SUCCESSES AND FAILURES WITH ENDOSULFAN (THIODAN®) USED FOR CONTROL OF APHIDS IN EASTERN WASHINGTON 1, 2/

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Since 1957, eastern Washington potato growers have depended chiefly upon endosulfan for control of the green peach aphid, Myzus persicae (Sulzer), the potato aphid, Macrosiphum euphorbiae (Thomas), and several other insects. Applications of endosulfan to potato foliage usually start some time in June, after the soil applications of disulfoton (Di-Syston®) have ceased to be effective. However, in late summer or early autumn, and particularly in 1970, some applications of endosulfan gave less than the customary 98-100% control.

During the 14 years that endosulfan has been used, one might have expected that the green peach aphid would have developed resistance to endosulfan because this aphid became increasingly difficult to control on crops with parathion and related insecticides in eastern Washington starting in 1952. Anthon (1955) believed this difficulty with parathion to be an indication of true resistance, but Shirck (1960) attributed the hardiness of the pest to vigor tolerance. Shanks (1967) reported that, starting in 1965, the strawberry aphid, Chaetosiphon fragaefolii (Cockerell), was no longer being controlled on strawberries in southwestern Washington with the routine application of spray (0.5 lb endosulfan/acre) and that some strains of the aphid were harder to kill with endosulfan than others in laboratory tests. We have therefore, re-evaluated endosulfan for control of aphids on potatoes each year and have also compared its performance with that of other insecticides having aphicidal properties. Since we have not found endosulfan-resistant aphids on potatoes, we are of the opinion that most failures of endosulfan to control aphids during late summer and early autumn can be attributed to weather conditions which reduce its effectiveness. The present paper summarizes the results of a number of laboratory and field experiments and also presents data from commercial applications that support our conclusions.

Laboratory Tests with Endosulfan and Its Isomers

In 1 laboratory test, aphid-infested potato leaves and 10 ml of a stock solution of endosulfan in a small glass dish were placed in a large glass jar, and the opening was sealed. Also aphid-infested leaves but no endosulfan were sealed in another glass jar. After 2 hr at 77°F, room temperature, all the aphids in the jar containing endosulfan had fallen from the leaves and were dead or paralyzed; none were so affected in the other jar (Schopp and Landis 1959). Similar tests showed that vaporized endosulfan killed aphids more quickly and in greater numbers when the ambient temperature was above 75°F.

Next, we tested the solvent and each of the wetter-spreader materials used in formulating the spray for their fuming action in sealed glass jars. They proved to have none.

In addition, since endosulfan contain 2 stereoisomers which have been designated I and II, several laboratory tests were made with the 2 stereoisomers separately at temperatures of 70-74°F for 24 hr, 84°F for 5 hr, 90°F for 6 hr, and 72-82°F for irregular intervals. The results (Table 1) show that aphid mortality increased with an extension of the exposure and that aphids were killed most rapidly with endosulfan I.

1/ In cooperation with the Washington Agricultural Experiment Stations and the Washington State Potato Commission.

2/ This publication reports research involving pesticides. Mention of a pesticide in this paper does not constitute a recommendation of the product by the USDA.

Table I.--Fumigatory action of endosulfan isomers I and II against variable numbers of green peach aphids confined on sugarbeet leaves in glass jars.

Exposure in hr.	No. aphids killed by Isomer II Living aphids	Isomer II Control %	Isomer I Living aphids	Isomer I Control %	II and I Living aphids	II and I Control %	No. living aphids in check a/
12	179	65.6	58	88.8	21	96.0	520
15	69	46.9	11	91.5	10	91.6	130
18	256	39.7	107	74.8	105	76.2	425
24	106	36.9	2	98.8	8	95.2	168
27	2	98.5	3	97.8	3	97.8	134
30	14	93.8	0	100.0	0	100.0	226
48	2	97.7	0	100.0	1	98.8	86
72	0	100.0	0	100.0	0	100.0	9

a/ Held in jars without endosulfan.

Field Trials with Endosulfan to Establish a Fuming Effect

Since endosulfan sprays were more effective than endosulfan dusts for control of aphids on potatoes, the mode of action of the compound was investigated in 3 field trials with 1 lb endosulfan in 5 or 10 gal of water spray/acre. In the first test, some aphid-infested plants were covered with plastic bags for a short time during spraying, and some aphid-infested plants or plant parts were introduced into the fields immediately after treatment to determine whether the chemical acted as a fumigant or killed by contact.

Some discrepancies occurred in the aphid mortality on plants temporarily protected with plastic bags in the treated field and in the mortality on plants introduced into the field after spraying, and, in general, the fuming action alone was very effective during the 1st day posttreatment and became more effective during the 2nd day (Table 2). Also, in 1 test, some aphid-infested potato leaves enclosed in sheer nylon cages were placed at random in a portion of the treated field 15-120 min. after spraying and left for 30 or 60 min. Populations in the cages were reduced 66% during the 1st 24-hr posttreated period and 100% during the next 24 hr, but greater numbers were killed during the first hr than during the first 1/2 hr. As in the 2 other trials, control was more effective near the center of the field. In the last test, an air sampling device was placed in the potato field soon after spraying, and 100-ft^3 samples of air were drawn through it every 3 days. Analysis made of the washed air samples by chemists of the Pesticide Chemicals Research Branch of this Division revealed measurable amounts of the parent endosulfan compound.

Table 2.--Control of the green peach aphid obtained by the fumigant action of and by contract with endosulfan on potatoes the 1st and 2nd days after application.

	Temperature °F.					% aphid control				
		At indicated day posttreatment								
		1st		2nd		Protected plants	Introduced plants		Exposed plants	
Test No.	At application	Max.	Min.	Max.	Min.	1st day	1st day	2nd day	1st day	2nd day
	1 lb endosulfan in 10 gal spray/acre applied with ground equipment									
1	83	92	59	100	68	84	90	-	96	-
2	63	72	43	84	43	50	87	98	99	-
	1 lb endosulfan in 5 gal spray/acre applied from aircraft									
3	74	77	43	84	44	84	96	100	97	100

Field Comparisons of Formulations of Endosulfan

A number of formulations of endosulfan applied with airplanes were compared in large field plots. In the 1st test, the relative effectiveness of 1 lb endosulfan/acre applied in 10 gal of water spray and dust mixture with talc were compared. The results (Table 3) showed that the spray was superior to the dust treatment.

In the 2nd test, the effectiveness of a talc-endosulfan dust mixture yielding 1 lb endosulfan/acre and a 5% endosulfan granule formulation applied at a rate of 66 lb/acre that yielded 2 lb endosulfan/acre were compared. The air temperature was about 80°F when the applications were made, and the maximum daily temperature remained above 79°F for the next 16 days. The granular treatment gave 100% control of aphids within 4 days and was slightly more effective than the endosulfan-talc treatment on the 9th and 16th days though some reinfestation had occurred.

In the 3rd test, we used a mixture of 0.5 lb endosulfan derived from a miscible stock solution in a mixture of kerosene and summer oil; no water was used. This treatment gave 100% control of aphids within 4 days and was 100% effective for 31 days (Table 3).

In the 4th test, water and kerosene formulations, a talc mixture, and a granular formulation were compared. The air temperature ranged from 70 to 74°F during the treatment period and reached the daily maximum, 78°F, a few hours later. Aphid control the 1st day posttreatment was not exceptional with any treatment, though the 1 lb endosulfan-kerosene reduced the population 89%. Endosulfan-water was most effective the 6th day posttreatment. This long interval from time of application to 100% control that occurred with many of the treatments may be attributed largely to the low minimum night temperatures (44 - 56°F throughout the posttreatment sampling period). One of the most successful applications of endosulfan (rate of 0.5 lb of toxicant in 20 gal spray/acre with a row crop sprayer) was made July 17 when the air shade temperature was 75°F and the humidity was 36%. During the following 5 days, the maximum temperature ranged from 86 to 96°F. The application gave nearly 100% control within 3 days, but, like some other trials in which excellent control occurred shortly after treatment, the apparent lack of residual toxicant on the plants allowed some reinfestation before the 7th day posttreatment (Table 4).

Table 3. --Control of the green peach aphid on potatoes with formulations of endosulfan applied with aircraft.

Rate/acre and formulations of endosulfan	Percentage control based on the number of wingless aphids/125 leaves									
	4 hr	1 day	3 days	4 days	6 days	8-9 days	11 days	13-16 days	19 days	31 days
	Test 1 - 6/13									
1 lb in 10 gal water				94	100					
1 lb in 33 lb talc dust				90	87					
	Test 2 - 6/20									
1 lb in 33 lb talc dust			98	-	-	90	-	89		
2 lb in 66 lb granules			100	-	-	94	-	93		
	Test 3 - 7/19									
0.5 lb in 3 gal kerosene + 1.75 gal summer oil				100	100	-			100	100
	Test 4 - 8/1									
1 lb in 10 gal water	45	73	-	98	100	94	99	-	99	-
1 lb in 10 gal kerosene	28	89	-	100	100	100	100	-	100	-
0.5 lb in 10 gal kerosene	9	46	-	83	90	95	99	-	100	-
1 lb in 33 lb talc dust	36	33	-	55	61	70	94	-	100	-
1 lb in 33 lb granules	12	15	-	55	51	85	93	-	100	-

Table 4. -- Control of the green peach aphid on potatoes obtained with standard and cottonseed-oil formulations of endosulfan-water sprays applied with a row-crop sprayer.

Formulation[a/]	Number of wingless aphids on 75 leaves on indicated day posttreatment			
	3	7	14	Total
Regular endosulfan spray	53	400	1625	2078
Cottonseed-oil endosulfan spray	101	326	1207	1634
Standard aphicide spray	1064	1987	13486	16537

a/ All formulations contained 0.5 lb active ingredient/acre.

Reported Failures of Endosulfan Treatments to Control Aphids

During our early tests with endosulfan applied with ground equipment, the insecticide looked promising for aphid control when it was used at a rate of 0.5 - 1 lb of the toxicant in 20-50 gal of water spray/acre but it rarely was as effective as when 1 lb of endosulfan was applied in 8 - 10 gal of spray /acre from the air. The ususal result was 98-100% control of aphids within 3 days of

application, which was attributed to the treatment of large areas within a very short time. However, as early as 1957, some failures with endosulfan occurred. For example, 1 field of White Rose potatoes with very long tangled vines near Quincy, Washington, was found to be heavily infested with aphids on June 26 (an average 273 aphids per 25 leaves was found on samples taken from different parts of the field). It was, therefore, sprayed July 5 with 0.5 lb endosulfan in 8 gal spray/acre with an airplane. The temperature was about 80°F when the field was sprayed and reached a maximum of 92°F later in the day. During the next 11 days, maximum and minimum temperatures ranged from 73 to 93°F and from 47 to 62°F, respectively. The aphid populations on rows 20 and 32 were reduced 63 and 71%, respectively, within the first 3 days, but on rows 40 and 80, the population was greater than before spraying. Twelve days after spraying, an average 178 aphids/25 compound leaves was found in the entire field. The same day, July 17, the field was sprayed again by airplane but with 1 lb of endosulfan in 5 gal water/acre. Then the field was sampled for aphids intermittently for 11 days (during this time the maximum and minimum temperatures ranged from 81 to 93°F and from 46 to 57°F, respectively). An average of 107 aphids/sample, a reduction of 40%, was observed 8 days after spraying: however, there was also a reduction of 93% 11 days after spraying. Also, in 1970, in 1 field, control was not obtained until 9 days after spraying.

On June 6, 1959, half a large field of Dazoc potatoes heavily infested with aphids was treated with 1 lb of endosulfan in 8 gal spray/acre with aircraft. The temperature at the time of application was about 73°F, and the maximum for the day was 75°F. Maximum and minimum temperatures for the next 6 days ranged from 70 to 83°F and from 37 to 58°F, respectively. Six days after spraying, the population of aphids in the sprayed area was still 64% that in the unsprayed part, an average of 370 aphids/25 leaves.

On September 25, 1959, 1 lb endosulfan in 5 gal water spray/acre was applied to plots of potatoe with a row-crop sprayer. The temperature ranged between 60 and 64°F at the time of application and fell to 47°F the 1st night. During the next 14 days, the maximum temperature did not exceed 75°F, and the lowest minimum temperature was 32°F. There were 246 aphids/100 compound leaves 3 days posttreatment, 62 at 7 days posttreatment, and 127 at 14 days posttreatment.

Again, on June 14, 1962, 33 lb of a 3% endosulfan dust/acre was applied with aircraft to large fields of potatoes near Zillah, Washington. The dust applications were made early in the morning when the air temperature was about 45°F. During the next 15 days, maximum and minimum temperatures ranged from 55 to 74°F and from 40 to 56°F, and there was no appreciable reduction in the aphid population. On June 30, 2 swaths of spray (1 lb of endosulfan in 7 gal water/acre) were applied to 1 of the fields, and on July 1, 2 swaths of dust (3% endosulfan dust to yield 1 lb of endosulfan/acre) was applied to a nearby field. The temperature at the time of application was about 70°F. During the next 14 days, the maximum and minimum temperatures ranged from 55 to 77°F and from 36 to 64°F, respectively. Table 5 shows the control obtained with the 2 formulations over 16 days. It therefore, took 5 days for the application of endosulfan to achieve 100% control of aphids during the cool period the last half of July 1962.

Again in 1970, a commercial applicator reported that he had witnessed poor aphid control with endosulfan sprays in several potato fields during August. In 1 field, the sprays were applied August 8, 21, and 29. Although day-time temperatures on the days of application and on several days thereafter were warm to hot, the minimum night temperatures were all relatively low, and also the humidity, as indicated by the dew point readings, was comparatively low for a day or two after each application.

Table 5. --Control of the green peach aphid on potatoes obtained with airplane applications of endosulfan spray and endosulfan dust at a rate of 1 lb actual toxicant/acre during a cool period of summer, 1962.

Date of sampling	Numbers of winged or wingless green peach aphids/25 compound leaves at indicated times after application of---			
	Endosulfan Spray		Endosulfan Dust	
	Winged	Wingless	Winged	Wingless
June 30 (4 hr after spraying)	5.0	182.5		
July 1 (8 hr after dusing)			1.5	150.8
July 1 (1 day after spraying)	1.5	59.3		
2	1.0	9.5	0.5	85.0
3	0.5	2.5	0	86.5
4	0	0.7	0	25.8
5	0.7	0	1.5	28.5
6	2.0	0	1.5	63.3
7	4.2	7.7	4.9	50.8
8	4.2	0.7	6.3	29.3
9	1.0	3.0	3.0	77.0
10	3.5	17.5	6.5	63.5
12	4.0	14.0	10.8	132.8
16	0.7	38.3	7.2	91.3

Another operator reported that on August 5, 1970, at 5 p.m., when the temperature was 90°F, 2 potato fields were sprayed with 1 lb of endosulfan in 7 gal spray/acre, and the next morning 2 more fields were sprayed at the same rate. Good control was obtained in the first 2 fields, but control was poor around the edges of the other 2 fields. Minimum temperatures the night following the 2 sets of sprayings were 50 and 56°F, respectively, and the dewpoints were 42 and 46%. Thus, the differences in control could not be explained on the basis of temperature and humidity. The fields were sprayed again with 1 lb endosulfan in 10 gal spray/acre, and aphid control was much improved.

Discussion

Failures of airplane applications of endosulfan to control aphids on potatoes can be attributed to errors of application as well as to unsuitable weather. For example, many spray planes are calibrated to apply 5 gal of spray/acre which entails flying at a definite speed and height and with a certain swath width, due consideration being given to nozzle size and the number and arrangement of nozzles on the boom and the pressure on the spray line. When 8 or 10 gal of spray/acre are to be delivered major adjustments are required in the spray equipment, the ratio of endosulfan to water in the spray tank must be changed, and/or an adjustment must be made in the swath width.

Experiments reported here show that not all the aphids present in a field of potatoes are contacted when applications of endosulfan are made with aircraft. However, if the contact alone provided the aphid control, the rate of mortality would be only 40 - 60%, which would be entirely unsatisfactory. Most aphid control obtained when the weather is satisfactory can be attributed to the volatilization of endosulfan and a kind of fumigant action since air sampling studies showed that the endosulfan material is releaed in the air. However, endosulfan does not volatilize rapidly at temperatures below 75°F, and volatilization may be less in very dry air than in air with an RH of 39% or more. Also, we have indications that the formation of dew scrubs the vaporized endosulfan from the air and redeposits it on the potato foliage where a part of it may be either volatilized again or oxidized to endosulfan sulfate and other breakdown products.

A few failures with endosulfan have been reported in late spring and early summer, but most seem to occur in August and September when minimum daily temperatures fall to the mid-40's. Also during late summer, the soil of potato fields warms up during the daytime and cools off at nights. In addition, the air over potato fields is usually quite stable early in the morning, but as the fields heat up during the day, the air is likely to become turbulent as the hot air rises (dust devils are extreme examples of air turbulence). If there is much turbulence, less of the spray or dust applied with aircraft will settle on the crop, and more will drift away. Therefore, failures with endosulfan could result from treating fields during hot, dry afternoons when there is considerable thermal radiation.

If most of the reported failures of endosulfan to control aphids can be attributed to cold night-time temperatures and dew formation, little can be done to increase the effectiveness of applications during unfavorable weather. An increase in the rate of application from 1 to 1.5 lb/acre or from 0.5 to 0.75 gal of the miscible concentrate/acre may increase the contact kill slightly but would not in itself increase the fuming action of the material. The use of 10 gal of spray/acre is always preferable to the use of 5 or 8 gal/acre since the greater amount of water gives a greater dilution of the insecticide and covers a greater surface of the potato plants.

No other insecticide that we have used has given as good control of aphids, generally, as endosulfan. Carbofuran, endrin, parathion, and naled applied to potatoes during periods when endosulfan gave poor control were no more effective than endosulfan. When night temperatures drop to the mid-40's and there are early morning dews, one should be certain that the maximum daily temperature will rise to at least 80°F before applying endosulfan.

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