CONTROL OF DDT--RESISTANT POTATO FLEA BEETLES

By James B. Kring

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Cover: Spraying test plots at the Experimental Farm, Mt. Carmel, Connecticut, for control of the potato flea beetle.

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by

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In 1951 and 1952 DDT was reported by potato growers in the Connecticut River Valley as failing to give satisfactory control of the potato flea beetle.[3] Early reports of failure were attributed to (1) the use of emulsifiable concentrates to avoid wettable powders, (2) improper or careless application, or (3) unusually high numbers of potato flea beetles. Investigation of grower application in the field in 1952 indicated the difficulty was not one of those mentioned above. Field tests were made in 1953 and 1954 to determine the effectiveness of DDT and several other insecticides against this insect. The purpose of this publication is to report the results of this investigation.

The Potato Flea Beetle

Britton (1918) pointed out that careful study of the potato flea beetle in Connecticut revealed only one generation a year. Observations by Lacroix (1931) on tobacco indicated again that only a single generation of this species occurs in Connecticut. Hanson (1933) has observed that the larvae of the potato flea beetle apparently develop only on the roots of plants belonging to the potato family and that although the adult insects feed on many flowers, vegetables and weeds, they do exhibit a preference for feeding on plants related to potato.

Adult flea beetles of the generation of the previous year that have overwintered are commonly referred to as the first brood. These insects damage the foliage of potato plants in May, June and July. The small, black, hopping flea beetles mate and lay eggs in June and July at the base of the potato plant and the larvae hatching from these eggs feed on roots and developing tubers. These larvae produce adult flea beetles that begin feeding on the aerial portions of the potato plant in July. Adult beetles continue to emerge from the soil until late August. These adults of the new generation are commonly referred to as the second brood. Individuals from this group that survive chemical treatments, the winter and attack by disease, parasites, and predators make up what is referred to as the first brood the following spring. Thus in any given year there are not two broods or two generations, but there may be present in July in a given field surviving adult flea beetles of the generation of the previous year and adult flea beetles of a new generation.

1 The use of information from unpublished data of Mr. Neely Turner, Chief Entomologist, is acknowledged with thanks. The assistance in the field of A. DeCaprio, Mrs. Joan Curtiss, and Miss Nancy Anderson is also acknowledged with thanks. The photographs were made by B. W. MacFarland.

2 Assistant Entomologist.

3 *Epitrix cucumeris* (Harris), the potato flea beetle.

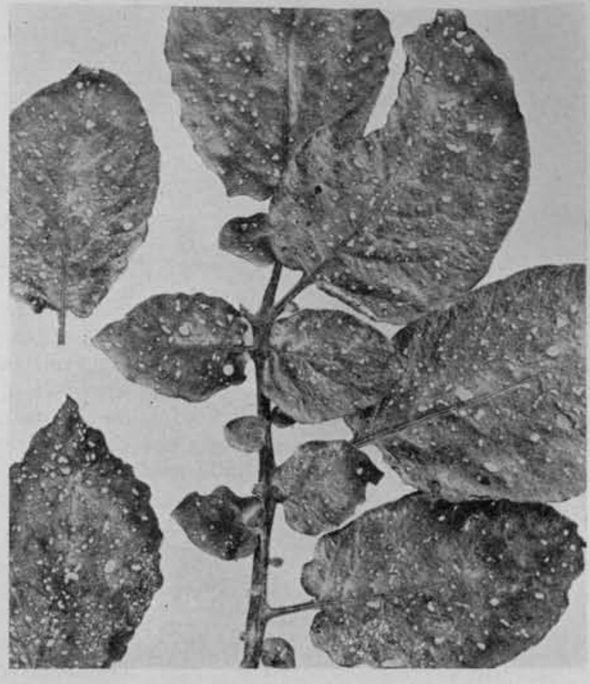

Figure 1. Photo at top shows foliage damaged by potato flea beetles; lower, tuber damaged by larvae of the potato flea beetle.

DDT-Resistant Potato Flea Beetles

Investigation for practical reasons was started in 1953 on the assumption that the flea beetles in this area were no longer susceptible to DDT. This was considered a sound approach, since it was evident in 1952 that what was considered proper application of DDT at increased dosages was not giving satisfactory control of these pests. A similar failure of DDT to control this insect on potatoes in Indiana has now been reported by Gould and McCrosky (1954). The difficulty in Indiana also began in 1951.

Widespread use of DDT to control potato insects began in 1946. A reduction in the effectiveness of this insecticide against the potato flea beetle apparently began to occur in an observable form in 1951, or approximately five years after the insecticide came into general use. The ability of this insect to persist despite applications of DDT has increased since 1951 until damage by the insect became a very serious problem in 1952 and 1953. Tolerance to DDT is thus evident in this insect after only five or six generations have been exposed to this insecticide.

Treatment of potato fields with DDT has been universal enough that probably most segments of the potato flea beetle population in this state have been treated with DDT. Residual studies of DDT have indicated that this material does accumulate in the soil from applications to the parts of the plant above ground (Chisholm et. al. 1950). Since this insect completes its life cycle in the potato field, leaving the field only to hibernate in the field margins, it has probably been in contact with DDT during all stages of development. The

TABLE 1. COMPARISON OF DDT AND CHLORDANE SPRAYS APPLIED FOR POTATO FLEA BEETLE CONTROL. CONNECTICUT 1946 - 1954.

		Per cent reduction in damage					
	Pounds actual	Mt. Carmel*				Windsor-ville	Windsor
Insecticide	toxicant/acre	1946	1947	1948	1953	1953	1954
DDT 50 per cent w.p.	2	86	....	....	....	12	....
	1	73	60	91	85	18	17
	.5	69	49	89	87	25	0
	.25	58	38	78	88	18	0
	.125	....	22	57	....	....	....
Chlordane 50 per cent w.p.	2	....	....	....	82	....	86
	1	....	60	....	85	....	78
	.5	....	44	....	74	....	18
	.25	....	35	....	....	....	....

* Woodruff and Turner (1947, 1949). Turner and Woodruff (1948)

few generations and short period of time in which this resistance has developed may indicate that this unintentional exposure to DDT of all stages has speeded the development of resistance in this pest. This probably reduced the effect of the dynamic variation of individuals (Beard, 1952) and speeded the development of resistance.

The protection from flea beetle damage provided by DDT 50 per cent wettable powder spray applications, as it has been demonstrated in field tests of several different years, is presented in Table 1. In this table, data on the effectiveness of DDT and chlordane wettable spray powders publishd by Turner and Woodruff (1948) and Woodruff and Turner (1947, 1949) are compared to data obtained when these two materials were tested in 1953 and 1954. All estimates of damage except those made at Windsorville in 1953 were based on the extent of leaf feeding by the new generation (second brood) of the year indicated. The test at Windsorville in 1953 was made on the overwintered 1952 generation (first brood). All estimates of damage except those at Mt. Carmel, 1953 and at Windsor in 1954 were made using the system of estimation proposed by Horsfall (1945). In these last two tests the damage appraisal was based on the actual number of feeding punctures per leaf. The difference in susceptibility

TABLE 2. COMPARISON OF TWO METHODS OF DATA ASSESSMENT IN FLEA BEETLE CONTROL STUDIES — MT. CARMEL, CONN. 1953

Insecticide	Pounds actual toxicant/acre	Estimated damage* Count**	Estimated damage* Per cent reduction	Actual damage Count**	Actual damage Per cent reduction
Chlordane 50 per cent w. p. + Aldrin, 25 per cent w. p.	1 + 1	10	79	5	98.2
	.5 + .5	9	81	21	92.6
	.25 + .25	14	71	11	96.1
Chlordane 50 per cent w. p. + Perthane 25 per cent w. p.	1 + .5	20	59	34	88.1
	.5 + .25	27	44	46	83.9
	.25 + .125	26	46	133	53.6
Chlordane 50 per cent w.p.	2	19	61	52	81.8
	1	19	61	43	85.0
	.5	45	67	74	74.2
Perthane 25 per cent w.p.	1	37	24	111	61.3
	.5	31	36	182	36.5
	.25	26	46	170	40.7
Untreated Check (Average)		48.5		287	

*Grading system proposed by Horsfall (1945), p. 39 Chap. IV of *Fungicides and their action.*

**15 leaves/plot - 3 replicates. Same leaves used in both counts.

to DDT in potato flea beetles at Mt. Carmel, Windsor, and Windsorville is quite striking.

The system of damage evaluation as outlined by Horsfall (1945) was designed primarily for use in plant disease study. It is a series of estimates based on a logarithmic scale of the percentage of leaf surface destroyed. This method itself is based on the Weber-Fechner law of visual-acuity. The scale is thus arranged on the correct assumption that more accurate appraisals are made at both ends of the scale than at its center.

The method of Horsfall (1945) when used at Windsorville, in 1953, seemed to underestimate the amount of protection given by the insecticides. To test this, damage estimates at Mt. Carmel in 1953 were made by Horsfall's (1945) method and by recording in the laboratory the actual number of feeding punctures per leaf of these same leaves. Table 2 gives a comparison of a portion of the evaluations of the per cent reduction in damage obtained by the two methods of damage estimation.

The method of Horsfall of damage calculation again under the population conditions of this test underestimated the amount of protection obtained. Both methods gave a similar ranking of the insecticides on the basis of their effectiveness. It is believed that this method as proposed by Horsfall (1945) and used by Turner andWoodruff would be more effective with greater flea beetle populations. The first two sprays in the Mt. Carmel 1953 test reduced the numbers of flea beetles to a point where damage on all plots could only be appraised in the lower portion of the grading range. For this reason the results obtained at Mt. Carmel in 1953 and Windsor in 1954 are based on the reduction in actual numbers of feeding punctures per leaf.

This method proposed by Horsfall (1945) has the advantage of less disturbance of the plant in the plot, the possibility of regrading the same leaf at a later date to determine residual protection, and speeding the whole process of data taking.

It is believed that under these conditions the estimation of damage on the actual number of holes per leaf is more comparable to the earlier data obtained at Mt. Carmel, 1946-1948, than is the estimation of damage by the method of Horsfall (1945).

While no data are available on the effectiveness of DDT for the Windsor, Windsorville areas prior to 1953, growers in that area had obtained prior to 1951 very satisfactory protection of potato plants from damage by this insect with applications of DDT equivalent to one pound of actual DDT per acre per application.

The Resistance Problem

The history of the development of resistance to insecticides is a rather long one, beginning in 1914. The most used approach in overcoming this problem has been the substitution of a second effective chemical for the one no longer providing protection. And so chemical follows chemical until against certain insects many of our modern insecticides lose their usefulness shortly after they are developed.

The resistance problem in bacteria has been approached from the genetic standpoint (Demerec, 1952). Given two effective antibiotics independent of each other in action, applied together, the possibility of a new strain of bacteria developing that is resistant to both is negligible. The success of this approach is indicated by the use in medicine today of combined antibiotics.

Combinations of insecticides have been tested here for a number of years. These comparisons were made in studies of the independent action of insecticides by Turner, who has discussed this approach (Turner, 1954).

To reach the desired effect of treatment with two insecticides two approaches may be used. Insecticides may be applied either in combination, as they are in medicine, or they may be applied alternately, (one following the other), either every application being different from the preceding one, or applications in alternate years being different. These methods of approach are also discussed by Wheatley (1955) in his study of the control of DDT-resistant imported cabbage worm.[1] With either type of treatment, insecticides having definitely different modes of toxic action are required.

The mode of action of the insecticides useful in controlling flea beetles is not known.

The validity of the use of either combination or alternation of insecticides against resistant insects is also dependent on a better knowledge of the genetic factors controlling this phenomenon than has been presented to date. While all geneticists concerned with the problem apparently do not agree, Crow (1952) indicated that on a theoretical basis, in the case of insect resistance to poisons, the use of poisons one at a time would be the best procedure. He did indicate that synergism or some other reason might dictate another approach.

Combinations of Insecticides to Control DDT-Resistant Potato Flea Beetles

When this work was begun in 1953 the use of combinations was suggested by Turner. For trial in the field, combination of insecticides was selected over alternation primarily because of the ease of application. For this approach two requirements were necessary for the chemicals tested. In the first place, these insecticides must be effective against flea beetles and secondly there should be some indication that their action might not be similar. The selection of chemicals tested has been based to some extent on unpublished data obtained by Turner in studies of independent joint action.

Turner and Woodruff (1948) demonstrated in 1947 that chlordane (Table 1) gave satisfactory protection against flea beetles. For that reason chlordane was picked as one of the partners in most of the combinations tested. Since references to the effectiveness of many of the newer insecticides against flea beetles were not found in the literature, materials tested were used at rates which had been found to be effective against other chewing insects. Combined insecticides were tested at half the expected effective rate of the insecticide used alone. In all tests the insecticides were compared in effectiveness to DDT.

[1] *Pieris rapae* L., the imported cabbage worm.

Field Tests — 1953 and 1954

To confirm the effectiveness of the combinations and to demonstrate the loss of effectiveness of DDT, three combinations and DDT were tested at Windsorville, on newly emerged Katahdin potato plants. Flea beetles in this field were the survivors of the 1952 generation. In 1952 flea beetles in this field were not controlled by increased dosages of DDT.

Insecticides used were tested in three replications of four dosage levels of each of three combinations, and DDT. Treatments and untreated checks were randomized in a solid block. Application was made by a single nozzle, gun-type

Figure 2. Hand spraying of test plots at Windsorville, Connecticut, for control of the potato flea beetle.

power sprayer. Pressure and nozzle opening were set to deliver two and one-half quarts of spray material in 53 seconds. Sprays were applied to 1/160-acre plots, five eighteen-foot rows, at a rate equivalent to 100 gallons of finished spray per acre. Applications were made on May 29 and June 10. Damage was assessed on June 5 and June 16 on 15 leaves per plot, using the scoring system devised by Horsfall (1945).

Field plot studies were also conducted in 1953 on Katahdin potatoes at the Experimental Farm, Mt. Carmel, and on the same variety in 1954 at Windsor. The spray equipment and plot methods used were those described by Woodruff and Turner (1946 and 1947). The 1954 tests were made at the Tobacco Laboratory, Windsor, to take advantage of the larger numbers of flea beetles and to test further the insecticides against flea beetles in an area where DDT was failing to give satisfactory control.

Applications in 1954 at Windsor again lowered the flea beetle populations

TABLE 3. COMPARISON OF THREE COMBINATIONS OF INSECTICIDES AND DDT APPLIED AS SPRAYS TO CONTROL FLEA BEETLES REPORTED TO BE RESISTANT TO DDT. WINDSORVILLE, CONN. 1953*

Insecticide	Pounds actual toxicant/acre	Leaves showing less than 3 per cent surface damage: Number of applications 1*	2**	Number of applications 1*	2**
		Number of leaves***		Per cent of leaves***	
Chlordane 50 per cent w. p. + Aldrin 25 per cent w. p.	1 + 1	40	33	88.8	73.3
	.5 + .5	44	33	97.7	73.3
	.25 + .25	42	34	93.2	75.5
	.125 + .125	33	33	73.3	73.3
Chlordane 50 per cent w. p. + Dilan 25 per cent w. p.	1 + .5	44	38	97.7	84.4
	.5 + .25	42	33	93.2	73.3
	.25 + .125	35	30	77.7	66.6
	.125 + .0625	30	26	66.6	57.7
Chlordane 50 per cent w. p. + Malathion 25 per cent w. p.	1 + .5	45	28	100.0	62.2
	.5 + .25	32	32	71.0	71.0
	.25 + .125	36	28	79.9	62.2
	.125 + .0625	18	21	40.0	46.6
DDT 50 per cent w.p.	2	26	26	57.7	57.7
	1	33	27	73.3	59.9
	.5	30	23	66.6	51.1
	.25	31	24	68.8	53.3
Untreated Check (Average)		21.3	8.8	47.3	19.5

*Application May 29, count made June 5.

**First application May 29, second, June 10. Count made June 16.

***In 45 leaves, 15 leaves from each of 3 replicates.

on all plots, including untreated checks. A second field of Katahdin potatoes separated from the test plot by twenty feet of fallow land, and treated only with DDT, was severely damaged by flea beetles throughout the growing season. These two areas were the division of a larger field, were planted the same day, and had received similar treatment prior to planting. Damage to the adjacent plot by the overwintered 1953 generation was about 1½ times higher than the average of the untreated checks in the test plots. The 1954 generation damaged the adjacent plot about 8 times more than the average of the untreated checks of the test plots. Marginal plots of the test field, especially those bordering the adjacent field, were more heavily damaged than plots within the test field.

The plots at Mt. Carmel were planted May 13 and harvested October 15. Seven weekly applications were made beginning on July 1 and ending on August 12. Damage was estimated on July 20 after three spray applications had been made. As indicated above, these same leaves were graded in the field by the method described by Horsfall (1945), and the same leaves were picked and graded in the laboratory on the actual number of feeding punctures per leaf.

The 1954 field test at Windsor was planted on April 20 and harvested in September, on the 28th. These plots were treated on May 27, June 8, July 6, 13, 20, and August 11. Damage was estimated by recording the number of feeding punctures on 45 terminal leaves per treatment; 15 leaves were selected from each of 3 replicates. Leaf samples were taken on June 3, July 22, and August 12 and 19.

Results

In the 1953 test at Windsorville (Table 3), applications of DDT 50 per cent wettable powder gave some protection. The degree of protection given by DDT in this test was inferior when compared to the joint application of chlordane 50 per cent wettable powder with either aldrin 50 per cent wettable powder or *Dilan* 25 per cent wettable powder. Chlordane 50 per cent wettable powder combined with malathion 25 per cent wettable powder gave protection that was comparable to DDT. This field test indicated that chlordane combined with either aldrin or *Dilan* gave protection superior to DDT, and that DDT at double the concentration previously used successfully in experimental and practical applications failed to give satisfactory control of potato flea beetles.

In the 1953 field tests at Mt. Carmel, all insecticides, except malathion, combined with chlordane gave control equal to or better than that obtained by chlordane used alone. These combinations as in the first field test were again made by combining one-half of the estimated effective dosage of each material to be tested. *Dilan* used alone was as good as or equal to chlordane and *Dilan* combined. DDT gave protection comparable to that of chlordane used alone but less satisfactory protection than that obtained by the more effective combinations (Table 4). The protection provided by *Perthane* was unsatisfactory.

In the 1954 field tests at Windsor (Table 5), dieldrin alone or combined with chlordane gave the best protection. Chlordane combined with either endrin or heptachlor, and chlordane and endrin alone gave good protection. *Dilan* alone and combined with either chlordane or endrin gave protection inferior to that of the other materials tested except DDT. All of the materials in the test except DDT are believed to be effective against DDT-resistant flea beetles. The reduced population over all the plots, including the checks, and lower dosage levels, was believed to be another indication of the effectiveness of these materials. If these treatments were compared to the adjacent plot rather than the randomized check plots the effectiveness was more striking.

TABLE 4. COMPARISON OF SEVERAL INSECTICIDES APPLIED ALONE AND COMBINED TO CONTROL THE POTATO FLEA BEETLE—MT. CARMEL, CONN. 1953

Insecticide	Pounds actual toxicant/acre	July 20 Feeding punctures*	July 20 Per cent reduction	Yield Pounds/36 ft. of row
Chlordane 50 per cent w. p. + Aldrin 25 per cent w. p.	1 + 1	5	98.2	66.0
	.5 + .5	21	92.6	68.6
	.25 + .25	11	96.1	58.4
Chlordane 50 per cent w. p. + Dieldrin 1.5 E	1 + .5	19	93.4	76.0
	.5 + .25	17	94.0	65.1
	.25 + .125	13	95.4	59.9
Chlordane 50 per cent w. p. + Dilan 25 per cent w. p.	1 + .5	12	95.8	63.6
	.5 + .25	31	89.1	70.8
	.25 + .125	32	88.8	71.4
Chlordane 50 per cent w. p. + Heptachlor 2 E	1 + .5	14	95.1	78.2
	.5 + .25	1	99.6	77.0
	.25 + .125	21	92.6	65.9
Chlordane 50 per cent w. p. + Malathion 25 per cent w. p.	1 + .5	34	88.1	68.5
	.5 + .25	159	44.6	72.4
	.25 + .125	86	70.0	69.3
Chlordane 50 per cent w. p. + Perthane 25 per cent w. p.	1 + .5	34	88.1	70.1
	.5 + .25	46	83.9	72.1
	.25 + .125	133	53.6	69.5
Chlordane 50 per cent w. p. + Rhothane 25 per cent w. p.	1 + 1	26	90.9	68.6
	.5 + .5	28	90.2	58.7
	.25 + .25	87	69.6	66.0
Chlordane 50 per cent w.p.	2	52	81.8	70.3
	1	43	85.0	70.0
	.5	74	74.2	57.0
DDT 50 per cent w.p.	1	43	85.0	66.9
	.5	38	86.7	65.0
	.25	34	88.1	59.4
Dilan 25 per cent w.p.	1	27	90.5	56.0
	.5	25	91.2	68.3
	.25	20	93.0	63.0
Perthane 25 per cent w.p.	1	111	61.3	66.2
	.5	182	36.5	69.4
	.25	170	40.7	72.9
Untreated Check (Average)		287		66.6

*In 45 leaves, 15 leaves from each of 3 replicates.

TABLE 5. COMPARISON OF SEVERAL INSECTICIDES APPLIED ALONE AND COMBINED TO CONTROL THE POTATO FLEA BEETLE — WINDSOR, CONN. 1954

Insecticide	Pounds actual toxic./acre	1953 Generation Overwintered June 3 Feeding punctures*	1953 Generation Overwintered June 3 Per cent reduct.	1954 Generation August 19 Feeding punctures*	1954 Generation August 19 Per cent reduct.	Yield 9/28 Pounds/36 ft. of row
Chlordane 50 per cent w. p. + Dieldrin 1.5 E	1.0 + .5	132	84.8	34	80.0	48.6
	.5 + .25	173	80.0	67	60.6	49.8
	.25 + .125	108	87.5	24	85.9	48.5
Chlordane 50 per cent w. p. + Dilan 25 per cent w. p.	1.0 + .5	448	48.4	68	60.0	50.0
	.5 + .25	361	58.4	115	32.4	39.9
	.25 + .125	912	0	129	24.1	43.1
Chlordane 50 per cent w. p. + Endrin 1.6 E	1.0 + .25	211	75.7	81	52.4	54.9
	.5 + .125	224	74.2	87	48.8	52.5
	.25 + .0625	357	58.8	48	71.8	55.4
Chlordane 50 per cent w. p. + Heptachlor 25 per cent w. p.	1.0 + .5	156	82.0	54	68.2	60.8
	.5 + .25	354	59.2	54	68.2	46.3
	.25 + .125	385	55.6	92	45.9	46.4
Dilan 25 per cent w. p. + Endrin 1.6 E	.5 + .25	158	81.8	96	43.5	58.4
	.25 + .125	360	57.6	130	23.5	60.5
	.125 + .0625	511	41.4	121	28.8	51.4
Chlordane 50 per cent w.p.	2.0	248	71.3	24	85.9	50.5
	1.0	217	75.0	37	78.2	41.8
	.5	790	9.0	140	17.6	39.2
DDT 50 per cent w.p.	1.0	385	55.6	141	17.1	49.6
	.5	993	0	181	0	51.4
	.25	291	66.4	210	0	53.0
Dieldrin 1.5 E	1.0	121	86.0	26	84.7	64.2
	.5	253	70.8	20	88.2	45.0
	.25	303	65.1	43	74.7	47.8
Dilan 25 per cent w.p.	1.0	308	64.5	89	47.6	53.6
	.5	392	54.8	113	33.5	55.7
	.25	389	55.2	108	36.5	51.0
Endrin 1.6 E	.5	123	85.8	58	65.9	49.5
	.25	128	85.2	17	90.0	57.3
	.125	249	71.3	25	85.3	41.8
Heptachlor 25 per cent w.p.	1.0	388	55.3	56	67.1	49.2
	.5	1351	0	115	32.4	39.8
	.25	251	71.0	40	76.5	49.3
Untreated Check (Average)		868.5		170.3		48.1

*In 45 leaves, 15 leaves from each of 3 replicates.

Effect on Aphid Population

The predominant aphids present in both the Mt. Carmel and the Windsor field tests were the green peach aphid,[1] and the potato aphid.[2] Several other aphid species were also present but the only one that was found consistently was the buckthorn aphid.[3] The only effective control of aphids in the 1953 test was given by the combination of chlordane with malathion (Table 6). There was evidence of reduction in aphid populations by the combined treatment of chlordane with dieldrin. Aphid populations were considerably higher than those on the check plots on plants treated with chlordane combined with *Dilan*, heptachlor, and *Perthane*. Populations were also higher on plots treated with chlordane, *Dilan*, and *Perthane* used alone.

In 1954 aphid populations (Table 7) on untreated plots increased slightly in July and abruptly in mid-August. This is a similar increase to that noted by Simpson and Shands (1954) in Maine. Aphids were apparently held in check on all treatments except chlordane combined with *Dilan*, DDT used alone, and *Dilan* used alone.

There was an apparent increase in aphid population in both years on plots treated with *Dilan*. There was a corresponding increase in the aphid population with the increase in the amount of *Dilan* used. Wheatley (1955) has observed a similar increase in cabbage aphid populations where this material has been used to control cabbage worms.

Effect on Infestation by European Corn Borer[4]

Estimation of the effect of these spray applications on damage by the European corn borer was made on July 22 at Windsor (Table 8). Damage was estimated on examination of six plants per plot in each of three replicates, for evidence of borer injury and the number of larvae present. All larvae recovered were corn borers. Damage was estimated only on plots that received the highest treatment.

The biology of the European corn borer in Connecticut has been studied by Vance (1943) and others. Vance reported that the eggs of the first generation hatch from the first week in June until as late as mid-July. These plants had been treated on May 27, June 8, July 6, 14, and 20 prior to this examination. No small larvae were recovered in any plants. The treatments of May 27, June 8, and July 6 were probably the effective treatments.

Endrin alone and combined with either chlordane, *Dilan* or DDT, dieldrin, and *Dilan* used alone all protected the potato plants from this insect.

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1 *Myzus persicae* (Sulzer), the green peach aphid.

2 *Macrosiphum euphorbiae* (Thomas), the potato aphid.

3 *Aphis nasturtii* Kltb. (A. abbreviata Patch), the buckthorn aphid.

4 *Pyrausta nubilalis* (Hbn.), the European corn borer.

TABLE 6. THE EFFECT ON APHID POPULATIONS OF SEVERAL INSECTICIDES APPLIED ALONE AND COMBINED FOR CONTROL OF POTATO FLEA BEETLE
MT. CARMEL, CONN. 1953

Insecticide	Pounds actual Toxicant/acre	July 20 Aphids*	July 20 Per cent Reduct.	August 14 Aphids**	August 14 Per cent Reduct.
Chlordane 50 per cent w. p. + Aldrin 25 per cent w. p.	1 + 1	3	82.3	48	0
	.5 + .5	18	0	24	44.1
	.25 + .25	4	76.4	240	0
Chlordane 50 per cent w. p. + Dieldrin 1.5 E	1 + .5	0	100	33	23.2
	.5 + .25	2	88.2	17	60.4
	.25 + .125	10	41.1	52	0
Chlordane 50 per cent w. p. + Dilan 25 per cent w. p.	1 + .5	45	0	222	0
	.5 + .25	57	0	111	0
	.25 + .125	66	0	191	0
Chlordane 50 per cent w. p. + Heptachlor 2 E	1 + .5	2	88.2	165	0
	.5 + .25	6	69.7	125	0
	.25 + .125	10	41.1	165	0
Chlordane 50 per cent w. p. + Malathion 25 per cent w. p.	1 + .5	0	100	1	97.6
	.5 + .25	0	100	3	93.0
	.25 + .125	0	100	25	41.8
Chlordane 50 per cent w. p. + Perthane 25 per cent w. p.	1 + .5	12	29.4	296	0
	.5 + .25	7	58.8	571	0
	.25 + .125	15	11.7	134	0
Chlordane 50 per cent w. p. + Rhothane 25 per cent w. p.	1 + 1	2	88.2	119	0
	.5 + .5	19	0	63	0
	.25 + .25	41	0	85	0
Chlordane 50 per cent w.p.	2	37	0	298	0
	1	37	0	326	0
	.5	52	0	142	0
DDT 50 per cent w.p.	1	11	35.2	36	16.2
	.5	16	5.8	172	0
	.25	3	82.3	97	0
Dilan 25 per cent w.p.	1	251	0	687	0
	.5	137	0	139	0
	.25	77	0	288	0
Perthane 25 per cent w.p.	1	51	0	133	0
	.5	52	0	159	0
	.25	49	0	46	0
Untreated Check (Average)		17		43	

*On 45 leaves, 15 leaves from each of 3 replicates.

**On 30 leaves, 15 leaves from each of 2 replicates.

TABLE 7. THE EFFECT ON APHID POPULATIONS OF SEVERAL INSECTICIDES APPLIED ALONE AND COMBINED TO CONTROL THE POTATO FLEA BEETLE WINDSOR, CONN. 1954

Insecticide	Pounds actual toxic./acre	Aphid Population* June 3	July 22	Aug. 12	Aug. 19	Per cent reduction Aug. 19
Chlordane 50 per cent w. p. + Dieldrin 1.5 E	1.0 + .5	0	0	13	1	99.4
	.5 + .25	0	0	2	11	93.5
	.25 + .125	0	1	8	18	89.4
Chlordane 50 per cent w. p. + Dilan 25 per cent w. p.	1.0 + .5	0	4	15	21	87.7
	.5 + .25	4	0	13	26	84.7
	.25 + .125	0	1	17	15	91.2
Chlordane 50 per cent w. p. + Endrin 1.6 E	1.0 + .25	0	0	1	0	100
	.5 + .125	0	0	0	1	99.4
	.25 + .0625	0	0	9	4	97.7
Chlordane 50 per cent w. p. + Heptachlor 25 per cent w. p.	1.0 + .5	0	0	4	3	98.2
	.5 + .25	0	1	4	2	98.8
	.25 + .125	0	4	7	13	92.4
Dilan 25 per cent w. p. + Endrin 1.6 E	.5 + .25	0	2	3	1	99.4
	.25 + .125	0	0	6	7	95.9
	.125 + .0625	0	0	11	11	93.5
Chlordane 50 per cent w.p.	2.0	0	0	10	7	95.9
	1.0	1	1	6	5	97.1
	.5	1	0	0	5	97.1
DDT 50 per cent w.p.	1.0	0	1	7	45	73.6
	.5	0	0	7	25	85.3
	.25	2	0	8	19	88.8
Dieldrin 1.5 E	1.0	1	0	3	3	98.2
	.5	1	0	4	1	99.4
	.25	5	0	5	7	95.9
Dilan 25 per cent w.p.	1.0	0	1	214	199	0
	.5	0	3	66	133	21.9
	.25	0	1	33	39	77.1
Endrin 1.6 E	.5	0	0	0	0	100
	.25	2	0	2	3	98.2
	.125	1	0	0	2	98.8
Heptachlor 25 per cent w.p.	1.0	1	0	5	0	100
	.5	0	1	5	1	99.4
	.25	0	0	5	8	95.3
Untreated Check (Average)		.25	1.25	12.75	170.25	

*On 45 leaves, 15 leaves from each of 3 replicates: June 3, July 22, and August 19. On 30 leaves, 10 leaves from each of 3 replicates: August 12.

TABLE 8. EUROPEAN CORN BORER CONTROL BY INSECTICIDES APPLIED FOR THE CONTROL OF POTATO FLEA BEETLES — WINDSOR, CONN.

Insecticides	Pounds actual toxicant/acre	Number Plants free	Per cent from borers*	Corn borer larvae	Per cent reduction in borers
Chlordane 50 per cent w. p. + Endrin 1.6 E	1.0 + .25	18	100	0	100
DDT 50 per cent w.p.	1.0	18	100	0	100
Dieldrin 1.5 E	1.0	18	100	0	100
Endrin 1.6 E	.5	18	100	0	100
Dilan 25 per cent w. p. + Endrin 1.6 E	.5 + .25	17	94.5	1	93.5
Dilan 25 per cent w.p.	1.0	17	94.5	1	93.5
Chlordane 50 per cent w. p. + Heptachlor 25 per cent w. p.	1.0 + .5	16	88.9	3	80.6
Chlordane 50 per cent w.p.	2.0	15	83.4	4	74.2
Heptachlor 25 per cent w.p.	1.0	14	77.8	5	67.7
Chlordane 50 per cent w. p. + Dieldrin 1.5 E	1.0 + .5	12	66.7	6	61.2
Chlordane 50 per cent w. p. + Dilan 25 per cent w. p.	1.0 + .5	11	61.2	7	54.8
Untreated Check (Average)		11.5	64.9	15.5	

*6 plants in each of 3 replicates.

Effect on Amount of Hopper Burn

Hopper burn or damage to potato foliage resulting from feeding by the potato leaf hopper[1] was somewhat reduced (Table 9) by application of several of the insecticides used in this test. The percentage of the leaf surface showing hopper burn injury was estimated on August 19 on 45 leaves (15 leaves from each of three replicates) from each treatment. Applications of chlordane combined with either dieldrin or *Dilan* and of DDT, dieldrin, *Dilan,* and endrin used alone gave the most significant protection.

Effect on Yield

Yield (Tables 4 and 5) in these tests was measured in the pounds of potatoes (all sizes) dug from 36 feet of row per treatment (12 feet of row from each of three replicates).

[1] *Empoasca fabae* (Harr.), the potato leafhopper.

TABLE 9. PROTECTION FROM HOPPER BURN INJURY BY SEVERAL INSECTICIDES APPLIED ALONE AND COMBINED TO CONTROL THE POTATO FLEA BEETLE — WINDSOR, CONN., AUGUST 19, 1954.

Insecticide	Pounds actual toxicant/acre	Number of leaves* showing less than 3 per cent hopper burn	Percent leaves showing less than 3 per cent hopper burn
Chlordane 50 per cent w. p. + Dieldrin 1.5 E	1.0 + .5	38	84
	.5 + .25	26	58
	.25 + .125	33	73
Chlordane 50 per cent w. p. + Dilan 25 per cent w. p.	1.0 + .5	39	87
	.5 + .25	35	78
	.25 + .125	31	69
Chlordane 50 per cent w. p. + Endrin 1.6 E	1.0 + .25	31	69
	.5 + .125	29	64
	.25 + .0625	27	60
Chlordane 50 per cent w. p. + Heptachlor 25 per cent w. p.	1.0 + .5	38	84
	.5 + .25	23	51
	.25 + .125	21	47
Dilan 25 per cent w. p. + Endrin 1.6 E	.5 + .25	27	60
	.25 + .125	28	63
	.125 + .0625	24	53
Chlordane 50 per cent w. p.	2.0	36	80
	1.0	29	64
	.5	25	56
DDT 50 per cent w. p.	1.0	31	69
	.5	40	89
	.25	32	71
Dieldrin 1.5 E	1.0	32	71
	.5	33	73
	.25	32	71
Dilan 25 per cent w. p.	1.0	42	93
	.5	30	67
	.25	32	71
Endrin 1.6 E	.5	38	84
	.25	41	91
	.125	36	80
Heptachlor 25 per cent w. p.	1.0	33	73
	.5	26	58
	.25	30	67
Untreated Check (Average)		25.8	57

*In 45 leaves, 15 leaves from each of 3 replicates.

In 1953 the greatest increases in yield above the average yield of the untreated checks were from plots treated with the highest concentrations of chlordane combined with dieldrin and of chlordane combined with heptachlor. Yields

were also appreciably higher on plots treated with chlordane combined with either malathion or *Perthane*.

In 1954 plots treated with dieldrin combined with chlordane again showed an appreciable increase in yield over the average yield of the untreated check. However, dieldrin, alone, at the highest concentration, gave the greatest increase in yield obtained. Plots receiving the highest amount of the combination of chlordane with heptachlor again showed an appreciable increase in yield. Yields were also greater following the use of endrin combined with either chlordane or *Dilan*, and DDT, *Dilan*, and endrin used alone.

None of these treatments in either year showed any visible indication of phytotoxic effects.

Discussion and Conclusions

The level of resistance of the potato flea beetle to DDT varies widely in Connecticut. It is evident that resistance to DDT has developed to a point where it is no longer economical or practical to increase the amount of DDT used. It is believed that this resistance was first present in an observable form after treatment of only four or five generations.

The practical approach to this resistance has been to test the effectiveness of insecticides used alone and in combination for control of the potato flea beetle.

There is no evidence from these tests that these combinations will offer any more relief from the problem than the insecticides used alone. There was an indication in the 1953 test that some of these combinations might be synergistic, but the 1954 test did not confirm this.

At Windsor in 1954 an adjacent potato field treated only with DDT was more heavily damaged throughout the season than the test plot. If the treatments are compared to this field rather than the randomized check plots, the effectiveness is more striking.

While it is difficult to draw conclusions as to the effect of these treatments on yield, several relationships between treatment and insect infestations were indicated.

The effectiveness of dieldrin and endrin in reducing the damage done by all the potato pests studied in these tests is probably reflected in the increase in yield following treatment with these insecticides.

The effectiveness of *Dilan* against all of these pests except aphids, and the effectiveness of malathion against aphids are probably reflected in the increase in yield following use of these insecticides.

The effectiveness of heptachlor against flea beetles alone may be responsible for the increase in yield where this insecticide was combined with chlordane.

Chlordane combined with *Perthane* did not give satisfactory protection to the potato plant from flea beetles or aphids. The estimates of insect damage made during this study offer no explanation for this increase in yield.

The increase in yield in 1954 on plots treated with DDT may be due to the effectiveness of this insecticide against corn borer and leafhoppers and to a certain degree in the prevention of aphid buildup.

Summary

DDT in three areas in Connecticut was less effective in protecting potato foliage from damage by the potato flea beetle than several insecticides used alone or in certain combinations. DDT in two of these areas failed to give satisfactory protection from damage by this pest.

Two approaches to the problem of the control of insecticide-resistant insects are discussed. Better insecticides are indicated as the first and most often used approach to this problem. It is indicated that present knowledge points out that this may be an endless search. The second approach is one similar to that used in dealing with resistant bacteria, the use of combined insecticides. It is pointed out that the validity of this approach cannot be established by the type of field tests used in these experiments.

Several insecticides used alone or in combination were effective in controlling potato flea beetles in one area where DDT was still giving satisfactory protection from this insect, and in two areas where DDT was no longer effective.

Where DDT (2-4 pounds 50 per cent w. p.) was no longer effective, chlordane (1 pound 50 per cent w. p.) combined with aldrin (1 pound 50 per cent w. p.), dieldrin (21 ounces 1.5 E), *Dilan* (1 pound 25 per cent w. p.), endrin (10 ounces 1.6 E), or heptachlor (1 pound 25 per cent w. p.), endrin (10 ounces 1.6 E), combined with *Dilan* (1 pound 25 per cent w. p.) and chlordane (2 pounds 50 per cent w. p.), dieldrin (42 ounces 1.5 E), *Dilan* (2 pounds 25 per cent w. p.), endrin (20 ounces 1.6 E) and heptachlor (2 pounds 25 per cent w. p.) used alone all gave protection superior to DDT.

Chlordane (1 pound 50 per cent w. p.) combined with *Rhothane* (2 pounds 25 per cent w. p.) was more effective than DDT against flea beetles still considered susceptible to DDT. This combination was not tested against the resistant insect.

Chlordane (1 pound 50 per cent w. p.) combined with malathion (1 pound 25 per cent w. p.) gave effective control of aphid populations. There was indication that dieldrin and endrin both held aphid populations in check. Aphid populations were consistently noticed to be higher where *Dilan* was used alone or combined with either chlordane or endrin. Aphid development was not as great where the other insecticides were combined with *Dilan.*

Endrin alone and combined with either chlordane, *Dilan* or DDT, dieldrin and *Dilan* used alone all protected the potato plant from European corn borer.

Injury from hopper burn was reduced by applications of chlordane combined with either dieldrin or *Dilan* and of DDT, dieldrin, *Dilan,* and endrin used alone.

Yield of potatoes was appreciably or regularly greater than the average of the untreated checks following treatment with chlordane combined with either dieldrin, endrin, heptachlor, malathion or *Perthane,* endrin combined with *Dilan,* and dieldrin, *Dilan,* and endrin.

LITERATURE CITED

BEARD, R. L., 1952—Insect resistance to insecticides. Science **115** (2996): 608-609. May 30.

BRITTON, W. E., 1918—Insects attacking the potato crop in Connecticut. Conn. Agric. Expt. Sta. Bull. 208: 103-120. October. (Reprinted 1934, with slight changes).

CHISHOLM, R. D., L. KOBLITSKY, J. E. FAHEY, and W. E. WESTLAKE. 1950 — DDT residues in soil. Jour. Econ. Ent. 43: 941-942.

CROW, JAMES F., 1952—Some genetic aspects of selection for resistance. In Conference on insect resistance and insect physiology. Nat. Acad. of Sciences, Nat. Res. Council Pub. No. **219**: 72-75.

DEMEREC, MILISLAV, 1952—Development of bacterial resistance to chemicals. In Conference on insect resistance and insect physiology. Nat. Acad. of Sciences, Nat. Res. Council. Pub. No. **219**: 67-69.

GOULD, G. E. and L. L. McCROSKY, 1954—Potato flea beetle with new insecticides. Jour. Econ. Ent. **47** (1): 190. February.

HANSON, A. J. 1933—The potato flea beetles. Wash. (Pullman) Agric. Expt. Sta. Bul. 280: 27. April.

HORSFALL, J. G., 1945—Fungicides and their action. Chronica Botanica Co., Waltham, Mass.

LACROIX, D. S., 1931—Tobacco insect studies in 1930. In Tobacco Sub-Station at Windsor report for 1930. Conn. Agric. Expt. Sta. Bul. 326: 424. February.

SIMPSON, G. W. and W. A. SHANDS, 1954—Fewer applications of DDT with proper timing produce equal yields of potatoes at less cost. Maine Agric. Expt. Sta. Bul. 533: 13-25. September.

TURNER, NEELY and N. WOODRUFF, 1948—Chlorinated insecticides for control of the potato flea beetle. Jour. Econ. Ent. **41** (2): 328-329.

__________, 1949—Effect of formulations of DDT, and of chlordane on potato flea beetles and yield. Jour. Econ. Ent. **42** (3): 470-473. August.

TURNER, NEELY, 1954—The insect resistance problem. In Frontiers of Plant Science. Conn. Agric. Expt. Sta. **6** (2): 7. May.

VANCE, A. M., 1943—The European corn borer in Connecticut. Conn. Agric. Expt. Sta. Bul. 472: 248-266. May.

WHEATLEY, G. A., 1955—Dust insecticides for the control of the imported cabbage worm (*Pieris rapae* (L.). Conn. Agric. Sta. Bul. 590: March.

WOODRUFF, N. and N. TURNER, 1946—Control of potato pests with new organic insecticides. In Conn. Agric. Expt. Sta. Bul. 512: 60-67. November.

__________, 1947—The effect of particle size on the toxicity of DDT diluents in water suspension. Jour. Econ. Ent. **40** (2): 206-211. April.

__________, 1949—concentrated DDT spray powders. Jour. Econ. Ent. **42** (2): 249-253. July.

__________, 1949—Effect of dispersing and spreading agents on toxicity of DDT spray powders. Jour. Econ. Ent. **42** (2): 243-248. April.