispersed as ground aerosols and as aerial sprays or aerosols for the control of adult mosquitoes.

LABORATORY RESEARCH. Two of the most important requirements for optimum droplet size are that droplets must be small enough to be produced in sufficient numbers to give adequate coverage and large enough to impinge readily on the body surface of adult mosquitoes. Latta *et al.* (1947) demonstrated in a wind tunnel that the most suitable droplet size for adult mosquito kill ranged from 11.9 microns (μ) to 20.4 μ with wind velocities of 2 to 8 m.p.h. (Table 1). During the same year LaMer *et al.* (1947) reported that the best droplet size for adult mos-

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[1] Mention of an insecticide or a proprietary product in this paper does not constitute a recommendation or an endorsement of this product by the USDA.

TABLE 1.—Milligrams of DDT passing through cross-sectional area of wind tunnel producing 50 percent mortality of *Aedes aegypti* (L.) (After Latta *et al.*, 1947).

Droplet diameter (μ)	Milligrams of DDT required at indicated wind velocities (m.p.h.) 8	4	2
1.1	126.00	184.00	81.00
2.5	5.90	14.20	32.00
5.0	1.74	3.24	6.40
11.9	.62	.62	.62
20.4	.87	.87	.87

quito kill in a confined (still) atmosphere was 11 μ. Yeomans *et al.* (1949) indicated from research on aerosol droplet deposition in still and moving air that optimum droplet size for adult mosquitoes was 15.81 μ.

The activity of free-flying mosquitoes enhances the impingement of droplets less than 10 μ in diameter (David and Bracey, 1944; David, 1945; David and Bracey, 1946). It was shown that adult mosquitoes under the influence of chloroform were little affected by insecticidal aerosols with maximum droplets of 7.5 μ. Exposures of free-flying mosquitoes to the same aerosols resulted in 58 to 62 percent kills. Apparently, large numbers of small droplets were collected on the wings of the free-flying mosquitoes, since wing amputation immediately after exposure caused a decrease in mortality.

Table 2 shows the effect of droplet size on density between ground level and 10 feet above the ground for several applications. These data indicate why extremely fine atomization is necessary to obtain maximum coverage with ultra-low volume (ULV) applications of highly concentrated or "technical" insecticides. For example, with a total volume of 4 fluid ounces per acre and droplets of 100 μ there would be only one droplet per 54 cubic centimeters (cc); if the droplets had diameters of 10 μ, there would be 972 in the same volume of air, almost a thousand-fold difference.

TABLE 2.—Effect of size on the density of droplets within 10 feet of the ground.

Droplet diameter (μ)	No of droplets per cc at indicated volume (fluid ounce) per acre 4	1	0.25
2.5	1,200.000	300.0000	75.0000
5.0	152.000	38.0000	9.5000
10.0	18.000	4.5000	1.1300
25.0	1.200	.3000	.0750
50.0	.150	.0370	.0090
100.0	.018	.0045	.0011

The size of one droplet of insecticide that would cause mortality of an adult mosquito may be a clue to optimum droplet size. For DDT this was calculated by Latta *et al.* (1947) to be a 34 μ particle of 100 percent DDT. Recent work by Weidhaas *et al.* (1970) indicated that a 25 μ droplet of technical malathion was needed. With applications of technical malathion the droplet size should be 25 μ, or less, since more than one smaller droplet could contact a mosquito; on the other hand, droplets larger than 25 μ are wasteful since they contain more malathion than required for kill.

GROUND AEROSOLS. This method of application depends entirely on natural winds for proper dispersal of the insecticide. Table 3 shows the theoretical drift (based on Stokes' law) of droplets of technical malathion during a 4-foot fall in stable atmospheric conditions at wind velocities ranging from 1 to 8 m.p.h. A droplet size of about 10 μ or less is necessary to achieve swaths of at least 300 feet during low wind velocities (2 m.p.h. or less).

Several investigators have demonstrated increased efficiency with fine to medium aerosols compared with coarse aerosols and sprays. Brescia (1946) indicated that DDT aerosols of 10 μ gave the best control of adult mosquitoes. DDT aerosols of 5 to 17 μ mass median diameter (mmd) were much superior to aerosols and sprays of 30 to 90 μ mmd in controlling adult mosquitoes in woodland areas (Brown and Watson, 1953). Mount *et al.* (1968) and Mount, Pierce *et al.* (1970) demonstrated that adequate control of adult mosquitoes was possible with ultra-low volumes (0.1 fluid ounce per acre) of technical insecti-

TABLE 3.—Theoretical drift of technical malathion droplets during a 4-foot fall in a stable atmosphere.

Droplet diameter (μ)	Distance (feet) droplets would travel during indicated wind velocity (m.p.h.)			
	8	4	2	1
2.5	64,416	32,208	16,104	8,052
5.0	15,714	7,857	3,928	1,964
10.0	3,776	1,888	944	472
25.0	656	328	164	82
50.0	152	76	38	19

side with proper atomization (see Table 4). Their results showed that aerosol droplets of 6 to 10 μ mmd were almost twice as efficient at the LD_{90} level as those of 11 to 22 μ mmd (LD_{90}'s of 0.009 and 0.015 lb. per acre, respectively).

For ground aerosol applications a droplet size range of 5 to 10 μ mmd appears to be optimum with few, if any, droplets over 25 μ. Droplets larger than 10 μ are subject to fallout before drifting at least 300 feet during light winds (<2 mph). Furthermore, large droplets will impinge more readily than small droplets and are likely to be filtered out by vegetation and other objects in their pathway. With ultra-low volume applications, droplets over 10 μ may not provide maximum coverage of the target area. Droplets less than 5 μ do not impinge readily on adult mosquitoes because of their high critical impingement velocities. These small droplets are also more subject to any upward convection currents of turbulent air which may place them above areas normally inhabited by adult mosquitoes.

AERIAL SPRAYS AND AEROSOLS. Conventional aerial spray methods for mosquito control rely, at least partially, on wind drift of the insecticide to obtain wide swaths and therefore are similar to the Porton method as described by Brown (1951). With this method the insecticide is emitted as a spray into a crosswind which transports the wide range of droplets various distances, depending on aircraft altitude, crosswind velocity, and droplet size. Droplet sizes of aerial sprays

TABLE 4.—Effect of droplet size on efficiency of kill of caged female *Aedes taeniorhynchus* with ultra-low volume nonthermal aerosols of technical malathion (after Mount *et al.*, 1968).

Dose[a] (lb. per acre)	Mass median diameter (μ)	Percent mortality after 18 hr. at indicated distance (feet)			Average percent mortality
		150	300	600	
0.0045	13.4	34	18	8	20
	11.6	34	38	18	30
	8.3	56	38	28	41
	6.0	50	38	38	42
0.009	17.4	90	52	70	71
	12.3	98	98	32	76
	9.7	100	100	88	96
	6.4	92	100	98	97
0.018	22.4	100	84	76	88
	14.0	100	100	100	100
	10.8	100	100	96	99
	7.6	100	100	100	100

[a] Based on actual amount of insecticide used for a 600-foot swath area.

and aerosols reported have ranged from <5 μ to 700 μ mmd. Most of these variations have been due to the different nozzles used to atomize the insecticide; however, some of them may have resulted from employing different methods and materials of estimating droplet size. Most of the ULV applications have been made with conventional hydraulic nozzles which yield droplets ranging from 23 to 65 μ mmd according to the estimates by Mount, Pierce *et al.* (1970).

Past research has indicated that reducing droplet size increases the efficiency of aerial applications. Brown (1952) reported that aerial sprays of 180 to 195 μ mmd produced better control of adult mosquitoes than sprays of 300 to 400 μ mmd (99 percent vs. 85 percent control). Davis *et al.* (1960) obtained an LD_{90} of 0.034 lb. of malathion per acre against caged *Aedes taeniorhynchus* (Wiedemann) with an aerial aerosol which was reported by Salmela *et al.* (1960) to have a droplet size of less than 5 μ mmd. Using the same laboratory colony of *A. taeniorhynchus,* Mount *et al.* (unpublished data) obtained an LD_{90} of 0.13 lb. of malathion per acre with ULV sprays and aerosols of 45 to 65 μ mmd. This represents about a 4-fold difference in efficiency, even though <5 μ mmd may be smaller than optimum droplet size.

Extensive aerial spray research against tsetse flies, *Glossina* spp., has shown that decreases in droplet size increased control. Hocking and Yeo (1953) indicated that aerial sprays of 100 μ mmd were more efficient than those of 350 to 700 μ mmd. Further reduction in droplet size (60 μ mmd) produced even better control of tsetse flies with comparable dosages of the same insecticide (Hocking *et al.,* 1954). Hocking *et al.* (1953) found that droplets over 80 μ did not reach the leeward side of obstacles, nor did they penetrate into thickets. Burnett *et al.* (1964) suggested that for better control of tsetse flies, there should be few droplets over 50 μ.

A major breakthrough in aerial spray research was provided recently by Himel and Moore (1967). Using a fluorescent particle tracer method they learned that 93 percent of spruce budworms, *Choristoneura fumiferana* (Clemens) collected had not been contacted by any droplets larger than 50 μ in diameter even though they used a broad-spectrum spray whose droplets ranged from about 1–3 μ to 300–400 μ. There was no evidence that any droplets over 100 μ reached the target insects.

The recent introduction of the ULV aerial application method into mosquito control has resulted in a reduction in the total volume of spray per given area, but no one has reported a reduction in the amount of actual insecticide needed. Mount and Lofgren (1967) showed that, in general, ULV concentrate applications were even slightly less effective than diluted applications (3 quarts per acre) at comparable insecticide dosages against adult mosquitoes.

Recent research on ULV aerial applications by Mount, Lofgren *et al.* (1970) and Mount, Pierce *et al.* (1970) indicated that it is not likely substantial reductions in droplet size can be achieved with conventional hydraulic nozzles (TeeJet). However, these studies do show the effect of a wide range of factors on droplet production with these nozzles and could lead to moderate reductions in droplet size, thereby possibly reducing the dosage of insecticide needed.

Increases in insecticide efficiency of aerial applications depend largely on the development of nozzles which will produce droplets nearer an optimum size range. Nozzles other than the hydraulic type have been used, but their potential for use in mosquito control has not been studied extensively.

Based on present knowledge, the optimum droplet size for aerial applications is probably 10 to 25 μ mmd with few, if any, droplets over 50 μ. Droplets over 50 μ are easily filtered out by vegetation because of their low critical impingement velocities. These large droplets are also the portion of present spray spectra that impinges on automobiles and other large objects and causes spotting. Droplets over 25 μ may not provide adequate coverage, especially with ULV applications of less than 1 fluid ounce per acre. On the other hand, droplets less than 10 μ are more easily influenced by marginal meteorological conditions such as turbulent air and high winds which can cause excessive drift away from the target area.

Somewhat contrary to the accepted Porton method, a wide range of droplet sizes should not be necessary for wide swath intervals with aerial applications when small droplets are utilized. From Table 3 it can be calculated that the drift differential between 10 and 25 μ droplets is 975 feet during a fall of only 10 feet and a wind velocity of 1 m.p.h. Stokes' law cannot be applied to the total distance between aircraft height and ground level because of downdraft which accelerates the downward motion of the droplets. Also, small droplets have a greater tendency to move in a horizontal fashion as they approach ground level than do large droplets, thus providing increased swath width much the same as in ground aerosol applications. To some extent, this phenomenon was noted by Mount *et al.,* (unpublished data) when much greater numbers of aerial ULV insecticide droplets were collected on oil-red dye cards held vertically 3 feet above the ground than those placed horizontally on the ground during wind velocities of over 2 m.p.h.

Research on optimum droplet size of aerial applications of insecticides is greatly needed and should be very rewarding. Even moderate increases in efficiency would lead to considerable savings in the amounts of insecticide needed to control adult mosquitoes. Reduced dosages would also mean less insecticide contamination in target areas.

Summary. A critical review of literature pertaining to the optimum droplet size of insecticides dispersed as ground aerosols and as aerial sprays or aerosols for the control of adult moquitoes was made. For ground aerosol applications a droplet size range of 5 to 10 μ mmd was considered optimum based on the various factors involved and field research. With aerial sprays or aerosols the optimum droplet size is probably 10 to 25 μ mmd, but these values need to be confirmed by additional research.

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