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Field Experiments on the Effects of Insecticides

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FIELD EXPERIMENTS ON THE EFFECTS OF INSECTICIDES[1]

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WHEN THE spotted alfalfa aphid, *Therioaphis maculata* (Buckton), appeared in California in 1954, the state was faced with a serious agricultural problem, for this insect threatened the very existence of the great alfalfa industry. Alfalfa is a basic agricultural crop in California, with an annual planting of well over a million acres. It is the foundation of the state's tremendous dairy and livestock industry as well as the major source of seed for out-of-state consumers. Moreover, it is a key crop in the various crop rotation systems employed throughout the state.

Very quickly after the establishment of the aphid, research was initiated to find and develop alfalfa varieties resistant to aphid attack, and a search was undertaken in the Old World for parasites and predators of this newly introduced alfalfa pest. Simultaneously, an insecticide evaluation program was initiated to find materials which would control this new alfalfa pest at reasonable cost and also meet residue tolerance regulations on alfalfa hay.

In the emergency situation, parathion, malathion, and TEPP filled the requirements for the badly needed insecticides. There can be no doubt that even though these materials were not the final answer for chemical control of the aphid, they prevented widespread devastation to California's great alfalfa industry in the early months of the emergency.

Experimentation with insecticides did not end with the adoption of parathion and malathion as chemical control measures. Early investigations indicated that even though they gave excellent aphid control, they also appeared to be highly destructive to native natural enemies of the aphid, particularly coccinellids. This factor became strikingly evident at Hinkley, California, during the late summer of 1956 where it was found that the aphid had developed a low degree of resistance to certain organophosphorus insecticides (Stern and Reynolds, 1958). In surveying the area where resistance had developed and growers had repeatedly treated their fields, it was invariably found that natural enemies of the aphid had been largely eliminated by spray materials. This was an extremely alarming situation and clearly revealed the inherent danger in a pest control strategy in which total reliance was placed on chemicals, especially where the chemicals were of indiscriminate toxicity. In the absence of biological checks, the resistant aphids freely multiplied to tremendous numbers and caused severe damage to the alfalfa despite the frequent chemical treatments.

Analysis of the Hinkley situation clearly indicated an imperative need for an insecticide that would give adequate aphid control and also allow the native predators to survive treatment. In addition, the aphid parasites *Praon palitans* Mues., and *Trioxys utilis* Mues., brought into California from the Old World, had become established in several areas (van den Bosch, 1956, and van den Bosch, Schlinger, and Dietrick, 1957). Preliminary studies indicated both to be highly promising enemies of the aphid. If they were to attain their full potential as biological control factors

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against the aphid, they would also have to survive any necessary chemical treatment to a considerable degree. What was needed was a control program in which chemical and biological control would complement one another. In such a relation the native and introduced enemies surviving treatment would remain in the treated area to attack any aphids not killed by the insecticide application or those migrating into the field after the insecticide had broken down. The preservation of enemies of the aphid in the treated area would thus serve to prolong the effectiveness of the chemical. Parasites and predators of other insect pests would also survive treatment and continue to attack their hosts either in alfalfa or on other adjoining crops. Moreover, with increased chemical control on alfalfa, consideration had to be given to the possibility that the extensive use of the widely toxic insecticides, parathion and malathion, might cause resistance to develop in a wide variety of other insect pests frequently found in alfalfa fields, which, though not necessarily damaging to alfalfa, might become resistance problems in other crops.

Numerous compounds were evaluated in the research program to find a selective insecticide for aphid control. Many were never tested in the field because research on other crops strongly suggested they would never meet residue tolerance regulations on alfalfa hay. In addition, because of the small margin of profit per cutting of alfalfa, a number of compounds were discarded owing to their high cost. Eventually five materials, parathion, malathion, Trithion, Phosdrin and Systox, were selected for a thorough analysis of their effect on the aphid as well as on enemies of the aphid.

GENERAL EXPERIMENTAL METHODS

Alfalfa grown for hay (or seed) proved to be a highly desirable medium for testing the relative toxicities of insecticides to beneficial insects, for it is normally of uniform growth and is often inhabited by large populations of beneficial insects, which are relatively easy to sample. In the experiments a variety of designs, plot sizes, locations, insecticidal materials, and application methods were used.

The method of evaluating the effect of each compound on the aphid was the same in all tests. Single alfalfa stems were cut just above ground level and the living immature apterous and adult aphids on them were counted. In most tests, treatments were replicated 4 times in randomized plots and 25 alfalfa stems were examined in each replicate to give 100 stems per treatment. Effectiveness of a material or dosage was determined by the reduction of aphids in the treatments as compared with the untreated check.

Two sampling methods were used to determine the effect of the insecticides on beneficial insects, these being (1) counts of beneficial insects in square foot areas, and (2) counts of insects collected by sweeps of the standard insect sweeping net (handle, 26 inches long; hoop, 15 inches in diameter; Indian-Head cloth bag, 24 inches deep). The square foot sampling method was employed during cold weather (winter) when the alfalfa was short and the insects relatively inactive and sheltering near the ground. Sweep sampling was used during the warm months when the insects were highly active in the vigorously growing alfalfa. In most cases, the beneficial insects were counted in the field at the time of sampling. When this was not possible, the samples from each replicate were emptied into pint ice cream cartons and brought into the laboratory under refrigeration and then counted.

With the exception of two airplane tests (nos. 6 and 8), all sprays were applied at a pressure of 60 pounds per square inch with a ground sprayer equipped with no. 4X hollow-cone nozzles arranged 18 inches apart for broadcast spraying.

PRELIMINARY STUDY

Early investigations by van den Bosch, Reynolds, and Dietrick (1956) showed parathion to be highly toxic to certain predacious insects in alfalfa. When the spotted alfalfa aphid developed a low degree of resistance to organophosphorus compounds at Hinkley, California, it was noticed that where parathion was repeatedly applied, the alfalfa fields were essentially barren of arthropods except resistant spotted alfalfa aphids and certain spiders. In addition, net sweeps taken during the summer of 1956 in parathion-treated fields showed that the complex of insects normally inhabiting alfalfa fields was drastically depleted. To carry these general observations further, a preliminary survey was made in the Mojave Desert to gather numerical data on the relative abundance of predators in a field repeatedly treated with parathion as compared with a field which had been untreated for about five months prior to sampling. The treated alfalfa field was sprayed twice by ground equipment during August, using 4 ounces of parathion per acre. It was treated twice in September and twice in October, using 6 ounces of parathion per acre. Before the survey was made, a number of moderate frosts occurred in the Mojave Desert which stunted growth of the alfalfa. This factor, plus retarded insect activity, made sweep sampling impractical. Thus, the relative abundance of beneficial insects in both fields was measured by sampling random square-foot areas as the

TABLE 1

RELATIVE ABUNDANCE OF PREDATORS IN A HEAVILY TREATED AND UNTREATED ALFALFA FIELD IN THE MOJAVE DESERT, CALIFORNIA, LATE OCTOBER, 1956

Ten square-foot samples were taken in each field

Sample field	Coccinellid spp.	*Geocoris* sp.	*Orius* sp.	Anthocorid sp.	*Collops* sp.	Average number of aphids per stem
	A* L	A N	A N	A N	A L	
Repeated parathion treatments‡	0—0	2—6	0—0	0—0	1—12	29
Untreated	66†—1	29—37	10—8	9—22	0—35	1.0

* A = adult; L = larva; N = nymph.

† A mixed population comprised of *Hippodamia convergens* Guèrin; *H. quinquesignata punctulata* LeConte; *H. parenthesis* (Say); and *H. sinuata* Mulsant.

‡ Treated twice by ground equipment in August (4 ounces of parathion per acre) and twice in both September and October (4 ounces per acre).

samplers moved diagonally across the fields. The aphids were sampled by cutting alfalfa stems and counting the aphids on them. The data are summarized in table 1.

The data in this table show that beneficial insect populations had been essentially eliminated in the field subjected to repeated parathion treatments whereas, by comparison, beneficial insects were quite abundant in the untreated field. Correspondingly, resistant aphids were 29 times as abundant in the treated field as in the untreated field. With this evidence from the preliminary survey, supported by the earlier knowledge of the indiscriminate toxicity of parathion and by field observations during the summer of 1956, it was apparent that when heavy repeated applications of parathion were made for aphid control, the alfalfa fields were literally defaunated. Under such conditions dispersing alate aphids could migrate into such biotic vacuums and reproduce explosively, leading to a treadmill of insecticidal treatment and eventual widespread resistance of the aphid to organophosphorus insecticides.

EXPERIMENTAL PROGAM

Test No. 1. Following the preliminary survey just discussed, an experimental program was undertaken to find a selective insecticide. The first of a series of field tests was conducted near Lancaster, on the western edge of the Mojave Desert, on November 17, 1956. This experiment was conducted to determine the effect of a number of insecticides on a heavy infestation of the spotted alfalfa aphid and a complex of associated coccinellid species. Each treatment was replicated five times, with each plot being 68 feet long and 30 feet wide. The alfalfa was 6 to 8 inches tall. Treatments were evaluated between 48 and 72 hours after application and on the sixth day after treatment. The data are summarized in table 2.

TABLE 2

GROUND-EQUIPMENT SPRAY TESTS OF THE TOXICITY OF SEVERAL INSECTICIDES TO ADULT COCCINELLIDS* IN ALFALFA NEAR LANCASTER, CALIFORNIA, ON NOVEMBER 17, 1956

15 square-foot samples per treatment

Material	Toxicant per acre	Coccinellids at 2 intervals after treatment					
		2–3 days			6 days		
		Number alive	Number dead	Per cent mortality	Number alive	Number dead	Per cent mortality
Parathion	8.2 oz.	4	58	94	92	140	60
Systox	6.2 oz.	42	44	51	92	51	36
Schradan	16.6 oz.	69	20	23	179	26	13
Pyrethrum†	1.6 pts.	73	24	25	204	21	9
Rotenone‡	1 qt.	111	20	15	139	22	14
Untreated	......	18	3	15	177	23	12

* A mixed population comprised of *Hippodamia convergens*, *H. quinquesignata punctulata*, *H. parenthesis*, and *H. sinuata*.

† By weight: pyrethrins 1.4%, mineral oil 23.6%, pine oil 45%.

‡ By weight: rotenone 2.5%, other cube resins 2.5%, ethylene glycol oleic esters 45%.

In the experimental field, because of the lateness of the season, the tips of the alfalfa had frozen, and the alfalfa cover was restricted to isolated clusters. Day temperatures were low and insect activity was restricted to a short period in midafternoon. In the brief warm period, the coccinellids would crawl from the litter and onto the alfalfa stems. There they would adjust themselves at right angles to the sun and feed on the spotted alfalfa aphid. As the temperature decreased, they would again crawl under the litter. Coccinellids were sampled by counting the live and dead adults within randomly selected square-foot areas. The first sample was started 48 hours after application and completed 72 hours after treatment. In sampling, a square-foot frame was cast at random using three such randomized subsamples in each replicate or a total of 15 samples per treatment. The disadvantage in casting the square frame was that it frequently landed between alfalfa clusters. In such cases, there were usually no lady beetles in the sample. This occurred quite often, particularly in the untreated plot on the first sampling period, which accounts for the low number of beetles in that sample. On the second sampling date, 6 days after application, the sampling method was changed somewhat so that if more than three fourths of the square-foot frame enclosed barren ground, the frame was recast. This tended to increase the numbers of lady beetles taken on the second sampling day. An additional increase may have been from some beetles migrating into the plots from an adjoining field where they had essentially eliminated the aphid food supply.

The data in table 2 show that parathion applied at 8.2 ounces per acre was more toxic to the coccinellids than Systox, schradan, pyrethrum, or rotenone. In comparison with tests conducted later in the investigations (summer, 1957) the relative toxicity of parathion to coccinellids in this test was not as high as when this material was applied at lower dosages. The reason for this difference appears to be that in the test under discussion,

TABLE 3

RESULTS OF SPRAY TESTS APPLIED BY GROUND EQUIPMENT FOR THE CONTROL OF THE SPOTTED ALFALFA APHID ON ALFALFA AT LANCASTER, CALIFORNIA, NOVEMBER 17, 1956

Material	Amount per acre		Interval between treatment and sampling			
			2–3 days		6 days	
	Toxicant	Gallons	Number of apterous aphids per 125 stems	Per cent reduction from untreated plot	Number of apterous aphids per 125 stems	Per cent reduction from untreated plot
Parathion	8.2 oz.	11.5	494	93	186	97
Systox	6.2 oz.	11.5	0	100	3	99
Schradan	16.2 oz.	11.5	582	92	318	94
Pyrethrum*	1.6 pts.	11.5	4,081	44	2,573	52
Rotenone†	1 qt.	11.5	4,292	42	2,850	47
Untreated	......	....	7,338	..	5,331	..

* By weight: pyrethrins 1.4%, mineral oil 23.6%, pine oil 45%.
† By weight: rotenone 2.5%, other cube resins 2.5%, ethylene glycol oleic esters 45%.

TABLE 4

RELATIVE TOXICITY OF VARIOUS INSECTICIDES APPLIED BY GROUND EQUIPMENT TO PREDATOR SPECIES IN ALFALFA AT THERMAL, CALIFORNIA, DECEMBER 3, 1956

Material and dosage per acre	Interval after treatment and number of predators per 200 sweeps													
	Coccinellids*		*Nabis* sp.		Syrphid spp.		*Orius* sp.		* *Chrysopa* sp.		*Sinea* sp.		Field spiders	
	24 hrs.	72 hrs.	24 hrs.	72 hrs.	24 hrs.	72 hrs.	24 hrs.	72 hrs.	24 hrs.	72 hrs.	24 hrs.	72 hrs.	24 hrs.	72 hrs.
	A† L	A L	A N	A N	A L	A L	A N	A N	A L	A L	A N	A N		
Parathion, 4.4 oz.	11—0	4—0	2—1	1—0	8—0	5—2	14—0	12—0	2—0	4—0	1—2	0—1	47	28
Systox, 2.5 oz.	29—8	17—23	43—6	16—4	5—2	10—0	103—0	43—1	173—3	42—3	5—35	0—10	69	40
Schradan, 6.9 oz.	38—9	30—11	31—6	8—2	17—12	18—18	83—1	38—2	216—0	34—3	3—10	2—1	47	22
Pyrethrum & rotenone,‡ 42.3 lbs.	29—10	21—11	20—3	4—0	5—11	16—22	12—0	11—0	68—1	26—0	3—14	3—2	32	42
Untreated	34—3	22—9	40—2	18—0	6—14	8—24	115—0	44—0	296—0	61—1	7—12	5—4	49	36

* Coccinellids were mainly *Hippodamia convergens*.
† A = adult; L = larva; N = nymph.
‡ The dust mixture consisted of pyrethrins 0.115%, rotenone 0.200% and MGK-264 0.400%. The balance was diluent with about 4% oil in the finished dust.

TABLE 5

EFFECTIVENESS OF VARIOUS INSECTICIDES APPLIED ON DECEMBER 3, 1956, BY GROUND EQUIPMENT FOR CONTROL OF THE SPOTTED ALFALFA APHID ON ALFALFA AT THERMAL, CALIFORNIA

Material	Amount per acre		Interval between treatment and sampling					
			1 day		3 days		8 days	
	Toxicant	Gallons	Number of apterous aphids per 125 stems	Per cent reduction from untreated plot	Number of apterous aphids per 125 stems	Per cent reduction from untreated plot	Number of apterous aphids per 125 stems	Per cent reduction from untreated plot
Parathion	4.4 oz.	13.1	8,651	15	1,595	64	1,200	77
Systox	2.5 oz.	11.8	199	98	39	99	92	98
Schradan	6.9 oz.	10.4	9,680	4	2,910	34	3,247	38
Pyrethrum & rotenone*	42.3 lbs.	....	7,328	28	3,629	17	4,086	21
Untreated	......	....	10,122	..	4,381	..	5,204	..

* The dust mixture consisted of pyrethrins 0.115%, rotenone 0.200% and MGK-264 0.400%. The balance was diluent with about 4% oil in the finished dust.

many of the beetles were under the ground litter when the materials were applied and many probably did not crawl onto the plants and contact the toxic residue. Nevertheless, Systox applied at the heavy dosage of 6.2 ounces per acre had far less effect on the beetles than parathion, while schradan, pyrethrum, and rotenone had still less.

Aphid control in this test varied. The data are summarized in table 3. Systox applied at 6.2 ounces per acre essentially eliminated the aphids. Control with parathion and schradan was slightly less effective, while pyrethrum and rotenone gave mediocre control.

Test No. 2. On December 3, 1956, insecticides were applied by ground equipment on alfalfa at Thermal, California, in the Coachella Valley. This experiment was conducted to determine the relative toxicity of a number of insecticides to the spotted alfalfa aphid and to a variety of predator species in alfalfa. Three sprays and one dust mixture material were applied. The alfalfa was about 16 inches tall at time of treatment and each treatment was replicated five times. The effects of the materials on the predator species were evaluated 1 and 3 days after application by sampling with a standard insect net. Forty 180-degree sweeps were made in each replicate, or a total of 200 sweeps per treatment. The sweepings from each replicate were placed in pint ice cream cartons, brought into the laboratory and held at 35° F until counted the next day. The data are summarized in table 4.

Twenty-four hours after application, coccinellids, syrphids, *Nabis* sp., *Orius* sp., *Chrysopa* sp., and *Sinea* sp., were largely eliminated from the plots treated with 4.4 ounces of parathion. Systox, schradan, and the pyrethrum-rotenone dust mixture were far less toxic to the predators. Seventy-two hours after treatment, the predator populations were still very low in the parathion plots. On the other hand, Systox applied at 2.5 ounces per acre caused little or no reduction in predators (except syrphids) in comparison with the untreated plots.

The effects of the materials on the aphid were evaluated 1, 3, and 8 days after application. The data are summarized in table 5. Twenty-four hours after treatment, Systox applied at 2.5 ounces per acre gave satisfactory aphid mortality. Results were very poor where parathion, schradan, and the pyrethrum-rotenone dust mixture were applied. The Coachella Valley is an area where the aphid had developed a low degree of resistance to organophosphorus compounds (Stern and Reynolds, 1958), which accounts for the mediocre kill with parathion. Even though schradan and the pyrethrum-rotenone dust mixture were relatively nontoxic to beneficial insects, further evaluation of these materials was discontinued because of their mediocre effect on the aphid in the test under discussion. It may be noted that in test no. 1, at Lancaster, schradan gave satisfactory aphid mortality when applied at 16.2 ounces per acre. However, the cost of treatment at this dosage would be prohibitive on alfalfa hay.

Test No. 3. After analyzing the data from Lancaster (test no. 1) and Thermal (test no. 2), it seemed evident that Systox was far less toxic to beneficial insects than parathion. The Thermal experiment and the work of Reynolds and Anderson (1955) and Bieberdorf and Bryan (1956) showed that Systox gave satisfactory aphid control when applied at 2 to 4

TABLE 6

EFFECTIVENESS OF VARIOUS INSECTICIDES APPLIED BY GROUND EQUIPMENT FOR CONTROL OF THE SPOTTED ALFALFA APHID ON ALFALFA AT HEMET, CALIFORNIA, ON FEBRUARY 5, 1957

Material	Amount per acre		Interval between treatment and sampling					
			1 day		3 days		7 days	
	Toxicant	Gallons	Number of apterous aphids per 100 stems	Per cent reduction from untreated plot	Number of apterous aphids per 100 stems	Per cent reduction from untreated plot	Number of apterous aphids per 100 stems	Per cent reduction from untreated plot
Systox	0.9 oz.	13.7	18	99	3	99	10	99
Systox	1.4 oz.	11.1	7	99	0	99	11	99
Parathion	3.1 oz.	12.5	95	99	10	99	31	99
Sevin	10.8 oz.	16.1	5,019	67	698	94	312	96
C-140*	10.4 oz.	12.5	6,243	59	1,255	88	140	98
Untreated	......	....	15,044	..	10,817	..	6,869	..

* Hydrochloride salt of the dimethylcarbamate of *o*-dimethylaminophenol (C-140 of Rohm and Haas Co.).

ounces per acre by ground equipment. At this dosage, however, the prospect of using Systox on alfalfa was not bright because of its high cost as compared with the other materials then registered for use against the spotted alfalfa aphid. Therefore, the dosage had to be reduced if this promising material was to be brought into the spotted-alfalfa-aphid control picture. Accordingly, a preliminary test using Systox at low dosages (0.9 and 1.4 ounces per acre) was conducted on alfalfa at Hemet, California, on February 5, 1957. A variety of materials in addition to Systox were also tested on this date. The alfalfa was about 10 inches tall and the treatments were replicated four times. Each replicate was 90 feet long and 30 feet wide. The materials were evaluated 1, 3, and 7 days after application. The data are summarized in table 6.

Systox was applied at two dosages, 0.9 and 1.4 ounces per acre, and both gave 99 per cent aphid mortality 1 day after application. Parathion, used as a standard comparison material and applied at 3.1 ounces per acre also gave 99 per cent mortality 1 day after treatment. There was little if any alate aphid dispersal in the area during the testing period and the excellent control with Systox and parathion continued throughout the experiment. Aphid mortality with Sevin and C-140 (the hydrochloride salt of the dimethyl-carbamate of *o*-dimethylaminophenol) was mediocre 24 hours after application. But by the third day after application the aphids had decreased greatly in both of these treatments and 7 days after application the populations were at low levels. The number of aphids in the untreated plots also decreased during the same period, however, and thus the aphid reduction in the plots treated with Sevin and C-140 may have been only partially due to the effects of the compounds.

Following the very promising performance of the low dosage of Systox in the Hemet test, another experiment was conducted at Calipatria, Imperial County, California. In this test, Systox was applied at 0.4 and 0.9 ounce per acre. Parathion, used as a standard comparison material, was applied at 4.2 ounces per acre. Both dosages of Systox and the parathion gave satisfactory control 24 hours after application.

Test No. 4. During the course of the investigations, two promising new materials, Trithion and Phosdrin, had been tested for aphid control (Stern and Reynolds, 1957) and were registered for use on alfalfa hay or seed in California. Since the relative toxicities to beneficial insects of these materials and also of malathion were not known, it was necessary to include them in a series of comparisons with Systox. Accordingly, on March 28, 1957, the first of a series of such experiments was conducted at Hinkley, California, in the Mojave Desert. Sprays were applied by ground rig when the alfalfa was about 18 inches tall. Each treatment was replicated four times. Each replicate was 325 feet long and 30 feet wide. To test the effect of the materials on beneficial insects, the plots were sampled with a standard sweep net 10 minutes after application and at 24 and 48 hours after treatment. The 10-minute posttreatment sample was made to determine whether predators suffered quick knockdown or whether the insecticides had a repellent effect on the adults. In all samples, 30 sweeps were taken in each replicate or a total of 120 sweeps per treatment. The first samples taken 10

TABLE 7

RELATIVE TOXICITY OF SEVERAL INSECTICIDE SPRAYS APPLIED BY GROUND EQUIPMENT TO BENEFICIAL INSECTS IN ALFALFA AT HINKLEY, CALIFORNIA, IN THE MOJAVE DESERT, MARCH 28, 1957

Material	Toxicant per acre	Number of live and dead predators recorded 8 hours after treatment from 120 sweep samples taken 10 minutes after application									
		Coccinellids		*Nabis* sp.		*Geocoris* sp.		Syrphids		*Chrysopa* sp., adults	*Orius* sp., adults
		Adults	Larvae	Adults	Nymphs	Adults	Nymphs	Adults	Larvae		
		D* L	D L	D L	D L	D L	D L	D L	D L	D L	D L
Malathion	9.5 oz.	101—0	13—0	2—1	0—6	4—5	0—1	0—0	9—5	2—0	1—0
Parathion	3.8 oz.	129—0	13—2	2—0	0—3	1—4	1—1	0—0	7—0	6—0	1—0
Trithion	11.6 oz.	74—46	15—26	0—7	0—2	5—4	0—0	2—2	3—3	4—1	0—0
Phosdrin	1.0 oz.	33†—0	25—0	10—0	1—4	3—1	0—0	0—0	11—3	5—0	0—0
Systox	0.7 oz.	9—119	1—49	0—21	0—6	0—5	0—1	0—0	0—2	0—3	3—10
Systox	1.5 oz.	9—106	3—43	0—17	0—18	0—6	0—2	1—0	1—7	1—4	2—11
Untreated	......	0—161	0—55	0—26	0—29	0—7	0—1	0—0	0—12	0—5	0—14

* D = dead; L = live.
† Adults are killed instantly, which accounts for the relatively low numbers of coccinellids swept 10 minutes after application.

TABLE 8

RELATIVE TOXICITY OF VARIOUS INSECTICIDE SPRAYS APPLIED BY GROUND EQUPMENT TO BENEFICIAL INSECTS IN ALFALFA AT HINKLEY, CALIFORNIA, MARCH 28, 1957

Material	Toxicant per acre	Interval between treatment and sampling and number of predators per 120 sweeps											
		Coccinellids		*Nabis* sp.		*Geocoris* sp.		Syrphids		*Chrysopa* sp.		*Orius* sp.	
		24 hrs.	48 hrs.	24 hrs.	48 hrs.	24 hrs.	48 hrs.	24 hrs.	48 hrs.	24 hrs.	48 hrs.	24 hrs.	48 hrs.
		A* L	A L	A N	A N	A N	A N	A L	A L	A	A	A	A
Malathion	9.5 oz.	3—0	5—0	1—0	0—1	0—1	0—0	2—0	0—1	0	0	0	0
Parathion	3.8 oz.	5—0	4—1	0—0	1—0	0—0	0—0	2—0	0—0	0	0	0	0
Trithion	11.6 oz.	1—2	1—2	0—0	3—0	0—0	1—0	0—2	1—1	0	1	0	2
Phosdrin	1.0 oz.	14—0	14—0	0—0	0—0	1—0	1—0	1—0	0—2	1	0	0	2
Systox	0.7 oz.	18—6	12—8	2—3	2—1	1—1	0—0	1—1	0—0	3	4	4	6
Systox	• 1.5 oz.	22—20	10—14	5—2	2—3	1—0	0—0	4—1	1—1	1	3	8	6
Untreated	......	36—19	16—33	6—2	2—3	1—0	0—0	2—5	1—7	1	3	9	6

* A = adults; L = larva; N = nymph.

minutes after each specific material was applied were placed in pint ice cream cartons and brought into the laboratory. The loose alfalfa leaves, tips and other debris were taken out of the net before placing the insects in the cartons. One or two untreated alfalfa sprigs were then placed in each carton which was then covered with cotton gauze.

The untreated plot was sampled near the middle of the treatment schedule. Treatments were started at 10 o'clock in the morning. Malathion was first applied and sampled, and then parathion, Phosdrin, Trithion, and the low and high dosages of Systox were applied and sampled. The untreated plots were sampled after the Trithion treatment and sampling. The last treatment, the high dosage of Systox, was applied at 12:30 p.m. The 10-minute samples were brought into the laboratory and examined 8 hours after treatment, at which time the number of living and dead predators was recorded. The summarized data are shown in table 7.

Parathion, malathion and Phosdrin applied at 3.8, 9.5 and 1 ounce per acre, respectively, had killed essentially all the coccinellid adults and larvae when the 10-minute sweep samples were recorded 8 hours after application. It is interesting to note that a small sample of adult coccinellids was taken where Phosdrin was applied, the reason being that this material gives a near instantaneous knockdown of the lady-beetle adults. The high susceptibility of coccinellids to Phosdrin was noticed in earlier tests when this material was being evaluated for spotted alfalfa aphid control. High mortality of adult *Chrysopa* sp. and *Nabis* sp. occurred in the malathion, parathion and Phosdrin treatments. In addition, low numbers of adult and nymphal *Nabis* sp. were collected where these three materials were applied in comparison with the check. *Orius* adults and *Nabis* adults and nymphs were also collected in low numbers where Trithion was applied at 11.6 ounces per acre, which suggests a rapid knockdown of these species. Samples of coccinellids taken from the Systox treatments (0.7 and 1.5 ounces per acre) were lower than those taken from the untreated plots but of the coccinellids collected nearly all were alive when the 10-minute samples were observed and recorded 8 hours after application.

Trithion, one of the new materials applied at a higher dosage than required to control nonresistant aphids, caused moderate mortality of coccinellid adults and larvae, *Geocorus* adults, and syrphid adults and larvae. However, samples taken 24 and 48 hours after application in this and in subsequent tests show that Trithion is quite toxic to beneficial insects when applied at dosages of 7.3 ounces per acre and above, but the material apparently requires at least 24 hours before its effects are fully realized.

The plots were next sampled for the relative abundance of predators 24 and 48 hours after application. On these two days, a strong cold wind was blowing, a frequent occurrence in the Mojave Desert during the spring. This accounts for the low numbers of predators obtained as compared with the 10-minute sample on the day of application. The summarized data from the 24- and 48-hour sample appear in table 8.

Twenty-four hours after application, parathion, malathion, Trithion, and Phosdrin applied at 3.8, 9.5, 11.6 and 1 ounce per acre, respectively, had virtually eliminated the entire complex of entomophagous species. By comparison, the beneficial species were still abundant in the two Systox treatments (0.7 and 1.5 ounces per acre) and in the untreated plot. Moreover, only a few miscellaneous insects and spiders were collected in the sweepings taken from the plots treated by the four widely toxic materials, particularly parathion and malathion.

In the plots treated with Phosdrin a number of adult lady beetles were collected. Phosdrin is a highly unstable compound and its toxic action is quickly lost. Insects migrating into the treated area a short while after application appear to be unharmed. The area concerned in this experiment was small and adjacent to large untreated areas. It is probable that the adult coccinellids swept in the Phosdrin plots 24 and 48 hours after application had migrated in soon after application. If, as a later test shows, Phosdrin is applied over a wide area, beneficial insects are reëstablished far less rapidly.

Systox appeared to eliminate a moderate number of the coccinellid adults but the larvae survived in greater numbers. This material appeared to have little effect on the other predators in the experimental area. In this and in another test, the lower dosage of Systox appeared to be more toxic to coccinellids than the higher dosage. This is felt to be a reflection of plot or sampling variation, there probably being no great difference in mortality between 1 and 1.5 or 2 ounces per acre.

In addition to testing the effect of the various materials on beneficial insects, the sprays were tested for their effect on the aphid, the main interest being in the effectiveness of the low dosages of Systox. The data are summarized in table 9.

Aphid populations at Hinkley, California, are resistant and the materials had a variable effect on the aphid. Twenty-four hours after application, malathion, Phosdrin, and the low and high dosage of Systox applied at 9.5, 1, 0.7 and 1.5 ounces per acre, respectively, gave satisfactory aphid mortality. Parathion and Trithion applied at 3.8 and 11.6 ounces per acre,

TABLE 9

EFFECTIVENESS OF VARIOUS INSECTICIDE SPRAYS APPLIED BY GROUND EQUIPMENT FOR CONTROL OF THE SPOTTED ALFALFA APHID ON ALFALFA AT HINKLEY, CALIFORNIA, MARCH 28, 1957

Materia	Amount per acre		Interval between treatment and sampling			
			1 day		4 days	
	Toxicant	Gallons	Number of apterous aphids per *100 stems*	Per cent reduction from untreated *plot*	Number of apterous aphids per *100* stems	Per cent reduction from untreated plot
Malathion	9.5 oz.	11.4	18	98	35	98
Parathion	3.8 oz.	11.4	500	73	218	87
Trithion	11.6 oz.	11.6	651	64	194	88
Phosdrin	1.0 oz.	11.6	1	99	3	99
Systox	0.7 oz.	11.4	32	98	109	93
Systox	1.5 oz.	11.9	1	99	8	99
Untreated	......	....	1,822	..	1,664	..

TABLE 10

RELATIVE TOXICITY OF VARIOUS INSECTICIDE SPRAYS APPLIED BY GROUND EQUIPMENT TO A NUMBER OF PREDATORS AND TWO SPOTTED ALFALFA APHID PARASITES IN ALFALFA AT THERMAL, CALIFORNIA, APRIL 10, 1957

Treatment and dosage per acre	Interval between treatment and sampling and number of predators and aphid parasites per 100 sweeps																	
	Coccinellids			*Praon palitans*			*Trioxys utilis*			*Orius* sp.			*Nabis* sp.			*Chrysopa* sp.		
	1 day	2 days	9 days	1 day	2 days	9 days	1 day	2 days	9 days	1 day	2 days	9 days	1 day	2 days	9 days	1 day	2 days	9 days
	A* L	A L	A L	A	A	A	A	A	A	A N	A N	A N	A N	A N	A N	A L	A L	A L
Malathion, 9.1 oz.	13—1	4—2	98—2	0	2	5	0	2	174	22—1	34—0	266—0	2—3	21—3	18—2	0—0	0—0	7—0
Parathion, 4.0 oz.	14—1	17—0	113—33	1	0	4	3	1	227	37—2	55—0	307—0	1—1	1—0	9—0	1—0	1—0	4—0
Phosdrin, 0.7 oz.	16—3	10—4	93—255	3	2	4	0	8	202	115—1	99—0	348—0	8—3	18—4	14—0	1—1	4—0	9—1
Trithion, 7.3 oz.	37—17	47—0	58—91	0	3	3	0	8	148	218—2	175—0	272—0	10—1	36—5	8—0	12—0	11—1	10—0
Systox, 0.5 oz.	42—48	97—79	69—344	6	1	2	4	10	67	391—3	206—0	142—0	12—0	25—0	12—0	7—0	22—1	6—0
Systox, 0.9 oz.	38—42	45—74	38—504	9	3	2	3	13	60	402—1	215—0	250—0	8—2	26—5	14—0	2—0	16—0	5—0
Check	78—54	385—210†	114—238	8	8	0	11	21	140	348—1	285—0	155—0	12—1	32—6	17—0	7—1	28—5	8—0

* A = adult; L = larva; N = nymph.
† Sample number is far greater than would be expected. Unquestionably an inadvertent error was made in counting or in recording the data.

respectively, gave poor kills. Four days after application, control decreased slightly where 0.7 ounce of Systox was applied. When the first sample was taken, one day after treatment, most of the aphids remaining in the low dosage Systox plots were apterous adults. These adults continued to reproduce and small colonies of first-instar nymphs accounted for most of the aphids taken 4 days after application.

Test No. 5. On April 10, 1957, sprays were applied by ground equipment on alfalfa at Thermal in the Coachella Valley, California. This experiment was conducted to determine the effects of parathion, malathion, Phosdrin, Trithion, and Systox on beneficial insects. The alfalfa was about 14 inches tall and each treatment was replicated four times. Each replicate was 300 feet long and 30 feet wide. The effects of the materials on beneficial insects were evaluated 1, 2, and 9 days after application. A standard sweep net was used to sample the beneficial insects. Twenty-five sweeps were taken in each replicate, or 100 sweeps per treatment. The data are summarized in table 10. It was not possible to count the various predators and parasites in the field at the time of sampling so the sweepings were placed in pint ice cream cartons and brought into the laboratory for counting and recording.

Twenty-four hours after application nearly all the coccinellid larvae were eliminated by parathion, malathion, and Phosdrin applied at 4, 9.1 and 0.7 ounce per acre, respectively. These materials were not quite as toxic to the adult lady beetles as to the larvae, although the adults were drastically reduced in comparison with the untreated plots. Trithion applied at 7.3 ounces per acre reduced the adult coccinellids by about 50 per cent and the larvae by approximately 66 per cent, 24 hours after application. Systox applied at 0.5 and 0.9 ounce per acre gave a comparable reduction in lady-beetle adults, whereas the larvae were only slightly, if at all, reduced.

The numbers of coccinellids swept from the treatments cannot be directly compared with those from the untreated plots 48 hours after application, since there appears to have been an inadvertent error in counting or recording the 48-hour coccinellid sample from the untreated plots. The recorded data show that the adults increased five-fold and the larvae four-fold in the 24-hour period between the first and second sampling. It is felt that such an increase in adults and larvae is far greater than would be expected. There were numerous egg masses in all plots but it does not seem likely that there would be such a large hatch in lady beetle larvae or adult emergence or migration in a 24-hour period.

Comparing the 48-hour samples from the treated plots with their corresponding 24-hour samples, there were very low numbers of coccinellids where parathion, malathion, and Phosdrin were used. The number of adult coccinellids in the 48-hour sample was similar to the 24-hour sample where Trithion was used, whereas the larvae appeared to be eliminated 48 hours after application. Eggs were hatching and the number of larvae increased in the second sample where both dosages of Systox were used. The adults increased in the low dosage of Systox (0.5 ounce per acre) and remained more or less the same at the higher dosage.

Nine days after application, larvae in the Phosdrin and Systox plots had increased and exceeded the number swept from the untreated plots. As mentioned earlier, Phosdrin has a high initial toxicity to coccinellid adults and larvae. However, the material breaks down rapidly and in this instance, where there were numerous egg masses in the plots at time of treatment, the hatching larvae appear to have been unharmed. Malathion, parathion, and Trithion all have residual toxicity and apparently kill the young lady-beetle larvae as they emerge from the eggs. Thus where these three materials were applied, the numbers of larvae in the respective samples remained markedly lower than in the untreated plots 9 days after application. There appeared to be little difference between the numbers of lady-beetle adults in the malathion, parathion, Phosdrin, and untreated plots 9 days after application. Again, as in the previously discussed experiment, the experimental area adjoined a number of large untreated alfalfa fields and immigration of adult coccinellids obscured the initial mortality differences 9 days after application.

Twenty-four hours after application, the aphid parasites *Praon palitans* Mues. and *Trioxys utilis* Mues., and also *Orius, Nabis,* and *Chrysopa* were markedly reduced where parathion, malathion, and Phosdrin were used. Trithion appeared to be equally toxic to the aphid parasites but was less toxic to *Orius, Nabis,* and *Chrysopa* than the three materials mentioned above. In general, of the materials used in this test, Systox was by far the least toxic to beneficial insects. Nine days after treatment, the harmful effects to the beneficial insects from parathion, malathion, Phosdrin, and Trithion had largely disappeared. With the exception of coccinellid larvae, however, very few immature stages of other insects appeared in any of the samples. Thus, the reëstablishment of the beneficial insects could only have occurred by immigration from the large untreated areas adjoining the small test plots. Had the test plots been several acres in size, it is felt that the reëstablishment of the predators and parasites would have required a considerably longer period of time. Under such conditions, as discussed below, the use of either parathion, malathion, or Trithion over a wide area might have resulted in a rapid flareback of the aphid.

In testing the effect of the materials on the aphid, samples were taken 2, 5, 8, and 25 days after treatment. The data are summarized in table 11.

When the materials were evaluated 2 days after treatment, control was highly unsatisfactory for all materials. This reflects the resistance of the aphid population at Thermal to organophosphorus materials (Stern and Reynolds, 1958). Phosdrin, malathion, and the high dosage of Systox (0.9 ounce per acre) were applied at dosage levels which quickly kill nonresistant aphids, while parathion and Trithion were applied at rates in excess of dosages required to give a quick kill of nonresistant aphids. The lower dosage of Systox used in this experiment (0.5 ounce per acre) was probably close to the limit of toxic effect of this material, even for nonresistant aphids.

In following the trends of the resistant aphid populations in the various treatments, the effects of the insecticides on the beneficial insects must be considered, particularly their effect on coccinellids, since they are the pri-

TABLE 11

EFFECTIVENESS OF VARIOUS INSECTICIDE SPRAYS APPLIED BY GROUND EQUIPMENT FOR CONTROL OF THE SPOTTED ALFALFA APHID ON ALFALFA AT THERMAL, CALIFORNIA, APRIL 10, 1957

Material	Amount per acre		Interval between treatment and sampling						
			2 days		5 days		8 days		25 days
	Ounces of toxicant	Gallons of water	Number of apterous aphids per 100 stems	Per cent reduction from untreated plot	Number of apterous aphids per 100 stems	Per cent reduction from untreated plot	Number of apterous aphids per 100 stems	Per cent reduction from untreated plot	Number of apterous aphids per 100 stems
Malathion	9.1	10.9	638	88	1,387	82	2,589	64	11
Parathion	4.0	12.1	1,050	80	1,874	75	2,608	64	9
Phosdrin	0.7	11.7	630	88	1,272	82	1,168	84	6
Trithion	7.3	10.9	1,677	68	3,566	54	3,190	56	9
Systox	0.5	11.1	1,693	68	2,620	66	1,746	76	15
Systox	0.9	10.9	1,426	73	1,678	78	1,141	84	7
Check	....	....	5,268	..	7,793	..	7,280	..	10

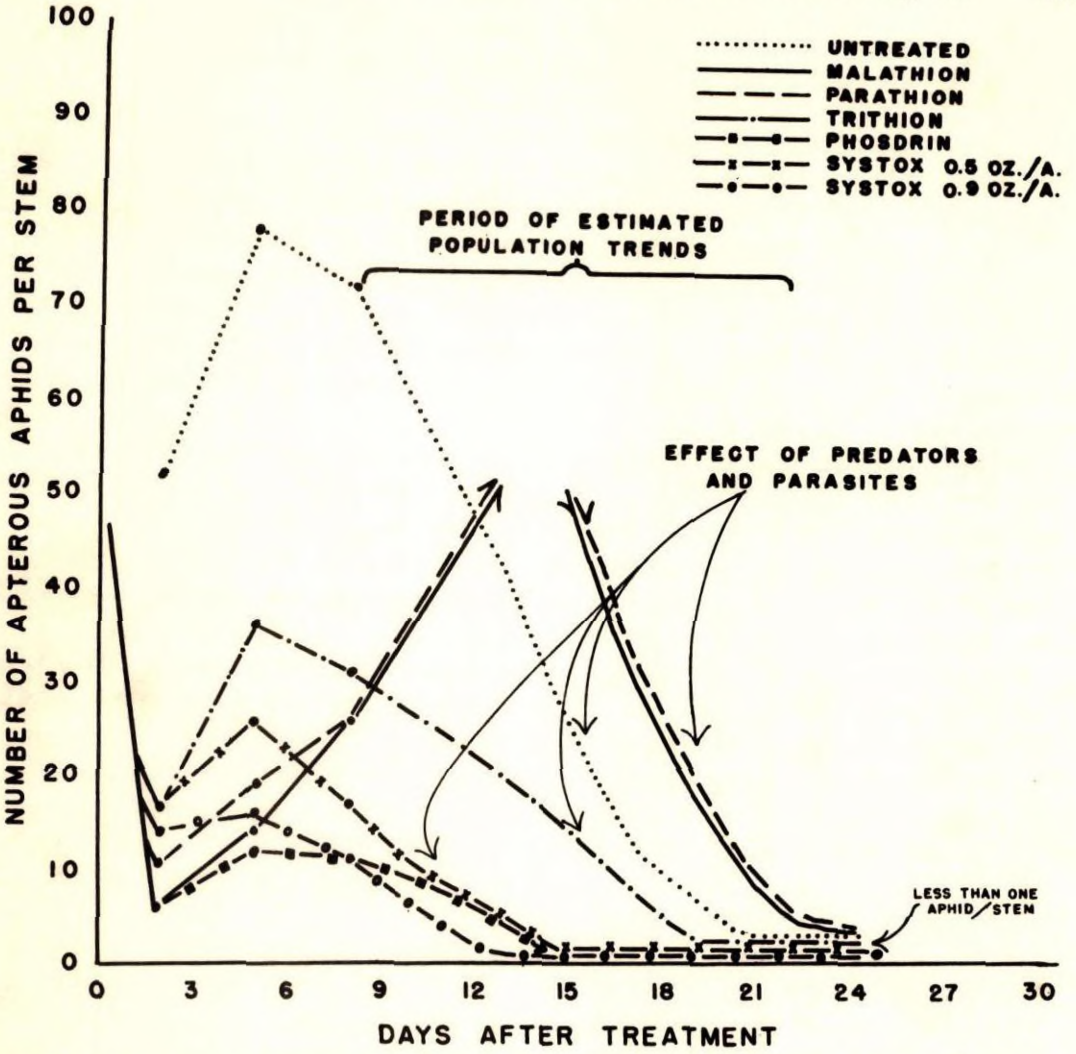

Fig. 1. Actual and estimated population trends of resistant spotted alfalfa aphid after treatment with various insecticides with different effects on beneficial insects; at Thermal, California.

mary aphid predators. The aphid population trends for the various insecticides appear in figure 1. Malathion, parathion, and Trithion were highly toxic to both immature and adult coccinellids. When the last sample for beneficial insects was taken 9 days after application, the lady-beetle populations were still low in these treatments. A characteristic of resistant aphids is that they continue reproduction after insecticide application. Thus, through the elimination of the coccinellids, the mature aphids surviving treatment continued to reproduce uninhibited by natural checks; and control decreased between the 2- and 5-day samples. Eight days after application, control decreased further where parathion and malathion were applied. On this day, aphid populations in the plots treated with parathion, malathion, and Trithion were all above the economic threshold. Where parathion and malathion were applied, the aphid population levels unquestionably increased to an even higher level before coccinellids reëstablished themselves and eventually eliminated the aphids. Unfortunately, samples were not taken at an intermediate date between the eighth and twenty-fifth day after treatment. However, the malathion and parathion treaments could be distinguished from the others by the damaged alfalfa.

In the Phosdrin plots, control decreased between the second day and fifth day samples but did not show a further decline on the eighth day. Apparently, the short-lived Phosdrin had broken down sufficiently to permit the hatching coccinellid larvae and immigrating adults to survive. Nine days after treatment, the coccinellid population in the Phosdrin plots had reached a level comparable to the untreated areas. The coccinellids in the Phosdrin plots obviously started to increase before the ninth day and had apparently checked the increase in aphids on or about the eighth day after application.

Where the low dosage of Systox (0.5 ounce per acre) was applied, the per cent control decreased slightly between the 2-day and 5-day samples but increased between the 5- and 8-day sampling period. Mortality to coccinellids was moderate at the low dosage of Systox. Where 0.9 ounce per acre of Systox was applied, the percentage control increased throughout the sampling period.

Twenty-five days after application, beneficial insects had essentially eliminated the aphids from all the plots. Although the aphid population was not sampled between the eighth and twenty-fifth day after application, the trends of the aphid in the various treatments can be followed with reasonable accuracy by using the combined data from the aphid and beneficial insect samples. In the Systox plots, the resistant aphids were probably eliminated soon after the 9-day sample was taken. Also, after the 9-day sample, the biotic checks slowly increased to a point where they overtook and eventually destroyed the resistant aphids in the parathion, malathion, and Trithion plots. However, it must be remembered that these were very small plots, and had the plots been extensive in size or had the parathion, malathion, and Trithion been applied in isolated areas where immigration of coccinellids was not a factor, control would have been of short duration. Even in the favorable circumstances of small plots the alfalfa was severely damaged where parathion and malthion were applied.

One point that warrants emphasis is that the increase in dosage of pesticides of indiscriminate toxicity in the early stages of arthropod resistance apparently not only hastens increased resistance directly through selection but also indirectly through elimination of natural enemies which would otherwise help destroy surviving resistant individuals. With the elimination of biological checks, the pest species is essentially free to increase to greater density, which further increases the frequency of the resistant gene or gene combination. The density level of the resistant population will be determined by the physical factors in the environment and host-plant resistance. The release of population reproduction potential nearly always results in severe damage or economic stress in the specific locality of the resistant arthropod.

Test No. 6. On April 11, 1957, 1- and 2-ounce dosages of Systox were applied in 5 gallons of water per acre by aircraft to alfalfa at Thermal in the Coachella Valley. The experiment was conducted to test the effectiveness of low dosages of Systox in commercial-sized blocks on the aphid and on coccinellids. Each treatment was replicated four times on alfalfa about 14 inches tall. The plots were 160 feet wide and 1,300 feet long. Pretreatment counts of the aphids and coccinellids were taken, but since this field was heavily infested with aphids at the time of treatment, it was not possible to leave untreated checks. The data obtained in the experiment are summarized in table 12.

TABLE 12

APHID AND COCCINELLID POPULATION TRENDS FOLLOWING TREATMENT WITH SYSTOX SPRAYS BY AIRPLANE AT THERMAL, CALIFORNIA, APRIL 11, 1957

Material	Toxicant per acre	Number of aphids per stem, pretreatment	Interval between treatment and sampling			
			24 hrs.	4 days	7 days	25 days
			Average number of aphids per stem			
Systox	1 oz.	74	23	24	12	<1
Systox	2 oz.		7	8	3	<1
		Number of coccinellids per 100 sweeps, pretreatment	Number of coccinellids per 100 sweeps			
		A* L	A L	A L	A L	A L
Systox	1 oz.	144—92	57—141	53—463	26—276	108—5
Systox	2 oz.		52—158	35—599	12—214	127—5

* A = adult; L = larva.

Both dosages of Systox (1 and 2 ounces per acre) gave an approximate 62 per cent reduction in lady-beetle adults 24 hours after application. The reduction in lady beetles in this test appeared to be higher than in other Systox tests. The sample was taken late in the afternoon, which may have resulted in the lower numbers of beetles or it may be that the adults feeding on the resistant aphids sprayed with Systox ingested sufficient quantities of the toxicant to kill the more susceptible ones. Ahmed *et al.* (1954) demonstrated this phenomenon in laboratory tests with *Hippodamia convergens.*

There was an increase in coccinellid larvae between the pretreatment sample and the 24-hour sample. Egg masses were rather numerous in the field and a certain number of these hatched between the two sample dates. Thus, it is not possible to determine larval mortality due to the Systox applications. But results of other tests show Systox to be relatively nontoxic to coccinellid larvae and therefore mortality was probably low.

Immediately after application, coccinellid egg masses were collected and brought into the laboratory to determine the effects of Systox on the eggs. There was no inhibition of hatch in these egg samples.

Twenty-four hours after application, the resistant aphids were reduced by approximately 69 per cent where 1 ounce of Systox per acre was applied

TABLE 13

RELATIVE TOXICITY OF SEVERAL INSECTICIDE SPRAYS APPLIED BY GROUND EQUIPMENT TO THE APHID PARASITE *Praon palitans* AND SEVERAL PREDATORS IN ALFALFA NEAR BAKERSFIELD, CALIFORNIA, JUNE 4, 1957

Interval between treatment and sampling and number of parasites and predators per 100 sweeps

Treatment and dosage per acre	*Praon palitans*			Coccinellids			*Nabis* sp.			*Orius* sp.			*Collops* sp.		
	5 hrs.	24 hrs.	72 hrs.	5 hrs.	24 hrs.	72 hrs.	5 hrs.	24 hrs.	72 hrs.	5 hrs.	24 hrs.	72 hrs.	5 hrs.	24 hrs.	72 hrs.
				A* L	A L	A L	A N	A N	A N						
Parathion, 3.0 oz.	11	108	410	14—0	6—0	8—0	5—20	1—6	5—5	17	23	67	11	2	7
Malathion, 9.7 oz.	10	147	364	12—0	11—0	7—0	25—64	11—22	26—21	22	19	61	11	7	6
Phosdrin, 1.0 oz.	39	206	397	12—1	13—0	20—0	18—39	13—18	28—22	49	36	108	18	10	13
Trithion, 5.0 oz.	39	253	586	53—3	15—0	15—1	26—59	14—25	26—31	47	34	76	20	9	14
Systox, 1.0 oz.	76	265	472	52—3	21—2	12—0	53—68	15—32	23—18	104	75	163	21	8	14
Systox, 2.0 oz.	126	318	473	60—2	29—4	14—0	45—82	25—27	30—32	149	91	100	17	8	10
Untreated	384	331	629	71—16	54—12	52—10	48—65	22—38	21—24	188	116	166	18	8	12

* A = adult; L = larva; N = nymph.

and by approximately 91 per cent where 2 ounces of Systox per acre were used. On the fourth day, there was no apparent change in the aphid population, whereas the hatching of coccinellid egg masses greatly increased the lady-beetle larval population during the same interval. Seven days after treatment, the aphids had decreased sharply, being about 50 per cent below the levels of the fourth day in both treatments. Large numbers of the coccinellid larvae pupated and the larval population also decreased simultaneously. In some instances, there were 3 or 4 coccinellid pupae on single alfalfa stems. Twenty-five days after treatment, the resistant aphids surviving treatment and their resistant offspring were essentially eliminated from the plots because of the predation of coccinellids surviving the Systox spray applications. A significant feature of this experiment is that in this case 99 per cent initial mortality of the pest insect was not necessary for satisfactory control because sufficient predators remained after treatment to reduce and hold the pest population below the economic threshold. Thus, on this resistant population where neither chemical control nor biological control by itself was able to prevent damage to the crop, the two together acted as perfect complements and gave complete control.

Test No. 7. By late spring 1957, a considerable amount of data had been obtained showing the advantages of Systox over certain other organophosphorus compounds in control of the spotted alfalfa aphid. Test no. 5, at Thermal in the Coachella Valley, had given some evidence of the relative toxicity of parathion, malathion, Phosdrin, Trithion, and Systox to the newly introduced aphid parasites *Praon palitans* and *Trioxys utilis*. However, at Thermal the parasite populations were low and another test was needed on heavier parasite populations to clarify this picture. *P. palitans* had become well established in the southern end of the San Joaquin Valley during the winter and spring of 1956–57, and a parasite population suitable for the desired experiment was eventually found at Famoso in Kern County.

On June 4, 1957, sprays were applied by ground equipment on alfalfa at Famoso. The alfalfa was about 15 inches tall. Plots were 60 feet wide and 150 feet long and four replications were made. The plots were sampled with a sweep net for predators as well as parasites 5, 24, and 72 hours after application. The data are summarized in table 13.

Parathion and malathion applied at 3.0 and 9.7 ounces per acre, respectively, were extremely toxic to the adults of *Praon palitans*. Five hours after application, approximately 97 per cent of the adults were eliminated in the plots treated by these two materials. Phosdrin and Trithion applied at normal commercial dosages for control of the aphid were slightly less toxic, eliminating about 90 per cent of the adult parasites 5 hours after treatment. Systox applied at 1 and 2 ounces per acre gave 80 and 66 per cent reduction of the parasite population respectively. Even though Systox eliminated many of the adult parasites, the reduction was far less drastic than with any of the other materials tested. The greater reduction where the lower dosage of Systox was applied again probably indicates that at these low dosages there may not be a measurable amount of differential in toxicity to the parasite under field conditions. As was mentioned earlier, this same difference occurred in certain other of the tests involving predators.

One day after application, the adult aphid parasites were still at relatively low levels in the plots treated with parathion and malathion. There were numerous cocooned parasites in this field during the test. The two materials just mentioned have residual toxicity and apparently killed the tiny parasitic wasps as they emerged from their cocoons or as they migrated into the small plots from the large untreated area adjoining the experiment. Three days after application, there was little difference in numbers of adult parasites in the various treatments. Parasites were more abundant in the untreated plots than in the treated plots and more abundant than before treatment. This may reflect emigration of the adults from the treated areas where the aphid had been eliminated, into the untreated plots where aphids were still plentiful.

Mummified aphids containing cocoons of *Praon palitans* were collected 24 hours after treatment and brought into the laboratory to determine whether any of the insecticides had had a toxic effect on the parasite. It was found that none of the sprays affected the parasite in the cocoon stage.

In this experiment, parathion and malathion were also very toxic to the other beneficial insects. Coccinellid adults were greatly reduced 5 hours after application, and there was not a single lady-beetle larva collected in these two treatments at any time during the sampling period. *Orius* sp. was also greatly reduced. *Nabis* sp. was drastically affected by parathion but malathion was not nearly so toxic to this predator. *Collops* sp. were moderately reduced in the plots treated with parathion and malathion, whereas there appeared to be no toxic effect to *Collops* sp. from the other materials applied.

Five hours after application, lady-beetle adults and larvae were very scarce in the Phosdrin plots. This material also caused considerable mortality to *Orius* and *Nabis*.

Where Trithion and the two dosages of Systox (1 and 2 ounces per acre) were applied there was a slight reduction in lady-beetle adults 5 hours after treatment but a sharp reduction in the larvae. The apparently heavy larval mortality caused by Systox in this experiment is somewhat puzzling. In all other tests, Systox caused only a slight reduction in the larval population.

TABLE

RELATIVE TOXICITY OF SEVERAL INSECTICIDE SPRAYS APPLIED BY
AND VARIOUS PREDATORS IN ALFALFA NEAR

Numbers of insects per 150 sweeps

Treatment and dosage per acre	Coccinellids			*Praon palitans*			*Orius* sp.		
	1 day	3 days	7 days	1 day	3 days	7 days	1 day	3 days	7 days
	A* L	A L	A L	A	A	A	A N	A N	A N
Parathion, 4.0 oz.	5—2	35—0	189—0	1	1	39	14—5	54—8	149—6
Phosdrin, 1.5 oz.	19—132	127—56	300—100	2	12	50	78—15	139—108	432—255
Systox, 2.0 oz.	60—312	217—662	583—196	1	12	114	287—26	273—217	438—579
Untreated	106—385	113—1094	330—1919	2	26	125	413—22	465—131	306—257

* A = adult; L = larva; N = nymph.

As for the decrease in the adult coccinellid population 24 hours after treatment, this may be correlated with the nearly complete elimination of the aphid population and the possibility that the adult lady beetles migrated to the outside of the testing area where aphids were still plentiful. Even though Systox caused a reduction in adult and larval coccinellids, its effect was not nearly as drastic as were the effects of parathion, malathion, and Phosdrin. Trithion was quite toxic to *Orius* sp. and *Nabis* sp.

Test No. 8. Except for the single test at Thermal involving two dosages of Systox, all materials had been applied by ground equipment on small plots. It was felt that at least one more experiment should be undertaken in which materials would be applied to large blocks of alfalfa by aircraft. A suitable alfalfa field was found near Famoso, Kern County, California, and sprays were applied on August 13, 1957. The alfalfa was nearing maturity and was about 25 to 30 inches tall. Plots were 215 feet wide and 1,240 feet long and were replicated three times. The toxicants were applied in 8 gallons of water per acre. In this experiment, the relative toxicities of parathion, Phosdrin, and Systox were tested on beneficial insects and on the spotted alfalfa aphid. Effects of those spray materials on beneficial insects were evaluated 1, 3, and 7 days after application by sampling with a sweep net. The data are summarized in table 14.

Parathion was again the most toxic material to all predators and to the aphid parasite *Praon palitans*. One day after application, this compound had essentially eliminated the adult and larval coccinellids. Approximately 95 per cent of *Nabis* sp., 96 per cent of *Orius* sp., and 100 per cent of *Chrysopa* sp. were eliminated in the plots treated with parathion.

At the time of application, coccinellid egg masses, larvae, pupae and adults were present in the experimental area, and during the test there was a population change from one life stage to another. At any period, however, only the larvae and adults could be sampled with the sweep net. Where parathion was applied, the coccinellid adults and larvae were essentially eliminated. The parathion residue continued its toxic action as the eggs hatched and as adults emerged from the pupae. Toxicity to the newly hatched larvae was particularly heavy, for at no time after application were there

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AIRPLANE TO THE SPOTTED ALFALFA APHID PARASITE *Praon palitans*
BAKERSFIELD, CALIFORNIA, AUGUST 13, 1957
at 3 intervals after treatment

Nabis sp.			*Chrysopa* sp.			*Geocorus* sp.			*Collops* sp.		
1 day	3 days	7 days	1 day	3 days	7 days	1 day	3 days	7 days	1 day	3 days	7 days
A N	A N	A N	A L	A L	A L	A N	A N	A N	A	A	A
7—19	11—13	30—4	0—0	3—13	24—25	14—4	7—15	5—2	12	29	38
34—135	63—180	199—85	1—5	20—60	37—96	35—11	38—29	141—41	13	37	63
175—293	275—576	381—322	9—9	39—46	55—42	15—11	57—60	91—19	24	39	58
249—241	247—311	277—178	38—5	54—26	74—40	19—2	22—10	23—6	18	48	33

any numbers of coccinellid larvae in the parathion plots. The adult population did increase to some extent after the first sampling date. These adults may have emerged from pupae after treatment or they may have migrated into the parathion plots. In either case, the toxicity of parathion to the lady beetles was extremely high.

Phosdrin was not quite so toxic to the lady beetles as parathion, but much more so than Systox. It appeared that the Phosdrin may have had some toxic effect on the coccinellid larvae beyond a 24-hour period.

Systox was the least toxic of the three materials. Adult coccinellids were reduced by approximately 43 per cent and the larvae by approximately 20 per cent 1 day after treatment. For an unknown reason, 3 days after treatment there were nearly twice as many adults in the Systox plots as in the untreated area. Many of the adults had recently emerged, as was attested by the softness of their bodies. Such adults were also found in the Phosdrin plots and to a much more limited extent in the parathion plots. The larval populations in the Systox and untreated plots increased rapidly 3 days after application. However, where Systox was applied, aphid mortality was 99.9 per cent 1 day after application, which essentially eliminated the food supply, while the aphid food supply in the untreated plots remained plentiful (table 15).

In the Systox plots, because of the limited food supply, the coccinellid larval population was far too high for all to survive. In observing the larvae 3 and 7 days after treatment, it was noticed that many were cannibalistic, which reduced their numbers. Many larvae were crawling on the ground in search of food while others undoubtedly died from starvation. Thus, on the seventh day after application, there was a tremendous difference in larval population between the Systox and untreated plots, where food was plentiful. In addition, many of the adults collected in the Systox plots 7 days after application were very small, indicating starvation. In the Phosdrin plots, there was some cannibalism and an occasional larvae was observed crawling on the ground but their numbers were not nearly so apparent as in the Systox plots. In the parathion plots, the coccinellid larval population did not recover during the testing period.

The data in table 14 indicate that the aphid parasites began to emerge from their cocoons soon after application. Those emerging in the plots treated with parathion were apparently adversely affected by the toxic residue. *Praon palitans* adults were less numerous in the Phosdrin plots than in the plots treated with Systox. However, since the peak of emergence occurred after application and Phosdrin has no residual action, no explanation can be offered for the lower numbers of *P. palitans* in the Phosdrin plots.

One day after application, there appeared to be little difference between *Geocorus* sp. numbers in any of the plots. However, the *Geocorus* sp. exhibit a certain activity cycle. Field observations indicate that many of them move up and down the plants at certain times of the day. It appeared that with this activity cycle the toxic residue of parathion gradually reduced their numbers.

Mummified aphids containing cocoons of *Praon palitans* were collected 24 hours after treatment and brought into the laboratory to determine whether the sprays had had a toxic affect on cocooned parasites. It was found that none of the insecticides affected the parasite in the cocoon stage, a result that agreed with the data obtained in test no. 7.

During the experiment, large numbers of winged aphids invaded the test area. This presented an opportunity to study the advantages of a selective insecticide (Systox) which gave good initial kill of the aphid and allowed the enemies of the aphid to survive treatment. The data are summarized in table 15.

TABLE 15

POPULATION TRENDS OF SPOTTED ALFALFA APHID AFTER APPLICATION OF THREE INSECTICIDES BY AIRCRAFT WITH VARIABLE EFFECTS ON BENEFICIAL INSECTS IN THE EXPERIMENTAL PLOTS SUMMARIZED IN TABLE 14

Material	Toxicant per acre	Average number of apterous aphids per alfalfa stem at 3 intervals after treatment		
		1 day	7 days	10 days
Parathion	4.0 oz.	<1	11	14
Phosdrin	1.5 oz.	<1	8	8
Systox	2.0 oz.	<1	<1	1.5
Untreated	...	201	426	138

One day after application, there was an average of less than 1 aphid per alfalfa stem in all three treatments. The plots were next sampled 7 days after treatment. At this time, the insecticides had broken down and no longer killed the alate aphids flying into the treated plots or their young. Aphids averaged 11 per stem in the parathion plots, 8 per stem in the Phosdrin plots. Because of the drastic reduction of natural enemies, particularly where parathion was applied, invading aphids reproduced practically unhindered. By contrast, in the Systox plots where beneficial insects survived the treatment in goodly numbers, the aphids were destroyed as they reinvaded the plots and thus there was less than 1 aphid per stem. Ten days after application, aphids averaged 14 per stem in the parathion plots, 8 per stem in the Phosdrin plots, and only 1.5 per stem in the Systox plots.

SUMMARY AND CONCLUSIONS

When it was found that parathion and malathion, the first materials used for control of the spotted alfalfa aphid, were highly destructive to native predators of the aphid, a search was begun for a material or materials that would complement rather than suppress biological control. Early investigations showed that Systox was relatively nontoxic to native predators in comparison with parathion. In the same tests, pyrethrum, rotenone, and schradan also proved to be relatively nontoxic to beneficial insects; however, mainly because they failed to control the aphid, they were eliminated from further tests.

In order to compete economically with parathion and malathion, Systox had to give effective aphid control at low dosages. Accordingly, experiments were conducted to test the effects of low dosages of Systox on *Therioaphis maculata*. It was found in these tests that Systox at 0.7 to 0.9 ounce per acre by ground equipment and 2 ounces per acre by aircraft gave satisfactory aphid control.

During the course of the investigations two promising experimental materials, Phosdrin and Trithion, were added to the list of potentially useful materials. Subsequently a number of experiments were conducted comparing the effects of commercial dosages of Systox, parathion, malathion, Phosdrin, and Trithion on native predators and the introduced aphid parasites.

When Systox was applied at dosages ranging from 0.7 to 6.2 ounces per acre it was not nearly so toxic to adult and larval coccinellids as parathion applied at 3.0 to 8.2 ounces per acre. Systox was also much less toxic to *Nabis* sp., syrphids, *Orius* sp., *Chrysopa* sp., and the small aphid parasites *Praon palitans* and *Trioxys utilis* than was parathion. Malathion applied at 9.1 to 9.7 ounces per acre by ground equipment was equally as toxic to the introduced aphid parasites and native predators (except *Nabis* sp.) as was parathion.

Phosdrin applied at 0.7 to 1.0 ounce per acre by ground equipment was not quite so toxic to the aphid parasites and native predators as parathion, malathion, or higher dosages of Trithion (11.6 ounces per acre), but was much more toxic than Systox. An additional advantage of Phosdrin over the more toxic materials was its short residual action. Thus, where this material was used, beneficial insects migrating into the treated area or emerging from the egg or pupal stages soon after application were unharmed.

Trithion was applied at dosages ranging from 5.0 to 11.5 ounces per acre. It was not nearly so toxic as parathion or malathion when applied at 5.0 ounces per acre. However, at 11.5 ounces per acre it was quite toxic to the native predators.

As mentioned above, where parathion and malathion are used on alfalfa they are highly toxic to a wide variety of phytophagous and entomophagous insects. In the case of the spotted alfalfa aphid control program, reëstablishment of the phytophagous species in the treated areas is greatly favored over that of its natural enemies. This, as mentioned previously, leads to repetitious treatments and increases the frequency of aphids resistant to organophosphorus insecticides. In addition, it is felt that the frequent and widespread use of parathion and malathion might cause resistance to develop in a wide variety of other insect pests frequently found in alfalfa fields, which, though not necessarily damaging to alfalfa, might carry resistance problems to other crops. It is extremely important that the entomologist be aware of this possibility wherever he uses insecticides of indiscriminate toxicity, especially where he is concerned with pest species which require widespread control and have the ability to reach the economic threshold rapidly.

One way to minimize this danger is through the use of selective insecticides which destroy the pest species but to a greater or lesser degree preserve the entomophagous forms. In the current investigations Systox proved to be just such a material and its use on a commercial basis has already alleviated the spotted alfalfa aphid problem in many areas.

Perhaps of even greater significance than the development of a "selective" control for *Therioaphis maculata* was the disclosure that where the selective material was used, insecticide-induced mortality of essentially 100 per cent was not necessary to give satisfactory control of the aphid. Thus in one experiment involving an aphid population resistant to all the tested materials, where Systox was applied and gave poor initial kill, the enemies of the aphid, which survived the treatment in goodly numbers, continued their attack on the resistant aphids and eventually effected complete control of the infestation. On the other hand, in this same experiment, where parathion and malathion were applied and the enemies of the aphid eliminated, the infestation actually increased soon after treatment since the surviving resistant adults reproduced unhindered by predation.

The investigations also showed that control with the selective material could be prolonged over that of the indiscriminate material even though initial kills by both materials were at a very high level. This occurred in one experiment where initial control of the aphid with both Systox and parathion was highly satisfactory. However, during the testing period large numbers of alate aphids invaded the treated area. Because coccinellids and other predators had been eliminated from the parathion-treated area these alate aphids reproduced unchecked after the parathion broke down, and the infestation level rose very rapidly. On the other hand, in the plots treated with Systox the aphid enemies survived in great numbers and maintained the invading aphid population at very low numbers even after the Systox was no longer effective.

The desirability of attaining a pest-control program in which chemical and biological control are as well integrated as possible is indisputable. This does not mean, however, that Systox would be the most desirable insecticide for use on other susceptible pests attacking other crops. Each pest problem and each crop has its own peculiar biological and ecological characteristics, and these must be analyzed and understood before any integrated chemical and biological control program can be undertaken. Through such ecological investigations on insect control we can expect chemical and biological controls to be utilized in true perspective.

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