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Investigations of the effects of some modern pesticides on certain coccinellid predators of aphids and mites in Massachusetts.

John August Weidhaas
University of Massachusetts Amherst

INVESTIGATIONS OF THE EFFECTS OF SOME MODERN PESTICIDES ON CERTAIN COCCINELLID PREDATORS OF APHIDS AND MITES IN MASSACHUSETTS

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ON CERTAIN

COCCINELLID PREDATORS OF APHIDS AND MITES IN MASSACHUSETTS

JOHN A. WEIDHAAS, JR.

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INTRODUCTION

Predators are important beneficial insects which play a significant role in the natural control of many harmful pests. The frequent use of highly toxic chemicals to control major pests may cause serious reduction of the natural enemies of previously minor or secondary species. Aphids and mites recently have become more important as pest problems since the newer organic pesticides were made available. The reason most frequently offered to account for such a disturbing phenomenon has been the destruction of natural enemies by insecticides which are only slightly toxic to their prey.

In spite of multimillion dollar expenditures for research and for the development of pesticides, there is little known of the effects of the more common agricultural chemicals on predators such as lady beetles or "ladybirds." These insects, in the family Coccinellidae, help to reduce injurious populations and to maintain low numbers of aphids and mites before they build up to damaging numbers. It is important to determine the influence of chemicals on our allies in the insect world in order that pesticides may be used wisely and effectively.

The Massachusetts Society for Promoting Agriculture has wholeheartedly supported a project submitted by Professor W. D. Whitcomb to study the effects of commonly used pesticidal chemicals on beneficial insects. Without that support, these investigations would not have been possible.

The purpose of this project was to determine the extent to which coccinellid predators of aphids and mites are killed or otherwise adversely influenced by the pesticides recommended in orchard and ornamental pest control programs. The objective of the studies was to determine if certain pesticides showed promise of favoring coccinellids when used in spray programs.

Investigations were conducted at the Waltham Field Station and in certain other parts of Massachusetts during June, July and August from 1951 through 1954. Laboratory tests were carried out in which various species of lady beetles were exposed to a number of pesticidal residues similar to those encountered in the field.

In the field, sprayed and unsprayed orchards and other areas were observed over long seasonal periods to determine the relative abundance of lady beetles on a large scale under the conditions of actual pest control operations. Data obtained on the life history, behavior, faunal interrelationships and response to chemical treatments contributed to a knowledge of the influence of sprays on the predator-prey complex.

A REVIEW OF THE LITERATURE CONCERNING THE EFFECTS OF PESTICIDES ON COCCINELLID PREDATORS OF APHIDS AND MITES AND THEIR PREY.

Since the introduction of DDT there has been increased interest in the fate of natural enemies of insect pests which have been subjected to repeated applications of pesticides. It has resulted, to a great extent, from the occurrence of many new pest problems which arose where other destructive species had been controlled. Ripper (1956) estimated that 50, or 1 percent, of approximately 5,000 important insect and mite pests have shown resurgence after treatment with pesticides. The development of new problems and the resurgence of species once easily controlled frequently has been attributed to the destruction of the natural enemies (Ripper, 1944; Pickett, 1949; Ross, 1952; Pickett and Patterson, 1953; Graham, 1956; and Blackburn, 1947; and others).

Little has been published on experiments designed to investigate the toxicity of pesticidal chemicals to beneficial insects. Haug and Peterson (1938) were the only workers who conducted extensive laboratory tests prior to 1944 on the effects of pesticides on beneficial coccinellids. Some fragmentary data were published by Froggatt (1905), Morrill (1921), Knight (1925), Pratt *et al*. (1933), and Smith and Fontenot (1942) prior to the introduction of DDT. More extensive studies have been carried on since 1944, but most of the available data have resulted from observations incidental to other investigations (MacPhee and Sanford, 1954).

There is no detailed review in the literature of the buildup of mites and aphids following treatment with pesticides, although Ripper (1956) refers to many recent and extensive papers in his discussion of the effects of pesticides on the balance of all arthropod populations. Such increases have been responsible for the attention directed to coccinellids and has been closely interrelated with observations on predators in sprayed areas. Therefore, an extensive summary of aphid and mite buildup associated with pesticidal use is included here. The importance of lady beetles as predators of aphids and mites is also reviewed in addition to the known effects of pesticides on species of Coccinellidae.

REPORTS OF MITE BUILDUP FOLLOWING THE USE OF PESTICIDES.

Mite outbreaks associated with pesticide applications have been reviewed in some detail by Metcalf (1948), Way (1949), Brown (1951), and others. Ripper (1956) has tabulated reports of mite increase along with those of other arthropods.

Although mite buildup is considered to be a "new" problem, there are several reports associated with the use of older, pre-DDT chemicals. All of those reports pertain to the European red mite, *Panonychus* (= *Metatetranychus ulmi* Koch), formerly *Paratetranychus pilosus* C. and F. The two-spotted mite, *Tetranychus telarius* (L.) (= *T. bimaculatus* Harvey), was virtually unknown as a pest in apple orchards until after the introduction of DDT (Chapman and Lienk, 1950 and Garman, personal correspondence).

All reports of increases of the latter species are associated only with the newer chemicals, discussed later.

Tar Washes and Oils.

Reports from Europe during the 1920's show that dormant tar distillate applications for scale control did not kill overwintering eggs of the European red mite. Subsequent high initial populations developed early in the season (Massee, 1928; Massee and Steer, 1929; Massee, 1929; Speyer, 1937; and Kearns and Martin, 1940).

Houser (1928) showed also that where overwintering eggs of the European red mite were not killed, the seasonal peak of abundance was higher and occurred earlier. He found relatively few females present in the fall, however, to deposit overwintering eggs, since decimation of food supply by mite feeding and the predators had reduced the population to very low levels. Where oils had killed overwintering eggs in the spring, the peak of abundance occurred later in the summer, and more females were present to lay large numbers of over-wintering eggs in the fall. The following year, therefore, there were more mites. Thus mite buildup could occur whether oils were used or not, but in different ways and at different times.

Sulfur and Lime Sulfur.

Mites have been found to be more numerous in orchards treated with sulfur or lime sulfur (Houser, 1928 and Houser and Cutright, 1941, in Ohio; Reed, 1936, in New York; Garman, 1945, in Connecticut; Holloway *et al.*, 1942, in California; Anon., 1943, in Maine; Kearns and Martin, 1940, in England; Thompson, 1944a, and Pickett *et al.*, 1947, in Canada). These materials were not effective in eliminating phytophagous mites, and sufficient evidence has been presented to demonstrate that predacious mites were destroyed, thus favoring the pest species (Garman and Townsend, 1938; Cutright, 1944; Huffaker and Spitzer, 1950; and Clancy and Pollard, 1952).

Nitrophenols.

Chapman and Lienk (1950) and Hall (1951) found that mites increased to larger proportions where di-nitros, such as DN 289, were used for dormant mite sprays. The former investigators attributed it simply to less effective coverage than with oils and subsequent large numbers resulting from a large initial population, similar to phenomena they observed also with oils.

Phenothiazine.

Marshall (1945) reported increased mite infestations in British Columbia where phenothiazine had been applied for codling moth control. No explanation was offered to account for the buildup.

Miscellaneous Pre-DDT Chemicals.

Thompson (1939) said that the application of inert residues such as copper fungicides led to heavy mite infestations. Later he apparently reconsidered his report (Thompson, 1944b) and suggested that climate and favorable weather probably exerted the major influence on the mites. Holloway et al. (1942) however, found that non-acaricidal copper and zinc residues were correlated with subsequent substantial mite outbreaks.

DDT.

The majority of reports of mite problems have been associated with DDT applications. Ingram (1944), Overley (1944), and Steiner et al. (1944) were among the first to publish accounts of such increases in mite abundance. Loftin (1945), reporting on cotton pest studies in 1943, noted a serious outbreak of the two-spotted mite and attributed it to the use of DDT.

The many reports referring to mite buildup associated with DDT, have been tabulated by state, crop, and species of mite in Table 1 for the period 1944 to 1954. Most of the records pertain to mites attacking citrus and apple trees, probably because fruit pest problems have been studied more intensively by entomologists than those of other commodities.

TABLE 1. Reports of increases in mite abundance associated with DDT applications.

YEAR	AUTHOR	AREA	CROP	SPECIES
1944	Ingram	Louisiana	sugarcane	*Tetranychus telarius*
	Overley	Washington	apple	*T. pacificus*
	Steiner *et al.*	Indiana	apple	*Panonychus ulmi*
1945	Baker and Porter	Washington	apple	*T. pacificus*, *P. ulmi*, *P. citri*
	Borden and Jeppson	California	pear	*T. telarius*
	Dean	New York	apple	*T. telarius*
	Ebeling	California	citrus	*P. citri*
	Graham	Tasmania	fruit	*P. ulmi*
	Hough *et al.*	Virginia	apple	*P. ulmi*, *T. schoenei*
	Hough	Virginia	apple	*P. ulmi*
	Loftin	Texas	cotton	*T. telarius*
	Smith	Australia	potato	*T. telarius*
	Steiner	New York	apple	*M. ulmi*
	Swanson and Michelbacher	California	almond	*Bryobia praetiosa*
1946	Hough	Virginia	apple	*P. ulmi*
	Newcomer and Dean	Washington	apple	*T. pacificus*
	Steiner *et al.*	Indiana	apple	*P. ulmi*
	Wheeler and LaPlante	New York	peach	*T. telarius*
	Woodside	Virginia	apple	*P. ulmi*
1947	Blackburn	Ohio	peach	*T. telarius*
	Chapman	New York	apple	*T. telarius*
	Griffiths and Thompson	Florida	citrus	*P. citri*
1948	Bromley	Connecticut	ornamentals	*T. telarius*, *Oligonychus bicolor*
	Caldwell	Australia	apple	*T.* sp., *B. praetiosa*
	Clancy and Pollard	Virginia	apple	*P. ulmi*
	Hoffman and Merkel	Pennsylvania	forests	*O. bicolor*
	Huffaker (b)	California	beans	*T. telarius*

TABLE 1. (Cont.)

YEAR	AUTHOR	AREA	CROP	SPECIES
1948 (cont.)	Metcalf	California	- -	lit. review
	Newcomer and Dean	Washington	apple	*T. pacificus*
	Ullyet	South Africa	apple	not specified
1949-	Miller	Tasmania	apple	*T. telarius*, *P. ulmi*, *B. praetiosa*
	Pickett	Nova Scotia	apple	*P. ulmi*
	Way	England	vegetables	*T. telarius*
1950	Chapman and Lienk	New York	apple	*T. telarius*
	DeBach *et al.* (a)	California	citrus	*P. citri*
	Dustan *et al.*	Ontario	fruit	*P. ulmi*
	Huffaker and Spitzer	California	pear	*P. ulmi*
1951	Barnes	California	apple, pear	*T. pacificus*, *B. praetiosa*
	Brown	Canada	- -	lit. review
	Hall	Ontario	apple	*P. ulmi*
1952	Bartlett and Ortega	California	walnut	*P. ulmi*, *T. telarius*
	Blair and Groves	England	apple	*P. ulmi*
	Clancy and Pollard	Virginia	apple	*P. ulmi*
	Davis (b)	California	citrus	*T. telarius* (= *multisetis* McG.)
	Gaines *et al.*	Texas	cotton	*T. telarius*
	Michelbacher *et al.* (a)	California	melon	*T. pacificus*
1953	Collyer (a)	England	apple	*P. ulmi*
	Klostermeyer & Rassmussen	Washington	vegetables	*T. telarius*
	Landis and Gibson	Washington	potato	*T. telarius*
	Miller	Tasmania	apple	*T. telarius*
	Pickett and Patterson	Nova Scotia	apple	*T. telarius*, *P. ulmi*
1954	English and Tinker	Illinois	elm	*T. Telarius*
	Klostermeyer	Washington	legumes	*T. telarius*
	Matthyssee *et al.*	New York	elm	*T. telarius* and *Eriophyidae*
	Targe	France	fruit, ornamentals	*T. telarius*, *P. ulmi*, *B. praetiosa*

Table 1 shows that the unusual abundance of mites has been associated with DDT regardless of crop, host plant, or geographical location. There apparently are no correlations between the categories listed.

Miscellaneous Organic Pesticides.

Relatively few accounts of mite increases were found in relation to pesticides other than DDT. Becnel *et al*. (1947), in Louisiana and Klostermeyer and Rassmussen (1953) in Washington, observed severe buildup of *T. telarius* on cotton and on beans and potatoes, respectively, following BHC sprays for aphid control. Stapley (1951) in England, however, reported that no buildup of *P. ulmi* occurred where BHC was used. Michelbacher *et al*. (1952b) in California found much larger numbers of *T. pacificus* McGregor where aldrin, dieldrin, and heptachlor had been used for control of the melon aphid. On beans, the two-spotted mite, *T. telarius*, reached destructive proportions following treatment with lindane, chlordane, and aldrin (Klostermeyer and Rassmussen, 1953).

REPORTS OF APHID BUILDUP FOLLOWING THE USE OF PESTICIDES.

The problem of aphid outbreaks associated with pesticide applications has been recognized for a long time, and has received considerable attention in cotton pest research (Folsom, 1930). However, accounts of increases of aphids following chemical treatment are not so numerous as was noted for mites, even with the newer materials.

Reports through 1954 of aphid increases associated with both arsenicals and DDT are summarized in Table 2. It is evident that the diversified uses of DDT have led to buildup over a wider variety of crops than have arsenicals.

Only a few records of aphid buildup following the use of other pesticides were found in the literature. Moore (1937) observed an unusually severe infestation of *Myzus persicae* (Sulz.), the green peach aphid, on potato after treatment with Bordeaux mixture. Harvey (1946)

TABLE 2. Reports of increases in aphid abundance associated with applications of arsenicals and DDT.

YEAR	AUTHOR	AREA	CROP	SPECIES
		ARSENICALS		
1927	Folsom	Louisiana	cotton	*Aphis gossypii* Glov.
1930	Folsom and Bondy	Louisiana	cotton	*A. gossypii*
1937	Moore	Louisiana	potato	*Myzus persicae* Sulz.
1941	Dunnam and Clark	Mississippi	cotton	*A. gossypii*
1942	Smith and Fontenot	Louisiana	cotton	*A. gossypii*
1943	Elmore and Campbell	California	pepper	*M. persicae*
	Ewing	Texas	cotton	*A. gossypii*
	Ewing and Ivy	Texas	cotton	*A. gossypii*
	Hill and Tate	Nebraska	potato	*M. persicae*
	McGarr and Henry	Louisiana	cotton	*A. gossypii*
1945	Bondy and Rainwater	South Carolina	cotton	*A. gossypii*
	Hill	Nebraska	potato	*M. persicae*
1946	Hervey	New York	cabbage	*Brevicoryne brassicae* (L.)
1947	Becnel *et al.*	Louisiana	cotton	*A. gossypii*
		DDT		
1944	Ingram	Louisiana	cotton	*A. gossypii*
	Stevenson *et al.*	Arizona	cotton	*A. gossypii*
1945	Baker and Porter	(Washington	apple	*Eriosoma lanigerum* (Hsman.)
		(Indiana	apple	*Aphis pomi* DeGeer
	Ebeling (a,b)	California	citrus	*Aphis spiraecola* Patch
	Loftin	Texas	cotton	*A. gossypii*
1946	Driggers	New Jersey	peach	*M. persicae*
	Gyrisko *et al.*	New York	potato	*M. persicae*
	Hervey	New York	cabbage	*B. brassicae*
	Hervey and Schroeder	New York	cucumber	*A. gossypii*
	Newcomer *et al.*	Oregon	apple	*E. lanigerum*

TABLE 2. (Cont.)

YEAR	AUTHOR	AREA	CROP	SPECIES
1947	Gaines and Dean	Texas	cotton	*A. gossypii*
	Yothers	Washington	apple	*E. lanigerum*
1948	Hoffman and Merkel	Pennsylvania	forests	not specified
1949	Hoffman and Linduska	Pennsylvania	forests	not specified
	Sylvester	California	potato	*Macrosiphum solanifolii* (Ashm.)
1950	Calhoun and Smith	Mississippi	cotton	*A. gossypii*
	Fenton	Texas	cotton	*A. gossypii*
	Michelbacher and Middlekauff	California	melon	*A. gossypii*
	Michelbacher *et al.*	California	walnut	*Chromaphis juglandicola* (Kalt.)
	Parencia and Ewing	Texas	cotton	*A. gossypii*
	Ripper *et al.*	England	apple	*A. pomi*
1951	DeBach	California	citrus	*A. spiraecola* and others
	DeBach and Bartlett	California	citrus	*A. spiraecola*
1952	Bartlett and Ortega	California	walnut	*C. juglandicola*
	Michelbacher *et al.*	California	melon	*A. gossypii*
	Michelbacher and Bacon	California	walnut	*C. juglandicola*
	Newton and List	Colorado	apple	*E. lanigerum*
	Taylor	New Zealand	apple	*E. lanigerum*
1953	Michelbacher *et al.*	California	melon	*A. gossypii*
	Newcomer and Dean	Washington	apple	*E. lanigerum*
	Young and Gaines	Louisiana	cotton	*A. gossypii*
1954	English and Tinker	Illinois	elm	*E. lanigerum*, *Tuberculatus* (=*Myzocallis*) *ulmifolii* (Mon.)
	Garman	Connecticut	apple	*E. lanigerum*
	Matthysse *et al.*	New York	elm	*T. ulmifolii*

observed increased numbers of aphids on cabbage where cryolite, lead arsenate, and rotenone had been applied for chewing insect control. However, aphids did not develop to serious proportions in plots treated with BHC. Ripper et al. (1951) found that treatments with paration and TEPP resulted in very rapid reinfestation by aphids, although initial kill was very high. Ripper et al. (1950) compared selective systemic insecticides with non-selective ones, such as parathion, TEPP, and para-oxon. In a subsequent review, Ripper (1956) commented as follows on the 1950 studies. "The consequences of deleterious effects of certain pesticides on the natural enemies as well as on the aphids were demonstrated. Treatments with non-selective insecticides were followed by resurgences of the aphids within 10 to 14 days which required treatment. Where para-oxon was used commercially, it produced on the sprayed fields the most enormous cabbage aphid outbreak, within a fortnight after spraying, which has ever been seen in England, although the mortality of the aphids at the time of treatment was very high. By contrast, the selective insecticide, schradan, which did not affect the natural enemies either directly or by ingestion of schradan-killed aphids, kept the cabbage aphid population at a low level without economic significance for the rest of the season."

Wilson and Davis (1952) have brought together much of the literature on aphid increases following sprays for the period 1944 to 1952. They presented evidence that notable increases of the pea aphid occurred on plots treated with toxaphene and dieldrin. They have shown, as have others, that DDT is very effective against the pea aphid, the only aphid for which DDT is recommended as a control measure.

THE DESTRUCTION OF MITE AND APHID PREDATORS OTHER THAN COCCINELLIDS.

Ripper (1956) has presented an extensive review of the whole subject of the influence of pesticides on population dynamics, including predators and parasites. However, the more important investigations concerning predators other than lady beetles are listed here for convenience, but will not be reviewed (see Table 3).

THE IMPORTANCE OF COCCINELLIDS AS PREDATORS OF MITES.

All arthropods attacking mites are predators. Not one reference to parasites of mites was found in the literature. The lack of mite parasites has not been noted previously in the literature concerning entomophagous insects and biological control (Gilliatt, 1935; Groves, 1951; Clausen, 1952b; Sweetman, 1958; and others).

The Coccinellidae, especially species of *Stethorus*, constitute one of the more important groups of mite predators. Of 45 different predator species preying upon the European red mite in England, *Stethorus punctillum* Weise is the most abundant predator if not always of the greatest significance (Collyer, 1953b). It feeds exclusively on mites and has been reported by Collyer to consume an average of 20 mites per day as an adult and 24 as a larva.

TABLE 3. More important sources of information on the effect of pesticides on predators other than coccinellids.

THYSANOPTERA

Gilliatt, 1935
Lord, 1949a
Clancy and Pollard, 1952
MacPhee, 1953
MaPhee and Sanford, 1954,1956
Ripper, 1956

HEMIPTERA

Gilliatt, 1935
Steiner, 1938
Steiner et al., 1944
Hill, 1945
Smith and Michelbacher, 1946
Lord, 1949a
Newson and Smith, 1949
Chandler, 1950
Davis, 1952b
Collyer, 1952
MacPhee and Sanford, 1954,1956
Gaines, 1954,1955
Ripper, 1956

NEUROPTERA

Walton and Whitehead, 1944
DeBach, 1947
Woglum et al., 1947
Doutt, 1948
Lord, 1949b
DeBach et al., 1950a
DeBach and Bartlett, 1951
Bartlett and Ortega, 1952
MacPhee and Sanford, 1954,1956
Gaines, 1954,1955
Ripper, 1956

DIPTERA

Ripper, 1944
Walton and Whitehead, 1944
Wright and Ashby, 1945
Potter and Perkins, 1946
Ripper et al., 1949
Way, 1949
Boyce and Leroux, 1951
Ripper, 1956

ACARINA

Garman and Townsend, 1938
Cutright, 1944
Lord, 1949a,b, 1956
Huffaker and Spitzer, 1950
Collyer, 1949,1953a,b
Clancy and Pollard, 1948,1952
MacPhee and Sanford, 1954
Gaines, 1955
Ripper, 1956

Stethorus picipes Casey was reported to be the most common predator of *Tetranychus telarius* in California (Quayle, 1912). *S.* sp. effectively controlled the same mite on cotton (McGregor, 1914) and also the citrus red mite, *Metatetranychus citri* in California, particularly late in the season (Borden, 1922). *Stethorus rotundus* Motsch. reduced the numbers of *T. telarius* considerably on Formosa (Takahashi, 1938). In Virginia, Clancy and Pollard (1948) stated that *Stethorus* was the most important mite predator in apple orchards, particularly when the European red mite builds up to serious proportions, but was not effective at low mite levels. According to Geijskes (1938), *Stethorus punctillum* and *Anthocorus nemorum*, a hemipteron, effectively reduced an infestation of the European red mite. Lathrop (1951) in Maine recorded the natural control of a mite infestation and stated that *Stethorus* was the most important species. Robinson (1952, 1953) referred to *Stethorus punctum* (probably *punctillum*) and said, "this species is probably the most important predator of mites in Manitoba." Clancy and Pollard (1952) found that 96 percent of all predators in DDT-treated blocks of apple trees were Stethorus.

In eastern Canada, investigations from 1943 to date have demonstrated the importance of general mite predators, including Stethorus (Pickett and Patterson, 1953). Lord (1949a,b, 1956) has concluded that the complex of predacious arthropods on apple trees in Nova Scotia can control phytophagous mite populations. The importance of Stethorus beetles has resulted in a detailed life history study of S. punctillum Weise (Putman, 1955a and b).

THE IMPORTANCE OF COCCINELLIDS AS PREDATORS OF APHIDS.

Coccinellids were rated as second in importance of all natural enemies of the pea aphid, including parasites, by Davis (1915). Ross (1918) listed 7 species of importance in aphid control. F. F. Smith (1926) reported that H. convergens and

A. bipunctata along with Aphidius, a hymenopterous parasite, reduced apterous individuals so that few aphids were present at the time of dispersal. Ruggles and Wadley (1927) listed 5 species of coccinellids which were the most important natural enemies of the grain aphid, Toxoptera graminum Rond., during an outbreak. Folsom and Bondy (1930) stated that coccinellids were the most effective natural enemies of the cotton aphid, but that they of themselves were unable to actually exterminate the aphids. In Kansas, H. convergens was credited with the control of aphids on lucerne in 1931 (Anon., 1934). In Louisiana, according to Harrison and Allen (1943), coccinellids were very important predators of Rhopalosiphum pseudobrassicae. Michelbacher and Middlekauff (1950) in California reported that the lady beetles were the most important predators and as such accounted for nearly perfect biological control of the melon aphid. Dunn (1951) in a study of parasites and predators of the pea aphid cited coccinellids as the most important of all predators. Fluke in 1925 concluded that Cera-

tomegilla fuscilabris was the most important predator of the alfalfa aphid. In addition to *fuscilabris*, other species were present and counts were made to determine the numbers of lady beetles per acre. From counts on 4 to 10 square feet plots of alfalfa, it was calculated that from 19,360 to 54,460 coccinellids were present per acre with some 100,000 to 2,095,000 aphids.

THE EFFECTS OF PESTICIDES ON COCCINELLID PREDATORS OF MITES AND APHIDS.

The effect of pesticides on beneficial coccinellids alone has not been reviewed heretofore. However, workers active in studies with natural enemies of pests have included coccinellids in their reviews. General summaries have been published by Clausen (1936), Brown (1951), MacPhee and Sanford (1954, 1956), and Ripper (1956).

The earliest report of observations on the effect of pesticides on beneficial Coccinellidae was that of Froggatt (1905) in Australia.

Studies of the reaction of coccinellids to some of the older, pre-World War II spray chemicals were carried on by Haug and Peterson (1938). With the exception of studies by Smith and Fontenot (1942), which included some data on cotton-aphid predators, Haug and Peterson were the only workers to assay the influence of older pesticides on coccinellids.

Way (1949), Campbell and Hutchins (1952), Davis (1952b), Bartlett (1953), Ahmed *et al.* (1954), Ahmed (1955), and Harries and Valcarce (1955) are the only workers who have reported on laboratory investigations to determine the effects of newer pesticides on beneficial coccinellids. Extensive field studies have been conducted by a larger number of workers whose work will be reviewed under the various pesticides discussed in following sections.

Hydrogen Cyanide.

Froggatt (1905) found that "steel-blue ladybirds" recovered from tent fumigation treatments of HCN applied for control of *Icerya purchasi*. Three reasons were given to account for the lack of toxicity to the coccinellids: 1) beetles dropped to the ground when disturbed by placing and adjusting the tent over the trees; 2) the air at ground-level probably had a much lower concentration of the gas which is lighter than air; and 3) the concentration applied to kill the scale is apparently low enough to leave the coccinellids unharmed or to stupify them so that they fall to the ground. Knight (1925) showed that a mean concentration of 0.45 percent HCN for 20 minutes was necessary to cause 100 percent mortality of *Hippodamia convergens*. Pratt *et al*. (1933), using a 0.2 percent concentration of HCN obtained 85 percent mortality of the same species in 10 minute exposures, 90 percent in 20 minute exposures, and 100 percent in 30 minutes.

Lead Arsenate.

Haug and Peterson (1938) sprayed caged eggs, first instar larvae, and adults of *H. convergens* directly with lead arsenate at the rate of 3 pounds per 100 gallons of water and observed no mortality.

No toxicity to coccinellids was reported by Annand (1942) when lead arsenate was used with lime sulfur and oil in orchard sprays. Yothers and Carlson (1948) observed normal sized egg clusters of *H. convergens* following applications of arsenicals.

Calcium Arsenate.

There are conflicting reports on the effect of calcium arsenate on lady beetles. Haug and Peterson (1938) in laboratory tests obtained 24 percent mortality of adults but none for eggs when caged specimens were sprayed with a combination of 3 pounds of calcium arsenate and 8 pounds of hydrated lime per 100 gallons of water. Smith and Fontenot (1942) in field tests observed that coccinellids were three times as abundant in untreated plots of cotton as in treated plots. Larvae were reduced in number following treatment, moreso than were adults. Aphids were much more abundant in the treated plots but did not support more lady beetles. Loftin (1945) in Texas observed 70 to 83 percent reduction of coccinellids in cotton fields treated with calcium arsenate. Newson and Smith (1949) observed a reduction of six unspecified species of lady beetles. However, the observations were based only on a negative correlation between the predators and the treatments and are inconclusive without data on the abundance of prey.

Contrasting results were obtained by Folsom (1927). He reported a large increase of coccinellid predators in cotton fields which had been treated with calcium arsenate dust. The lady beetles were not killed, apparently. Folsom and Bondy (1930) made sweeps on treated and untreated plots just before dusting and afterwards at intervals of 30 minutes, 5 or 6 hours, 24 hours, and later also. When counts were compared to curves showing the degree of aphid infestation, it was found that all the predators increased in numbers as the prey increased. In attempts to recover any insects which might have been killed, they spread cloths under a number of plants but found only 12 adults and no larvae during two months of field tests.

Oils.

Early reports pertain to tar oils, referred to as tar distillates. Massee (1928) and Massee and Steer (1929) stated that mite predators, including Stethorus, apparently, were destroyed by these compounds. Although Hemiptera have been reported to be of greatest importance in England, Stethorus is one of the more significant predators (Collyer, 1949). Speyer (1934) observed that tar distillates affect Stethorus indirectly by controlling the prey. When mites increased in the absence of the sprays, numbers of Stethorus increased proportionately. When mites were reduced by tar washes, Stethorus had a very limited food supply and was scarce. Putman (1955a) has since shown that a minimum level of prey is necessary for Stethorus to oviposit and develop subsequently.

Speyer (1936) collected numbers of Adalia bipunctata and sprayed them with tar distillates.

The species proved to be somewhat resistant to the treatment. By a detailed study of the stigmata, Speyer has shown that *Adalia* has an effective protective device for closing the spiracles.

Geijskes (1938), in contrast to Speyer, stated that tar distillates killed coccinellids. However, he worked with a different species, *Stethorus punctillum* Weise. Data are not available on the nature of spiracular control of this species.

Petroleum oils were found to be non-toxic by Haug and Peterson (1938). Direct sprays of Volck oil at 3.2 percent concentration showed very low toxicity to eggs and adults. Houser and Cutright (1941) stated that dormant oil was probably toxic to *Stethorus*. They admitted there was no evidence to support their claim, and suggested that *Stethorus* was lacking in the treated block because of the lack of mites. The same situation has been reported elsewhere (Anon., 1929). MacPhee and Sanford (1956) have reported that summer oil sprays were toxic to *Stethorus*. It is obvious that there is very little evidence to demonstrate what effect oils have on coccinellids.

Rotenone (derris).

Haug and Peterson (1938) sprayed *H. convergens* adults and larvae with a 5 percent ground derris-root suspension. Mortalities of adults from 57 to 78 percent resulted. Mortality of larvae averaged 46 percent and eggs showed an average of 14 percent. Harrison and Allen (1943) stated that derris dust remained effective for about a week and was more toxic to coccinellids than nicotine dust in field applications for cabbage aphid control on turnip. Way (1949) in tests with *Coccinella septempunctata* found that 0.005 and 0.01 percent sprays of rotenone caused nearly 100 percent mortality to larvae and from 90 to 100 percent mortality of eggs. Ovicidal action was recorded also for *A. bipunctata* Muls. Direct spraying of convergent lady beetle adults resulted in 50 percent mortality. The general reaction of the coccinellids to rotenone was paralysis. No evidence is available to indicate the effect of residues on treated plants to coccinellids.

Pyrethrum.

In laboratory tests very low mortalities were obtained with all stages of *H. convergens*. Pyrethrum at 1-400 dilutions produced no mortality of adults, an average of 8 percent to larvae, and an average of 3 percent to eggs (Haug and Peterson, 1938). In studies of the effects of pyrethrins on flying insects, Page *et al*. (1949) found that high concentrations must be used to cause any appreciable effect on the 7-spotted lady beetle. The authors concluded that spray pickup by coccinellids is very low based upon the proportion of body weight to the size of the insect. The symptoms of pyrethrum poisoning were given for *C. septempunctata*; the elytra were observed to be "cocked," the wings beat intermittently but actual flight was not achieved. Generally, the beetles pitched forward on their heads. Indications are that normal concentrations of pyrethrum have little effect upon coccinellids.

Nicotine.

Nicotine has been found to be relatively inocuous to lady beetles in direct applications of dusts and sprays (Morrill, 1921; Haug and Peterson, 1938; Walton and Whitehead, 1944; Ripper, 1944; Way, 1949; Brown, 1951; and Ripper *et al.*, 1951). Gilliatt (1935) in reporting that nicotine sprays had no ill effects on *Stethorus*, suggested that the many minute hairs on the body may have prevented wetting by the spray. In laboratory tests Haug and Peterson (1938) did show a mortality of about 18 percent from direct sprays of nicotine at a dilution of 1 to 800 with soap, 1 to 100. Walton and Whitehead (1944) and Ripper (1944) attributed the success of nicotine in control of aphids in part to its inocuous effect upon coccinellids. After most of the aphids were eliminated by the sprays, the predators destroyed remaining aphids. However, nicotine often depletes the aphid population to the point where the coccinellids disperse and do not return until after the aphids have reached a high level of abundance again (Ripper *et al.*, 1951).

DDT AND OTHER CHLORINATED HYDROCARBONS.

In regard to the effect of DDT and the newer pesticides upon beneficial insects, the words "apparently," "probably," and "suggested," along with bold statements without supporting evidence, abound in the recent literature. The following summaries were prepared to indicate the degree to which workers have stressed the apparent interference of pesticides with predators. Coccinellids were included either by specification or by implication. The destruction of predators was stated as "apparent" by Cutright (1944), Baker and Porter (1945), Smith *et al.* (1945), Newcomer *et al.* (1946), Griffiths and Thompson (1947), Bromley (1948), Caldwell (1948), Hoffman and Linduska (1949), DeBach *et al.* (1950b), Rosenstiel (1950), and Lathrop (1951). Predator destruction was stated to be probable by Steiner (1944), Strickland (1945), Clancy and Pollard (1948), Hoffman and Merkel (1948), Griffiths and Fisher (1949), and Lathrop (1951). The following authors without presenting evidence stated that predators were adversely affected by pesticides: Ripper (1944); Anon. (1947); Pickett (1949); Ripper *et al.* (1951); Holmes (1952); Ross (1952); Bartlett (1953); MacNay (1953); Pickett and Patterson (1953); Graham (1956); and Blackburn (1947). Reports in which predators were observed to be reduced or killed following sprays or dusts of the newer chemicals include: Ingram (1944); Steiner *et al.* (1944); Borden and Jeppson (1945); Hill (1945); Loftin (1945); Michelbacher and Swanson (1945); Osborn (1945); Wright and Ashby (1945); DeBach (1946a); Potter and Perkins (1946); Smith and Michelbacher (1946); Wilson (1946); O'Kane (1947); Huffaker and Spitzer (1950); Kelley (1951); Bartlett and Ortega (1952); and Blair and Groves (1952).

Authors who have provided experimental evidence on the subject are cited here chronologically to illustrate the extent to which the problem has been studied. The investigations will be discussed later under specific insecticides. Investigations in California citrus groves were conducted by: DeBach (1946b); DeBach (1947); DeBach *et al.* (1950a); DeBach and Bartlett (1951); Ewart *et al.* (1952);

Davis, (1952); and Bartlett (1953). Griffiths and Thompson (1947) made limited studies in Florida citrus. In apple orchard pest control, the following authors published data on coccinellid predators: Clancy and Pollard (1952); Clancy and McAllister (1956) in Virginia; Robinson (1953), MacPhee and Sanford (1954); MacPhee and Sanford (1956); and Lord (1956) in Canada. Studies including coccinellids on cotton aphids and mites include Newson and Smith (1949); Campbell and Hutchins (1952); and Gaines (1954, 1955). Harries and Valcarce (1955) in Arizona tested several of the most recent pesticides using _Coleomegilla maculata_ and _Hippodamia convergens_. Studies with systemic insecticides as they are applied to various crops have been reported by Ripper _et al_. (1949, 1950, and 1951), Ahmed _et al_. (1954), and Ahmed (1955). On raspberry in Oregon, Rosenstiel (1950) conducted some tests with _Stethorus_. Yothers and Carlson (1948) in Oregon studied the effect of DDT on the predators of the green peach aphid. Way (1949) in England conducted some laboratory experiments on the effect of DDT and BHC on certain aphidophagous insects and their hosts.

DDT.

DDT has been reported to eliminate or to be highly toxic to all species of *Stethorus*. Gunthart (1945) obtained 100 percent mortality of all stages of *S. punctillum* Weise with a 1 percent DDT spray emulsion. Davis (1952) exposed *S. picipes* Casey, adults to residues of 0.015, 0.03, and 0.06 mg. of DDT per sq. cm. on Petri dishes. One hundred percent mortality resulted in 50 hours with all concentrations. In Indiana, Steiner *et al.* (1944) reported that *S. punctum* (Lec.) was eliminated by 0.25 percent concentrations of DDT suspension. DeBach (1947) showed that DDT seriously interfered with *S. picipes* Casey. Where DDT was diluted to 12.5 percent in talc, 2302 mites per 100 leaves were found, with an average of only 9.7 predators (*S. picipes* Casey; *Oligota oviformis* Casey, a staphylinid; and *Conwentzia hageni* Banks, a neuropteron). On plots with talc only, 1896 mites per 100 leaves were observed with an average of 32.8 predators, and on plots with no treatment, mites numbered 377 per

100 leaves and predators averaged 28.8. It should be emphasized that DeBach qualified his results as preliminary, since the counts were taken two months after treatment on one occasion. The author pointed out the possibility of a shift in populations of predators. It has been shown by other workers that _Stethorus_ is usually active early in untreated plots and then moves into areas which have been treated and contain high mite populations. Steiner (1944) reported that _Stethorus_ was effective in eliminating mites in spite of spray treatments. Clancy and Pollard (1948) reported a drop in mite abundance in treated plots paralleling that in untreated plots, although they observed that _S. punctum_ was easily killed by DDT. Apparently, the mite buildup in the DDT plots attracts the predators resulting in the destruction of the mites. Clancy and Pollard (1952) showed that 96 percent of all predators present in high mite populations where DDT had been applied earlier were _Stethorus_. Thus, although _Stethorus_ itself is eliminated by DDT toxicity, mite buildup resulting from DDT sprays and the mobility

of predator adults actually may favor a general increase in Stethorus population. Steiner et al. (1944) observed that Stethorus was effective in spite of sprays.

Other experimental evidence demonstrating the effect of DDT on Stethorus has been presented. When Robinson (1953) dipped apple leaves into solutions of DDT wettable powder mixed at the rate of 0.5 pounds per 100 gallons of water and exposed 70 adults of S. punctum for 2 hours, he obtained a mortality of 33 individuals. No further explanation was given as to other conditions of the tests. The results should be considered preliminary at most. MacPhee and Sanford (1954, 1956) reported that S. punctillum Weise was eliminated in various tests conducted in Nova Scotia on apple trees. Lord (1956) deliberately applied DDT to regulate the abundance of Stethorus in experiments designed to study mites in the absence of or under various conditions of predatism.

In 1945, several workers first noted the effect of DDT upon other, mostly aphidophagous, coccinellids. Borden and Jeppson (1945) observed that coccinellid eggs were not present until late season in DDT treated blocks of pears in California. Smith *et al.* (1945) reported, although no data were taken, that DDT aerosols applied to vegetable crops in Maine and Maryland had only a temporary effect upon predators including coccinellids. Smith and Michelbacher (1946), in studies on the control of certain alfalfa pests, observed that coccinellids were eliminated by DDT applied at the rate of 30 pounds of 5 percent dust per acre. They noted that hemipterous predators seemed to be less affected. Michelbacher (1945), without specifying which predators were observed, reported that DDT killed the walnut aphid and its predators when used to control codling moth. The aphids built up rapidly following the treatment whereas the predators did not. Wright and Ashby (1945) observed dead adults of the 7 and 11-spotted lady beetle in field cages set up to demonstrate the effect of a 1 percent emulsion on the carrot fly, *Psila rosae* Fab. The authors found also that 100 percent mortality was obtained in 24 hours when coccinellid adults were exposed to 32 day old residues of the DDT. In studies on cotton pests, Loftin (1945) reported somewhat lower toxicity of DDT to lady beetles. In two different tests, a reduction of 67 percent and 75 percent was noted for coccinellids. This was less than the reduction observed in calcium arsenate plots. In 1946, Wilson reported that a 1 percent DDT emulsion destroyed unspecified coccinellids with no effect upon prey aphids. In tests conducted on pests of Brassica, Potter and Perkins (1946) found coccinellids and the parasite Aphidius sp. eliminated from plots which had been sprayed and dusted with DDT, whereas syrphid predators were not killed. Michelbacher et al. (1950) conducted observations following an outbreak of the melon aphid which was associated with the use of DDT. Nearly perfect biological control was noted after the influx of natural enemies about 4 weeks later. Lady beetles were said to be the most important predators, effectively reducing aphids in 1 week.

In 1948, Yothers and Carlson published the results of investigations on the effect of DDT on the green peach aphid and its coccinellid predators. The authors state, "It appears that coccinellids were either repelled or destroyed by the DDT residues, and that oviposition of the few coccinellids that entered the DDT plots was reduced. The few egg groups found in the DDT plots contained only 3 - 5 eggs each as compared to 10 - 15 per group in the other plots." Coccinellids were abundant in other plots, numbering up to 20 adults per 5 minute counts and up to 341 egg clusters per 900 terminal shoots in the lead arsenate block. It is difficult to draw any conclusions from the study by Yothers and Carlson. In two applications, DDT resulted in very low coccinellid counts yet there was no indication as to whether or not coccinellids were killed. The aphid population was very low in one DDT plot and lady beetles may have left due to lack of prey. In the second plot where it was known that aphids were numerous, TEPP was included with the DDT. No conclusion can be drawn to indicate that toxicity is due necessarily to DDT. It is true, however, that in all plots where DDT was applied, coccinellids were either few or absent.

Way (1949) carried out some laboratory studies on the effect of some pesticides upon the two-spotted and the seven-spotted lady beetle. He found that DDT on cabbage foliage was destructive to adults of the seven-spotted lady beetle. Aphids were maintained with the beetles during the tests. Observations were made at 1, 2, 3, 4, and 10-day intervals following exposure to the foliage. In all cases where total mortality was high some dead beetles were recorded each day. In those where total mortality was low, no dead beetles were found the first two days. Thus it is evident that DDT is toxic at high concentrations, that DDT retains its toxicity as a residue and exerts its effect slowly, and that some recovery may be expected with light concentrations. A few tests were conducted with eggs and larvae, but generally were unsuccessful because of the cannibalistic habits of the larvae upon hatching. The deleterious effect of DDT on the eggs, if any, was indirect and was not evident until the larvae died after they had hatched. Half-grown larvae of the seven-spotted lady beetle were treated with DDT and moderate mortality was observed.

Campbell and Hutchins (1952) exposed eight species of lady beetles to 13 pesticides on cotton shoots bearing two leaves which had been treated on a rotary sprayer. The shoots were maintained in vials of nutrient solutions which, with the insects, were kept in gauze-covered lantern chimneys. *Coleomegilla maculata* and *Sycmnus* sp. were more susceptible to DDT than *Hippodamia convergens*. Compared with all of the insecticides used, DDT was the only one which consistently produced lower mortalities if used in a dust formulation. Way (1949) also obtained the lowest mortalities of *C. septempunctata* with dust formulations. In field tests, where DDT was compared with dieldrin and toxaphene, the greatest reduction of coccinellids was noted with DDT. Toxicities of from 22 to 71 percent were produced within 48 hours after treatment with little variation between species.

Gaines (1954, 1955) recorded the abundance of all predators of the cotton aphid throughout the season. Beginning in July, 8 dust treatments were applied over the rest of the summer. DDT was used in two fields: the first, in combination with dieldrin and sulfur; the second, with BHC (3 percent gamma) and sulfur. Large populations of coccinellids were present in all fields up until the time the dusts were applied. After the third treatment, there were no longer any coccinellids or other predators present. Unfortunately, there is no indication in Gaines' data to indicate the presence of absence of prey. If the treatments removed the prey, the coccinellids would have dispersed. Thus it is not possible to attribute the elimination of lady beetles to the direct toxicity of the dust to the beetles.

Harries and Valcarce (1955) exposed C. maculata and H. convergens to residues of DDT on growing sugar beet plants and recorded only very low mortality. However, the counts were taken only the day following application. DDT has been shown to take effect slowly (Campbell and Hutchins, 1952) and thus the validity of these tests is questionable.

Because of the importance of certain lady beetles which feed on scale insects, they are included here, although they do not feed on aphids or mites and do not occur widely in New England.

Cottony cushion scale, *Icerya purchasi* Mask., has been cited often in entomology texts as an outstanding example of biological control due to the predation of the vedalia lady beetle, *Rodolia cardinalis* Muls. No serious outbreak had occurred since the vedalia was imported into California. In 1947 (Anon.) the cottony cushion scale was reported to be increasing following sprays of DDT for control of other citrus pests. DeBach (1946) stated that *Rodolia* was eliminated by DDT along with other predators of the long-tailed mealybug, *Pseudococcus adonidum* L. DeBach took advantage of the action of DDT to develop an insecticidal check method for studying pests in the absence of predators and parasites. DDT was applied with the intention of removing natural enemies. DeBach and Bartlett (1951) showed that 2-month old residues of DDT were toxic to the vedalia adults in 24 hours. Ewart *et al*. (1952) also demonstrated with field data that DDT was highly toxic to Rodolia.

The species of lady beetles in the genus Chilocorus are important predators of scale insects throughout the United States. Osburn (1945) observed, in tests with DDT to control the little fire ant, Wasmannia auropunctata (Roger), that Chilocorus stigma Say was killed by the sprays in two instances. Griffiths and Thompson (1947) found as many as 62 dead C. stigma under trees sprayed with DDT. They recommended that DDT not be used for citrus pest control in Florida as a result.

Adults of Scymnus binaevatus Muls. were experimentally exposed to foliage and bark residues of DDT by Doutt (1948), and the number of days was recorded which elapsed before 100 percent mortality occurred. On residues which were 4 months old, 100 percent mortality was obtained after 24 hours. Huffaker (1948) exposed adults of the same species to macerated leaves which had been treated with DDT and found 87 percent mortality as compared to 13 percent in the check.

Bartlett (1953) carried on some of the most extensive tests ever conducted with a lady beetle. He used 35 pesticides, some of which included more than one formulation or concentration. Three predators were used, including only one coccinellid, Lindorus lophanthae (Blaisdell). DDT was found to exert a much longer-lasting toxic residue than parathion and all other chemicals. It was considered as most deleterious to the natural enemies studied.

Aldrin.

Primarily used against pests of field crops, aldrin is seldom if ever recommended for control of apple or ornamental pests in the northeastern United States. Because of its importance in cotton-growing areas, Campbell and Hutchins (1952) included it with their studies. Adults of three lady beetles were exposed to residues on foliage treated at the rate of 1/4 pound of toxicant per acre. Aldrin was found to be of relatively low toxicity.

Bartlett (1953) in tests with <u>Lindorus lophanthae</u> also found aldrin not significantly toxic compared to DDT and the checks.

<u>BHC</u>.

O'Kane (1947) tested two preparations of BHC containing 0.5 and 0.1 percent gamma isomer respectively as dusts against a great many fruit, ornamental, and vegetable pests. He found no dead lady beetles in cages or plots where the materials were used, and observed many live ones, concluding that the beetles apparently were resistant.

Way (1949) conducted some laboratory tests comparing BHC with DDT. He found that the direct spraying of adult <u>C. septempunctata</u> with 0.026 and 0.052 percent gamma BHC resulted in about 50 percent mortality, similar to that obtained for DDT. However, following treatment, he noted that the beetles which were alive on the fourth day recovered whereas those in the DDT tests did not. In field tests, BHC did not show ovicidal action, but like DDT did produce mortality to new emerged larvae of both the 7-spotted and 2-spotted lady beetle. Field applications of BHC showed only slight toxicity to half grown larvae of lady beetles.

Newson and Smith (1949) observed the reactions of coccinellid and other predator populations in field plots treated with BHC dust containing 3 percent gamma isomer mixed with 5 percent DDT and 40 percent sulfur, applied at approximately 10 to 11 pounds per acre. Although pointing out that the results are preliminary and may depend upon factors other than the insecticides alone, they stated that no significant reductions of lady beetles occurred where two early applications were made. In plots where 6 and 8 treatments were applied, there was a significant reduction, but not elimination of the lady beetles.

In laboratory tests, Campbell and Hutchins (1952) exposed 3 species of coccinellids to cotton foliage treated with BHC at an indicated dosage of 0.4 pounds of gamma isomer per acre. Mortalities were higher generally than with exposures to DDT under similar conditions. H. convergens showed lower mortality consistent with its reaction to other pesticides tested by Campbell and Hutchins.

Somewhat different results were obtained with a scale predator, Lindorus lophanthae. Foliage treated with 0.75 percent gamma isomer of BHC at the rate of 1 pound per tree (citrus) gave less than 50 percent mortality after exposure for over 100 hours (Bartlett, 1953).

Chlordane.

Several workers have studied the effect of chlordane upon coccinellids. Newson and Smith (1949), testing insecticides for cotton pest control, observed that a dust containing 3 percent chlordane and 3 percent DDT and a dust containing 10 percent chlordane alone did not produce a significant reduction of 6 unidentified species of coccinellids. Both formulations were applied at the rate of 10 pounds per acre. The authors stated that the results were inconclusive, however.

DeBach and Bartlett (1951) included chlordane in some citrus pest experiments and observed that 64 percent reduction of Stethorus picipes occurred after one application and only 22 percent after three applications. No explanation was offered by the authors to indicate why more predators occurred where more treatments had been applied. An abundance of prey could have accounted for the large numbers of the lady beetle in plots which received 3 applications. Since Stethorus comprised 51 percent of the predator population following the three applications, it appears that chlordane is less toxic to it than to other predators.

DeBach and Bartlett (1951) found that 76 to 86 percent of trees sprayed with chlordane supported larval coccinellid populations during normal periods of aphid infestation.

In the tests of Campbell and Hutchins (1952), the following mortalities were observed when adults of three species were exposed to residues of chlordane resulting from treatments at the rate of 1 pound per acre:

Species	Percent Mortality* sprays 48 hr.	96 hr.	dusts 48 hr.	96 hr.
C. maculata	23	64	16	33
H. convergens	--	--	0	7
Scymnus sp.	55	17	--	--

*Abbott's formula

These data support the low to moderate toxicity observed by DeBach and Bartlett (1951).

Bartlett (1953) obtained very low mortalities of *L. lophanthae* when he exposed adults to residues of chlordane field weathered for 1 week and 1 month. One-day old wettable powder residues produced 50 percent mortality in 51 hours. Dusts were less toxic.

Dieldrin.

Little evidence is available on the effect of dieldrin on coccinellids. Campbell and Hutchins (1952) included it and obtained low mortalities; none were above 55 percent.

In field tests, where dieldrin was applied at the rate of 0.15 and 0.3 pounds per acre, coccinellid populations showed a slight increase over the check, whereas DDT plots had a drastic reduction (Campbell and Hutchins, 1952).

Harries and Valcarce (1955) also demonstrated low toxicity of dieldrin to lady beetles. When exposed to plants dusted with 2 percent dieldrin, adults of *C. maculata* and *H. convergens* showed mortalities of 4 and 24 percent, respectively.

Ewart *et al.* (1952) found that neither a spray of 25 percent wettable powder at the rate of 2 pounds per 100 gallons nor a 0.125 percent emulsion reduced numbers of *Rodolia cardinalis* in citrus plots. In comparison, no predators were present in the DDT plots for 1-1/2 months after treatment.

Bartlett (1953) showed that field-weathered residues 1 day old failed to kill more than 50 percent of *L. lophanthae* adults which were exposed for 94 hours.

Heptachlor.

Campbell and Hutchins (1952) and Harries and Valcarce (1955) have published the only available data on heptachlor affecting beneficial coccinellids. Low toxicity was recorded for *C. maculata*, *H. convergens*, and *Scymnus* sp. The highest mortality, 54 percent, was observed for *Scymnus*. For the other two species, mortality never exceeded 40 percent.

Methoxychlor.

The only report found concerning tests with methoxychlor was that of Robinson (1953). Apple leaves were dipped into wettable powder suspensions of methoxychlor and DDT which contained 0.5 pounds of toxicant each per 100 gallons of water. *Stethorus* beetles were exposed to the resulting residues for two hours. Of 70 beetles treated, 44 died in the methoxychlor group and 33 in the DDT. The author concluded that the two materials are equally toxic under the conditions of the test. In order to establish the actual toxicity of the chemicals, it would be necessary to insure a uniform exposure of each beetle to the residue, but there is no indication in the paper of such a procedure. Thus the conclusion has little significance.

Toxaphene.

Newson and Smith (1949) obtained reduction of 6 species of aphidophagous coccinellids in field plots of cotton treated 6 and 8 times with toxaphene. Little reduction compared to the check was noted in the average of 5 records where only two treatments were applied. A significant reduction occurred compared to the untreated where 8 applications were made. The treatment consisted of a 20 percent toxaphene and 40 percent sulfur dust combination applied at the rate of 11.1 pounds per acre.

Gaines (1954, 1955) used the same standard dust mixture as Newson and Smith, above, but in airplane applications. He recorded an earlier and greater decrease of coccinellids in toxaphene plots than in those receiving DDT and dieldrin or DDT and BHC. It is unfortunate that the abundance of prey is not recorded in Gaines' paper. If toxaphene caused a radical reduction of aphids, the larger numbers of predators in other plots might be explained.

Laboratory tests by Campbell and Hutchins (1952) indicated that toxaphene is more toxic than DDT. In field tests, the reduction was less than in DDT plots. The prevalence of aphids was not included by the authors. The amounts of toxicant applied are much lower than those used by Gaines, and Newson and Smith, above.

Harries and Valcarce (1955) exposed _H_. _convergens_ and _C_. _maculata_ adults to plants treated with 10 percent dust. Mortalities of 12 and 36 percent were obtained for the two species respectively.

Other Chlorinated Hydrocarbons.

Endrin gave mortalities of less than 40 percent when _C_. _maculata_ and _H_. _convergens_ were exposed to residues on growing plants in the laboratory, (Campbell and Hutchins, 1952; Harries and Valcarce, 1955). Isodrin was found also to cause but slight mortality under experimental conditions (Campbell and Hutchins, 1952). TDE (DDD) was included in tests with _L_. _lophanthae_, but less than 50 percent mortality was recorded after 100 hours exposure of adults to 1-day old residues.

Perthane and Strobane as 5 percent dusts were very slightly toxic to H. convergens and C. maculata (Harries and Valcarce, 1955).

General Comments.

Chlorinated hydrocarbons have not been sufficiently assayed against coccinellids. Preliminary studies indicate that most of the materials are toxic, at least to a certain extent. DDT, BHC, and toxaphene appear to be the most toxic, while aldrin, dieldrin, and chlordane have shown less toxicity in tests. No data of any consequence are available on methoxychlor and TDE. Dieldrin, in light of its high toxicity to many pests (Brown, 1951) appears remarkably low in toxicity to lady beetles, although little information is available and further study is necessary. One interesting feature noted is that no chlorinated hydrocarbon gave complete kill in laboratory tests. Therefore, it seems likely that some recovery and partial survival is a characteristic associated with the use of such materials. Where field tests have been reported to eliminate coccinellids, it should be remembered that a complex of factors influence the presence, dispersion and apparent effectiveness of field populations. The observations of a negative correlation between the treatments applied and resulting insects present is not sufficient to establish a deleterious effect in itself.

ORGANIC PHOSPHATES.

EPN.

Little information is available on the toxicity of EPN to lady beetles. Campbell and Hutchins (1952) included it in their tests, using 0.2 pounds per acre. EPN was found to be very highly toxic, producing 100 percent mortality in most instances within 48-90 hours.

The residual effect of EPN was found to be slight on *Lindorus lophanthae* (Bartlett, 1953). Low mortalities resulted when adults were exposed to 1-day old residues of EPN sprays.

Parathion.

The effect of parathion on lady beetles has been summarized also by MacPhee and Sanford (1954) and Ripper (1956).

All investigations have shown that parathion is extremely toxic to coccinellids. Rosenstiel (1950) obtained field evidence that parathion eliminated the mite predator, Stethorus, and its prey as well, causing both direct and indirect deleterious effects on the lady beetle. Ripper et al. (1950) and Michelbacher and Middlekauff (1950) adequately demonstrated that parathion is highly toxic to lady beetles. Campbell and Hutchins (1952) obtained 100 percent mortality in all tests with C. maculata and H. convergens. Bartlett (1953) showed that parathion residues break down more rapidly than the chlorinated hydrocarbons. In tests with L. lophanthae, tests on fresh residues produced 100 percent mortality, but exposures of over 100 hours to week-old residues produced even less than 50 percent mortality.

Parathion as a 2 percent dust applied to sugar beet leaves produced 78 percent mortality of H. convergens and 98 percent of C. maculata adults (Harries and Valcarce, 1955).

TEPP.

Extremely high toxicity of TEPP to lady beetles has been reported by Yothers and Carlson (1948), Ripper et al. (1950), Michelbacher and Middlekauff (1950), and Bartlett (1953). One advantage of TEPP, however, is the lack of any residual effect. Bartlett (1953) demonstrated that 1-day old residues of TEPP produced no mortality.

Malathion.

Very little information is available to evaluate malathion. Harries and Valcarce (1955) were the only authors who tested the material against lady beetles. A 5 percent dust produced 90 and 100 percent mortality after one day exposures of H. convergens and C. maculata, respectively.

Other Organic Phosphates.

Harries and Valcarce (1955) found that Diazinon and Chlorthion were equal in toxicity to parathion and malathion. Complete kill of lady beetles (*H. convergens* and *C. maculata*) resulted after short exposures.

General Comments.

All evidence points to the extremely high toxicity of the phosphates to lady beetles. Mortality is more rapid and more readily produced by direct application of the insecticides. However, the residual effect is less than with the chlorinated hydrocarbons. In consideration of the number of individual lady beetles exposed over the extended periods which orchards are treated, the phosphates may be less deleterious overall than the long-lasting residues of DDT and related materials.

ACARICIDES

Aramite.

Rosenstiel (1950) reported that Aramite

"appears to kill and disrupt" predators, including *Stethorus*. However, his only basis for the observation was the negative correlation between the predator and the treatment. Since Aramite effectively depleted the food source of mites, it is likely that *Stethorus*, even as larvae, either sought prey elsewhere or starved. Bartlett (1953) exposed *Lindorus lophanthae* to 1-day-old residues of Aramite and obtained less than 50 percent mortality after 100 hours. He stated on the basis of his work that Aramite was practically non-toxic to this insect.

Neotran.

DeBach and Bartlett (1951) showed conclusively that Neotran (Dow K-1875) caused a reduction of coccinellid larvae (*Stethorus*) by eliminating the mite prey. Where mites increased sharply following DDT sprays, *Stethorus* increased 208 percent over pre-spray counts. When Neotran was applied and reduced the mite population, there was an 88 percent decrease of *Stethorus* in one plot and 100 percent reduction in another.

Bartlett (1953) showed that Neotran was non-toxic to *L. lophanthae* as 1-day old residue.

Ovex.

Only one reference was found which included the effect of ovex on coccinellids. No toxicity from exposure to residues of a spray containing 1.5 pounds of 50 percent wettable powder per 100 gallons of water was obtained by Bartlett (1953).

SYSTEMIC INSECTICIDES.

Ripper and his associates were the first to conduct detailed studies with systemic insecticides and their relation to biological control. Ripper (1944) suggested that non-systemic insecticides contribute to the buildup of resistance in insect pests when they kill natural enemies because those resistant pest individuals which survive are not eliminated by natural control. He reasoned that the selective insecticides which kill only the pest species would result in nearly perfect control because natural enemies are not killed and would outnumber the prey following treatment.

It has been shown that schradan did not kill C. septempunctata or A. bipunctata, even when these species had been fed aphids which were moribund from feeding on treated plants (Ripper et al., 1949, 1951, and Kelley, 1951).

The lack of deleterious effect is not characteristic of demeton, however. Ahmed et al. (1954) and Ahmed (1955) obtained moderate to high mortality of Scymus spp. and Cycloneda sanguinea larvae which fed on aphids killed with demeton.

Ahmed et al. (1954) used isotope-tagged demeton to trace its distribution from the plant through the aphids to the coccinellids. H. convergens larvae which survived treatment were found less radioactive than larvae which died, when both were fed in the same manner for the same period of time. It was suggested that demeton accumulates in the body since dead larvae had much higher radioactivity. It was not apparent from the data presented, whether or not both groups of larvae actually consumed equal numbers of aphids, however.

Schradan was compared with demeton by Ahmed (1955). Schradan produced no mortality, whereas demeton was extremely toxic when direct applications were made on coccinellids. When the lady beetles were not treated directly but fed aphids killed by feeding on treated plants, schradan produced little mortality while demeton produced moderate toxicity of the 11-spotted lady beetle and Scymnus syriacus Mars. It is evident that the effect of systemic insecticides upon coccinellids depends on the type of treatment. Considerable work still needs to be done with systemics, although the results so far are promising. It appears that it might be possible to devise chemical control measures which will utilize rather than destroy important predators.

FUNGICIDES.

Bordeaux mixture has been reported to be only slightly or non-toxic to coccinellids (Haug and Peterson, 1938; MacPhee and Sanford, 1954, 1956;

and Bartlett, 1953). Some reduction of Stethorus populations by sulfur and Phygon has been reported by Bartlett (1953) and MacPhee and Sanford (1954 and 1956). Studies in Nova Scotia have shown that ferbam has no ill effect on Stethorus (MacPhee and Sanford, 1954, 1956). In a general review of pesticides upon beneficial arthropods, MacPhee and Sanford (1956) indicated that no information was obtained with captan, glyodin, Phygon and lime sulfur as they affect Stethorus. Lime sulfur was reported as deleterious to some beneficial insects, but not to the lady beetle, L. lophanthae when it was exposed to 1-day-old residues by Bartlett (1953). He found, however, that wettable sulfur did cause a 50 percent reduction in numbers of that species when tested as a 1-day old residue. It had been applied at the rate of 4 pounds per 100 gallons of water. MacPhee and Sanford (1956) also reported reduction of S. punctillum exposed to wettable sulfur.

It is evident that little is known how fungicides influence coccinellids directly or indirectly. Indications point to only a slight, if any, deleterious effect.

A REVIEW OF THE LITERATURE PERTAINING TO REARING, LABORATORY TESTING, AND FIELD STUDIES WITH APHID AND MITE EATING COCCINELLIDAE.

Standard procedures for the studyof phytophagous insects are not well-adapted to predacious forms. Predator abundance depends on the occurrence and quantity of prey species and a source of sufficient host plant material, rather than the latter only as in the case of plant feeders. Lord (1956) has stated that there is no rapid and accurate method for measuring predator populations in the field, but that a rough estimate can be obtained by certain techniques. Thus the special techniques which have been developed by others are reviewed here as follows: 1) rearing; 2) methods for exposing coccinellids to pesticides in the laboratory; 3) methods of estimating field populations of prey and predators; and 4) methods for studying the efficacy of beneficial insects.

Rearing.

Culture methods for insects in general have been reviewed by Galtsoff *et al*. (1937). Flanders (1949) published a paper titled "Culture of Entomophagous Insects" but included very little on the more common lady beetle species which are found in Massachusetts.

Some detailed work has been done on rearing, especially with species not directly considered in this paper. Branigan (1916) developed rearing techniques for coccidophagous lady beetles by mass producing mealybugs on potato sprouts. Smith and Armitage (1931) reared mass cultures of *Cryptolaemus montrouzieri*. Sellers and Robinson (1950) produced large quantities of several coccinellid predators of a diaspine scale for shipment to Bermuda. Dunn (1952) reared coccinellids on the pea aphid to study the effect of temperature on feeding habits.

Rearing of coccinellid species to which these studies pertain has been difficult and usually unsuccessful. Clausen (1915) reported the problem of water condensation and beetles crawling to the top of lantern globe cages in which aphid-infested plants were maintained. Way (1949) experienced the same difficulty and noted, as did Flanders (1949) that cannibalism among the larvae was a major problem. Burgess (1903) and others have reported that _A_. _bipunctata_ feeds on its own eggs, even when ample prey were present. Haug and Peterson (1938) lost one-third of the eggs from feeding by newly hatched larvae of the same egg cluster, although the culture dishes were examined every 3 to 4 hours during the day and every 6 hours at night. After hatching they had a loss of 12 percent from cannibalism among the larvae.

In all instances where lady beetles were reared successfully (Haug and Peterson, 1938; Bartlett, 1953; Ahmed _et_ _al_., 1954, Ahmed, 1955; and Putman, 1955), rather elaborate methods, materials, and facilities were utilized. Where such were not available field-populations were used. DeBach (1946), Way (1949), Campbell and Hutchins (1952), and Harries and Valcarce (1955) relied entirely upon field-collected specimens. Haug and Peterson (1938) also used large numbers of adult beetles obtained from California via the mails in addition to those reared.

METHODS FOR EXPOSING COCCINELLIDS TO PESTICIDES IN THE LABORATORY.

Haug and Peterson (1938) first designed methods and techniques to determine the effect of pesticides on lady beetles, using Hippodamia convergens. Most of these tests involved spraying the lady beetles directly with a number of standard insecticides commonly used in field pest control practices. Adult beetles were obtained from California. These and reared immatures were fed with bean aphids cultured on nasturtium plants.

Three types of cages were devised in which to treat Hippodamia convergens. Most of the treatments were applied to adults in conical, paraffined, wire cages enclosing potted nasturtium plants infested with the bean aphid. In other tests either flat, rectangular, wire cages or wire covered

Petri dishes were employed. Treatments of adults were carried out in several ways: in cages of the first type; the beetles remained in contact with the spray materials following spraying; in other cages beetles were sprayed, then removed to clean containers; and in some tests beetles were sprayed with water prior to sprays of chemicals to provide a predrinking period. Eggs were sprayed in clusters on Spirea leaves and placed in moistened pans under one-half a Petri dish. Observations were made every 3 to 4 hours during the day and 6 hours at night when the eggs began to hatch. Even under such stringent observation, 12 percent loss was recorded. Larvae were sprayed in groups placed in Petri dishes. Results were recorded as dead, moribund, and live individuals which were expressed as percent mortality according to Abbott's formula (Abbott, 1925).

Way (1949) treated Coccinella septempunctata in three ways; namely, spraying, dusting, and exposure to residues. Adults were sprayed or dusted and then placed in 18" x 18" x 12" cages on cabbage plants similarly treated. DDT and BHC were the only materials which he used. Insecticide residues were obtained by treating Petri dishes containing a Whatman No. 1 filter paper with 4 cc. of spray or known weights of dust. Then dry insects were exposed in the dishes for 4 to 6 days. Daily observations were made and the number of dead beetles recorded. The percent dead at the end of the test period was determined. The major difficulty in the tests was the tendency of the beetles to crawl to the cage and remain there. Some tests were conducted with the egg stage. Eggs on bean leaves were sprayed or dusted, the leaves were placed in vials. Results were vague because many eggs were eaten and larvae which died shriveled and could not be found. Larval tests were attempted unsuccessfully.

Davis (1952) exposed Stethorus picipes adult to DDT residues obtained by dissolving the DDT in acetone placed in Petri dishes. Following the evaporation of the acetone, beetles were exposed. He also utilized the method of dipping leaves in suspensions and emulsions to obtain residues.

Bartlett (1953) devised an elaborate method for exposing Lindorus lopanthae and other natural enemies to pesticides. Using modified Munger cells (Munger, 1942; Huffaker, 1948; Bartlett, 1951) standard field spray and dust applications were tested. Leaves treated with field equipment were placed in 100 Munger cells with atmospheres maintained at 80°F. and 50 percent humidity. Ten beetles were inactivated with ether and placed in cells. The process was replicated 5 times. Toxicity was recorded as the number of hours required to give 50 percent kill. Tests were conducted for 100 hours.

Ahmed et al. (1954) and Ahmed (1955) developed a procedure for killing aphids, with systemic insecticides (demeton and schradan), tagged with a radioactive tracer, which were fed to lady beetles. Five species including H. convergens were used. Largely first instar larvae and adults were tested. Results were recorded as percent dead over a 4 to 7 day period. Cotton plants and the cotton aphid were used as host plants and prey. In order to avoid the problem of lady beetles leaving the plants or treated prey, the cages were covered with dark paper.

PROCEDURE FOR DETERMINING ABUNDANCE OF MITE PREY.

Extensive techniques have been developed for obtaining indices of mite abundance.

Microscopic examination of orchard leaf samples long has been standard practice in measuring mite population. A tremendous volume of literature exists on control of mites most of which deal in part with sampling methods. Only those methods used in predator studies will be reviewed here, with a few exceptions.

Morgan et al. (1955) have reviewed methods for estimating orchard mite populations. They have presented an excellent discussion of all methods which have been applied and are listed below:

A. Direct methods

1) Counting mites on entire leaves
2) Delineation of small circular count areas on leaves
3) Use of mask with standard area-observation window
4) Visual examination of trees for webbing and damage
5) Siegler (1947) and Reynolds *et al*. (1952) devised a leaf-disk technique.

B. Indirect methods

1) Paper-impression procedure
   Leaves are placed on white mimeograph paper and run through a mangle (wringer). The impressions of crushed mites and eggs are preserved for semi-permanent record
2) Solution removal and aliquoting
   Jones and Prendergast (1937) suggested this method and it was subsequently

modified by Newell (1947). Mites were washed off leaves and maintained in vials. When the counting was done, the sample was diluted, agitated, and a standard amount was drawn off. The aliquot was placed on filter paper and the mites counted

3) Jarring twigs and foliage
Mites were collected in pans or funnels held beneath twigs and foliage which were jarred to knock individuals into the collecting devices. Boudreau (1953) also has described the technique.

4) The method now used most widely and generally accepted as best is the mite-brushing machine developed by Henderson and McBurnie (1943) and manufactured by H. Gearing in California (see figure 4). Two contra-rotating brushes are driven at high speed by a small electric motor. As leaves or other materials are moved

through the brushes, all stages and loose material on the leaves are brushed downward onto a revolving adhesive-coated glass plate. A pair of curved metal slides between the brushes and the plate prevent the mites from being thrown outside of the area occupied by the glass plate. Remarkably little, if any, injury occurs to mites in any stages in spite of the apparent rough handling. The high speed of the soft brushes prevents mangling of the mites. Morgan et al. (1955) have given a very detailed analysis of the use of the machine, illustrating counting discs, and the reliability of the apparatus by means of charts.

Other workers who have described methods for determining the abundance of mites include Clancy and Pollard (1948), Chapman and Lienk (1950), Asquith and Kane (1952), Boyce (1952), Clancy and Pollard (1952) and Summers and Baker (1952).

A unique method for making counts on large shade trees was to knock down sample leaves from elm trees with a specially constructed sling shot which propelled 20 to 30 gram stones. Thirty-two whole leaves were taken per tree at weekly intervals throughout the season.

Most mite population estimates have been based upon 50 to 100 leaves per treatment. Dean (1950), Chapman and Lienk (1950), and Clancy and Pollard (1948, 1952) used 25 leaves per tree and a total of four trees per treatment. Asquith and Kane (1952) took 50 leaves from inside the tree and 50 from the periphery on each of two trees in the center of a 4 by 4 tree block. Sampling by most workers has been at biweekly intervals throughout the growing season (Clancy and Pollard, 1948, 1952; Woglum et al., 1947; DeBach et al., 1950a; Cutright, 1951; Pickett and Patterson, 1953; MacPhee and Sanford, 1954; Lord, 1956; and others).

Most investigations have been conducted in orchards in production receiving regular spray schedules. The Canadian workers (Pickett, Lord, MacPhee and others) have worked also with abandoned and neglected orchards to compare prey as well as predator abundance.

PROCEDURE FOR DETERMINING ABUNDANCE OF APHID PREY.

Techniques for estimating the abundance of aphids have been studied more on vegetable and field crops than on fruit or ornamentals. Sweeping has been used to the greatest extent, particularly in cotton investigations (Hill, 1945; Newson and Smith, 1949; Campbell and Hutchins, 1952; Glick and Lattimore, 1954; and Gaines, 1954 and 1955). Smith and Fontenot (1942) counted the number of aphids on measured leaf areas and gave the abundance in aphids per square inch of leaf. Banks (1956) estimated the abundance on 12 bean plants in each row of his plots.

Leaf samples were used by Kelley (1951), Ripper _et al_. (1951) and Gaines (1954, 1955). Considerable work has been done on aphid sample methods in virus disease research. That subject has not been reviewed. However, some notations were made. Broadbent (1948) found that an estimate of the number of aphids per plant and the proportion of infested plants was more indicative of infestation than the number of aphids per 100 leaves. Bradley (1952) also found the 100 leaf sample method unreliable. He pointed out that *Myzus persicae* and *M. abbreviata* inhabited the bottom leaves whereas *M. solanifolii* more commonly was found on the upper leaves. It is evident that careful observation of species habits is necessary to obtain reliable methods for determining relative abundance estimates of aphids.

Yothers and Carlson (1948) estimated aphid abundance on fruit trees by recording the number of infested terminals per block of peach trees in a sample of 900 terminals. Schread (1954) working with *Aphis pomi* on hawthorn used the average number of aphids per 10 leaves.

Generally, methods for estimating aphid

abundance have not been refined and little work has been done, at least in predator studies, to determine levels of aphid infestation. Few correlation procedures have been developed.

METHODS FOR ESTIMATING THE ABUNDANCE OF COCCINELLIDS.

The various methods which have been used to sample prey populations have not been adequate for determining the relative abundance of predators (DeBach et al., 1950a; Huffaker and Spitzer, 1950; English and Tinker, 1954; Putman, 1955; Lord, 1956; and others). Several separate procedures have been developed ranging from a simple negative correlation of predators with sprays (Ripper et al., 1949) to more elaborate methods for determining the efficacy of predators as well as their densities. A number of authors, including Michelbacher and Swanson (1945) and Ripper (1951) published results of predator determinations with little indication of the methods used.

In low-growing crop studies, sweeping with an insect net has been used most extensively. Hill (1945) used 350 sweeps per plot of potatoes and recorded the total number of coccinellids observed. Newson and Smith (1949) made 50 - 100 sweeps per plot of cotton on the day treatments were to be applied, carrying out such procedure over a period which included 4 to 8 treatments. The observations were averaged to present the relative abundance of coccinellids in the various treatment plots. Campbell and Hutchins (1952), in more extensive investigations on cotton, took 100 sweeps per plot also, but before, as well as 24 and 48 hours after treatment. Large plots were used, measuring 40 rows of which each was 200 yards in length. Also on cotton, Glick and Lattimore (1954) made 100 sweeps per 2 to 20 acre plots. They confined the sweeping to an area centrally located in each plot. Observations were taken before, directly after, and at weekly intervals following treatment. In other cotton investigations, van den Bosch et al. (1956) recorded the number of adult and larval coccinellids per 450 sweeps, using one full row for counting.

Examination of foliage with the microscope or other means has been utilized for immature coccinellidae and other smaller predators which are relatively inactive such as mites and thrips. DeBach (1947) took 100 leaf samples per plot and determined the total number of predators. Huffaker and Spitzer (1950) began in 1948 using 25 leaves to sample mites in each plot. Later, 200 leaves per plot were examined in the field to determine the number of Stethorus adults and larvae. Rosenstiel (1950) obtained predator counts when he examined leaf samples to obtain the relative numbers of mites on raspberry plants. He determined only the relative abundance of Stethorus larvae as a result, since adults drop from leaves when disturbed. MacPhee (1953) and MacPhee and Sanford (1954) examined foliage in the field and recorded predators as the number per group of leaves. Counts were supported with timed visual inspection to determine adult abundance. Putman (1955) in detailed studies on the biology of Stethorus punctillum Weise, made field counts of larvae every two weeks by selecting 6 leaves per tree in 100 tree blocks except those in outer rows. The leaves were swept with a brushing machine. He used timed visual-inspection and jarring techniques to estimate adult abundance. English and Tinker (1954) had a unique method for sampling mites on tall elms. They shot leaves down from tall elms with a specially constructed slingshot, and noted that few Stethorus were observed. Since it is known that jarring dislodges Stethorus (MacPhee and Sanford, 1954; Putman, 1955; Lord, 1956) it is not surprising that English and Tinker observed very few Stethorus beetles.

Yothers and Carlson (1948) described a technique for estimating aphidophagous coccinellid populations. Following a visual inspection of 900 peach terminals for aphids, a single large branch on each of 10 trees per plot was examined and the total number of beetles was recorded. In reviewing the literature no other detailed description was found of methods for estimating populations of aphid-eating lady beetles on fruit trees.

Several workers have taken advantage of the tendency of Stethorus to drop from plants when disturbed. MacPhee (1953) and MacPhee and Sanford (1954) used a cloth covered tray held beneath branches which were jarred with a stick. Putman (1955) improved on the jarring method when confronted with the problem of dislodging fruit. He used a broom which he brushed lightly over the branch. He noted that the jarring technique was reliable only when the trees were dry, the wind was very light, and the temperature was relatively low. Above 21 degrees C. he found that the beetles flew as they dropped.

A widely used, and perhaps the most representative method for estimating mite predators is the timed visual-inspection technique. DeBach (1950) gives the most detailed description of the technique. Leaves, twigs, and fruit on each plot tree were scanned thoroughly for 5 minutes without disturbing the tree. If more than one individual made observations, each scanned a part of every tree so that the total period of observation equaled 5 minutes per tree. All Stethorus larvae, pupae, adults, and exuviae were recorded, as was the presence or absence of other predators. Clancy and Pollard (1948 and 1952) employed the same technique, but used a 6 minute's observation on each of 10 trees per plot. The same technique was followed by MacPhee and Sanford (1954) and MacPhee (1953). Yothers and Carlson were the only workers found to use this technique for aphidophagous coccinellids. Each observer recorded the number of beetles found in a 5 minute period.

A special technique was devised by Collyer (1951), and used by MacPhee (1953) to sample predators. Collyer (1951) enveloped trees in a cloud of mist by atomizing 0.3 percent pyrethrum in oil from 6 applicators placed beneath the trees. Insects present in the trees were collected on the ground cloth 12 feet square which had a trunk collar and a 9 inch high border on the edge. Screens were placed around the trees. MacPhee (1953) collected specimens in inverted paper cones suspended under the trees when he dusted apple trees with a DDT (6 percent), derris (10 percent), and pyrethrum (30-40 percent mixture.

METHODS OF STUDYING THE EFFICACY OF BENEFICIAL INSECTS.

Considerable study has been made, especially in California, of the efficacy of natural enemies. Predators are particularly difficult to sample effectively because interactions are difficult if not impossible to measure between components in one ecological area. Although progress has been slow in investigations of the indirect effects of pesticides on the effectiveness of predators, several methods have been devised to study the population dynamics of prey in the absence of predators.

Smith and DeBach (1942) pointed out that standard practices of comparing treated plots with non-treated checks was not suitable for studying certain aspects of biological control because natural enemies invaded check plots. They devised a "sleeve-cage method" whereby open and closed cages on branches permitted an indication of the effectiveness of predators in relation to areas where they were excluded. DeBach (1946a) called attention to an early paper by Smith (in Trans. Intern. Cong. Ent. II, 1929) which suggested natural enemies could be eliminated by arsenicals. DeBach devised an "insecticidal check method" where plots treated with an insecticide (DDT) toxic to natural enemies but not the prey were used as checks. The increase of prey in the absence of predators could be evaluated. Later DeBach _et al_. (1949) excluded predators by treating organdy sleeve-cages with DDT.

DeBach _et al_. (1950) suggested still another method for evaluating the effectiveness of predators. By using the Argentine ant, _Iridomyrmex humilis_ Mayr to ward off predators including _Lindorus_ sp. and _Chilocorus_ sp., he could determine the development of aphids in the absence of predators. Plots supporting predators gave relative measures of their effectiveness of maintaining low aphid populations.

The antagonistic tendencies of ants has been known for a long time. Flanders (1951) has given an excellent review of many papers on the subject of the role of ants as biological control.

In spite of many elaborate methods of studying the relationship between prey, predators, and pesticides, standard methods of entomological investigation seem inadequate for a full understanding of interactions between related and unrelated fauna. Perhaps the most extensive and successful approach has been that of Canadian workers who have contributed to a study of the influence of spray programs on the fauna of apple orchards in Nova Scotia since 1943 (Pickett et al., 1946; 1947; Lord, 1947, 1949; Pickett, 1949; Pickett and Patterson, 1953; MacPhee and Sanford, 1954; MacPhee, 1953; and Lord, 1956). The studies have included all faunal types, large acreages, varied types of environments, and extended periods of time (now in the 16th year). Pickett and Patterson (1953) commented, "The practical results summarized in this paper show not only that the studies have modified spray practices in the Annapolis Valley, but also that the spray practices in turn are having an influence on the trends of the study." At present great emphasis is being placed by most workers on ecological studies and population dynamics as evidenced by the review of Ripper (1956). Among many who have contributed to a detailed understanding of the factors involved in population dynamics are Clausen (1936, 1951, 1954 and 1958), Collyer (1949, 1951, 1952 and 1953, a, b, c), DeBach (1947), DeBach and Bartlett (1951), Morris (1957), Nicholson (1956 and 1958), Pickett and Patterson (1953), Ripper (1944, 1956), Ross (1952), Sellers (1953), Simmonds (1956), Solomon (1949), Taylor (1955), and Thompson (1929, 1951, 1955, and 1956).

METHODS AND PROCEDURES OF INVESTIGATION

In June of 1951, exploratory studies were initiated in the field and library to determine which phase of the broadly outlined project could be investigated most profitably. The major group selected for study were the lady beetles, or Coccinellidae, which prey on aphids and mites, on the basis of the following considerations.

Lady beetles were found to be common and widely distributed in Massachusetts. Among other predators, only syrphid larvae were numerous enough to compare with coccinellids. Lacewing flies, thrips, mites, and leatherwing beetles were observed occasionally. Parasites were remarkably scarce.

Adults and larvae are predacious on the same prey. Both are important in consuming large numbers of aphids and mites and are usually found in close association with each other, whereas most other predators are not (Balduf, 1936). Syrphid and lacewing flies are also important predators of aphids, but adults are present only for oviposition.

The bright colors and relatively large size make most lady beetles conspicuous in the field. The dark color of the much smaller Stethorus beetles provide sufficient contrast to compensate for their minuteness.

Coccinellid adults are robust, hardy, and handled freely without apparent harm. They were stored at low temperatures for up to three weeks and longer, yet responded the same in tests as those not exposed to refrigeration. The beetles ate normally and laid eggs after storage periods, but studies were not conducted on longevity or oviposition.

The long life-span of 20 to 30 days for larvae and 30 to 40 days for adults (Balduf, 1936) provided a satisfactory period of potential exposure in which the effects of the sprays could be determined. Seasonal population studies in areas such as orchards which received planned spray programs through most of the spring and summer could be carried out effectively.

Coccinellids, while feeding and ovipositing, are not prone to flight or "death-feigning" unless disturbed by contact. A great many insects are more active and fly away at even slight disturbances. Where sufficient prey were available, adult lady beetles were observed to remain in the same limited area for several days or more and were counted without difficulty. When handled for laboratory purposes, the adults usually crawled and very seldom attempted to fly. The strong ability to fly in search of prey, however, was useful in field studies, since the beetles migrated in and out of test plots naturally.

Cannibalism is generally a disadvantage, especially with the larvae and with adults consuming eggs of their own species. However, adults were not observed to feed on each other and thus were easily handled for laboratory tests in replicated groups. It was for this reason that most results in these studies pertain to the adult stage.

INVESTIGATIONS IN THE LABORATORY.

Various species of coccinellids were exposed to residues of commonly-used pesticides. Residues were prepared to approximate those which could be expected to be found in the field. Some biological studies were also included to provide general background knowledge of the predators involved. Attempts to rear sufficient numbers of specimens for tests were not successful.

SPECIES OF COCCINELLIDAE USED IN TESTS.

The following species were used in extensive test series:

1) *Adalia bipunctata* (L.), the two-spotted lady beetle
2) *Coccinella transversoguttata* Fald., the transverse lady beetle
3) *Hippodamia convergens* G. - M., the convergent lady beetle

The following were used in limited tests:

1) *Anatis 15-punctata* Oliv., the 15-spotted lady beetle

2) Coccinella 9-notata Herbst, the 9-spotted lady beetle

3) Hippodamia 13-punctata L., the 13-spotted lady beetle

4) Stethorus punctillum Weise (no approved common name)

SOURCES OF COCCINELLIDS FOR LABORATORY WORK.

Three sources provided sufficient numbers of individuals for laboratory tests; naturally-occurring field populations; colonies of hibernating adults; and shipments from California. Sources of each species used are discussed below.

The two-spotted lady beetle.

The largest group of this species was found in hibernation in the "Mountain House" atop Mt. Holyoke in South Hadley, Mass. In early spring several hundred adults were collected with an aspirator as they crawled about on the inside of the windows. Some beetles were also obtained in houses around window casings both in the fall and in the spring.

The most extensive field populations of the two-spotted lady beetle were found on aphid-infested apple (Malus sp.), spirea (Spirea vanhouttei), horse nettle (Solanum carolinense), and Norway maple (Acer plantanoides). Very few individuals of this species were found on low-growing vegetable crops, corn, or other herbaceous plants.

The Transverse Lady Beetle.

This was the most common species found on lettuce, broccoli, cabbage, and melons. Since broccoli and lettuce were grown for plant breeding experiments, they remained in the field for extended periods of time and were not treated for insect control, except occasionally for extreme infestations. Large numbers of beetles were obtained from these sources.

No hibernating adults were found during these studies. Balduf (1936) cited many reports of massed hibernation at high altitudes in other parts of the world. Apparently they overwinter as adults in Massachusetts also.

<u>The convergent lady beetle</u>.

This species was less abundant than the two preceding species, but more widely distributed on all types of aphid-infested vegetation. Sufficient numbers for tests were obtained only in shipment from California. In 1953, L. W. Higgins of Dobbins, California sent several thousand beetles via parcel post. They were shipped in a cardboard carton with 15 large pine cones to provide crawl space and a wire screen cover for aeration. Upon receipt, they were placed in a cold room at about 40 to 45 degrees Fahrenheit, and used within a two-month period after arrival. Many beetles remained alive from July until the following June.

<u>Other Species</u>.

<u>Anatis</u> <u>15-punctata</u> was found in very small numbers on trees, shrubs, and rarely on vegetable crops. One sizeable population occurred in South Amherst, Mass. in 1951 among birch aphids (probably

Calaphis betulaecolena (Mon.)). Adults were used for one test.

C. 9-notata and H. 13-punctata were moderately abundant on cucurbits, lettuce, broccoli, and cabbage, and were incorporated in a few tests only.

Ceratomegilla fuscilabris Muls., the spotted lady beetle is mentioned here to indicate its relative abundance, although it was not used in laboratory tests. This species was very common and more abundant than other species on corn, sudan grass, and rye grass infested with aphids. It was found only occasionally on other plants. One very large colony of hibernating adults was collected on the University of Massachusetts campus.

LABORATORY REARING.

Many attempts were made to rear local endemic species of lady beetles; Adalis bipunctata, Coccinella transversoguttata, Hippodamia convergens, and Stethorus punctillum, on their natural host prey. Cages used were: individual plastic specimen boxes, gauze-covered lamp chimneys, battery jars, screen cages approximately 1' by 1' by 2', a cheesecloth cage approximately 8' by 2.5' by 3' completely covering a greenhouse bench, and an entire greenhouse compartment. Field plots were also used to culture plants, aphids, and subsequent lady beetle populations.

Although some success was obtained in rearing aphids for prey, it was difficult to maintain the colonies long enough to rear coccinellids. Several other difficulties were experienced also.

During the summer months daily maxima of 114 degrees F. or higher were not uncommon. The plant grew satisfactorily and in most cases the prey colonies did also. Lady beetles were extremely active and neither reproduced nor remained on the plants. Clausen (1915) and Way (1949) were unable to produce coccinellids because of similar difficulties with high temperatures.

Coordinating the proper condition of the plant to support aphids, the development of prey colonies, and the introduction of lady beetle predators was one of the more difficult problems. It was not accomplished with woody plants.

The two most difficult problems were trying to keep beetles on the plants and cannibalism. No solution was found to prevent beetles from crawling on the cage and remaining there. Cannibalism at the time of hatch was very destructive. Soon after the first larvae hatched, they began feeding on unhatched eggs and also on each other. Adults also fed on egg clusters occasionally, as well as on larvae.

Moderate numbers of eggs and larvae of the two-spotted lady beetle were obtained by placing field-collected adults on aphid-infested apple sprouts in the laboratory. Egg clusters were placed in separate cages. As larvae hatched, they were placed individually in plastic specimen boxes with a supply of green apple aphids. The process required continual attention and a great amount of time in proportion to the number of individuals obtained. Losses of individually caged larvae were frequent, in spite of aphid food which was supplied.

Small numbers of Stethorus punctillum were reared to study the developmental stages. Procedures were too time-consuming and unproductive to provide numbers of beetles for insecticide tests. Some interesting observations were obtained from rearing attempts, however.

In one attempt to produce large numbers of Stethorus, waxed beans were planted in the greenhouse and infested with the two-spotted mite. At the peak of the mite population, large numbers of Stethorus migrated to the beans from mite-infested arborvitae near the greenhouse. Reproduction and development of the lady beetles were anticipated. About 10 days later there were no larvae in spite of the deposition of eggs and active feeding of adults. Some of the bean leaves were taken to the laboratory for observation under the microscope. Larvae of Stethorus taken from apple leaves became impaled on the trichomes when placed on the bean leaves and subsequently died. Other workers have published similar observations (Abraham, 1938; McKinney, 1938; deFluiter and

Ankersmit, 1948; Armstrong, 1950; and Johnson, 1953). Armstrong, suggested using Scarlet Runner, a less pubescent variety of bean, but Putman (1955) found that it also had trichomes which were unsuitable for rearing *Stethorus*. However, he used the variety to rear mites which he transferred to peach leaves for biological studies with *Stethorus*.

COLLECTION AND STORAGE OF COCCINELLIDS

Beetles were collected easily by forcing them to drop from the plant into screw-top pint jars. The beetles' natural habit of "death-feigning" and dropping from foliage when disturbed facilitated rapid collection of large numbers. The jars were provided with one or two absorbent tissues to prevent water of condensation and to give an abundance of surface area over which the beetles could crawl. The beetles exhibited a very strong tendency to crawl upward and were maintained away from the mouth of the jar by inverting it except for short periods when more adults were being added. From 25 to 35 beetles were held in each bottle. As each jar was filled it was placed in the shade. The beetles were then stored in a walk-in refrigerator at 40 to 45 degrees F. without being removed from collecting bottles.

Sthethorus adults were more evasive and tended to escape from collecting jars. They did not so consistently crawl upward. An aspirator with a 10 inch tube about 1/4 inch in diameter was found suitable for collecting these beetles from the undersides of apple, willow, and arborvitae foliage. Stethorus beetles were stored at cold temperatures at first, but since they did not survive satisfactorily, tests were run only with non-stored beetles.

HANDLING BEETLES FOR TESTS.

Beetles were transferred from the collection jars to test cages in the walk-in refrigerator. Beetle activity was greatly reduced by the low temperature. They were taken out of the jars, placed on cheesecloth stretched over a square frame. Those beetles which crawled around slowly without difficulty were then picked up with an aspirator and placed into treated half-pint test cages. Beetles resumed normal activity within 10 minutes of removal from cold storage. Cages were placed in an 80 degree F. temperature cabinet and observed for periods of 3 to 10 days.

In the majority of the tests the beetles were not fed during the period of exposure. The introduction of aphids with or without the plant host material was undesirable from the viewpoint of uniformity in feeding and apparently unnecessary from the viewpoint of beetle livelihood. Tests usually ran up to 5 or 7 days.

Counts were made each day of adults which were alive, dead, and moribund. The reactions of the beetles to the various treatments were noted. Beetles suffering moderately from pesticides had difficulty in righting their position. Unaffected beetles consistently and quickly regained a walking position if they were jarred onto their backs.

Adults were recorded as dead when the legs no longer moved.

TYPES OF CAGES AND METHODS OF EXPOSING BEETLES TO CHEMICALS.

Most workers have used methods in which lady beetles were confined with sprayed foliage. To determine whether this method would be satisfactory or not, sprayed apple foliage was placed in round, half-pint pasteboard cages with lady beetles. Table 4 shows that only twice during the 5-day period were there more than half the beetles on the leaves. On treated leaves the average number observed on the leaves was lower in all treatments than the untreated samples. The low and variable mortalities in the treatments apparently are due to lack of uniformity in contact with residues. Therefore, this method is unsatisfactory for testing series of pesticide residues.

By trial the half-pint ice-cream carton was selected as the best spray cage. Uniform coverage was obtained by opening the container, spraying both the top and the bottom on the inner surface, and reassembling it to provide a completely treated

Table 4. Observations of contact with treated foliage and resultant mortality of 15-spotted lady beetle adults in toxicity tests with three concentrations of DDT.

Lbs. 50W DDT/100 Gal.	No. days after treatment				
	1	3	4	5	Ave.
	No. beetles on foliage*				
None	8	5	8	8	7.25
0.5	7	5	7	5	6.00
1.0	6	5	4	3	4.50
2.0	7	7	4	5	5.50
	Percent mortality*				
None	0.0	0.0	0.0	0.0	
0.5	0.0	0.0	13.3	6.7	
1.0	0.0	6.7	13.3	13.3	
2.0	0.0	6.7	40.0	40.0	

*Based on 15 beetles per treatment.

surface on which the beetles were forced to remain.

In all tests, three replicates were used per treatment. Depending on the number available, from 5 to 10 beetles were placed in each replicated cage.

To determine if closed cartons produced toxic effects by vaporization, 15-spotted lady beetle adults were confined in wire screen cages inside of DDT-treated cages so that no contact with treated surfaces was possible. No mortality resulted in those cages where the beetles were not exposed to the residue.

LABORATORY SPRAY EQUIPMENT AND METHODS OF TREATING CAGES.

The sprayer was permanently mounted in the laboratory and consisted of a nozzle head connected to an air pressure line which maintained approximately 12 p.s.i. An off-on lever controlled the flow of air which drew the spray material from a battery jar and propelled it through the nozzle which was made to deliver 66 ml. per minute. The sprayer is illustrated in Fig. 1.

FIGURE 1.

Laboratory sprayer used for applying residues to cages.

To determine spray distribution on the cages visually, water sprays of India ink were used. Test cages were held at various distances from the nozzle and for varying lengths of time. The best coverage was obtained when the cages were held approximately 12-15 inches from the nozzle for about 5 seconds. Boxes were held by hand and the time was measured by oral count. Every effort was made to make the motions as uniform as possible. The deposit obtained with the ink spray is illustrated in Fig. 2. In a few tests the boxes were placed on a turntable while they were being treated. Direct spraying of caged adults was done with this device.

Residues of pesticides were obtained by mixing sufficient amounts of wettable powder formulations to make 1 gallon of spray. The dry concentrate was weighed out on a balance accurate to 0,05 gram. One gallon quantities of spray were mixed in order to minimize the effects of slight variations in handling small amounts of chemicals. During spraying, the suspension was agitated before and continuously

Test cage

unsprayed

sprayed
with India ink

FIGURE 2

Half-pint pasteboard carton (upper photo) used for test cages and coverage obtained with the laboratory sprayer as shown by India ink sprays.

during the spraying operation.

Following spraying of replicates for each treatment, the battery jar was rinsed thoroughly with clean water, scrubbed and rinsed three times more. No soap or other detergent was used. The sprayer was then cleared with clean water for about a minute. With a new material, the sprayer was run for 20 to 30 seconds before the cages were treated. After treatment, cages were removed to another room and left open to dry for 3 to 4 hours. Insects were not introduced for at least one full day.

PESTICIDAL CHEMICALS AND FORMULATIONS USED IN TESTS.

Chemicals included chlorinated hydrocarbons reputedly non-toxic or of low toxicity to mites and aphids, organic phosphates which exhibit high toxicity to a wide range of various arthropods, and miscellaneous compounds with either acaricidal or fungicidal properties. They are listed in Table 5.

TABLE 5. Pesticides used for laboratory tests with coccinellids.

Common or Coined Name	Chemical Name	General Use
DDT	dichloro diphenyl trichloroethane	insecticide
DDD (TDE)	dichloro diphenyl dichloroethane	insecticide
methoxychlor	1,1,1-trichloro-2,2-bis-(p-methoxyphenyl) ethane	insecticide
dieldrin	1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-1,4,5-endoexo-octahydrodimethanonaphthalene (85% min.)	insecticide
malathion	0,0-dimethyl dithiophosphate of diethyl mercaptosuccinate	acaricide insecticide
parathion	0,0-diethyl 0-p-nitrophenyl phosphorodithioate	insecticide acaricide
ovex	p-chlorophenyl p-chlorobenzenesulfonate	acaricide
Aramite	2-(p-tert-butylphenoxy)-isopropyl 2-chloroethyl sulfite	acaricide
ferbam	ferric dimethyldithiocarbamate	fungicide
lead arsenate	diplumbic hydrogen arsenate	insecticide

- -

TABLE 5. (Cont.)

Common or Coined Name	Chemical Name	General Use
Limited testing		
toxaphene	chlorinated camphene containing 67-69 percent chlorine	insecticide
lindane	1,2,3,4,5,6 hexachlorocyclohexane 99% gamma	insecticide
aldrin	1,2,3,4,10,10-hexachloro-1,4,4a,5,8,8a-hexahydro-1,4,5,8-endoexo-dimethano-naphthalene	insecticide
nicotine	1-3-(1-methyl-2-pyrrolidyl) pyridine	insecticide
sulphur	sulphur	fungicide
captan	N-trichloromethyl mercapto-4-cychlohexene-1:2-dicarboximide	fungicide
dichlone	2:3-dichloro-1:4-naphthoquinone	fungicide

Table 6 lists materials, formulations, amounts of formulation recommended per 100 gallons in spray programs, amounts of actual toxicant per gallon, and the amount of concentrate per gallon of spray material mixed for tests.

INVESTIGATIONS IN THE FIELD.

Two types of studies were conducted in the field; 1) surveys and observation of the biology and habits of coccinellids, and 2) determination of the effect of pesticide treatments on lady beetles and other predators.

Orchards comprised the majority of field plots for evaluating the effects of sprays. They are large, relatively uniform ecological units of a definite faunal composition, and have the problem of aphid and mite buildup attributed to destruction of natural enemies. Normally they receive planned, frequent and regular treatments. Large scale tests were possible by making observations in both experimental and commercial blocks of trees. The more important areas used are described below.

Table 6. List of grams of formulation and grams of actual toxicant used to prepare 1 gallon quantities of spray for laboratory tests in relation to the amounts of formulation recommended in pest control programs.

Pesticide	Formulation	Pounds of formulation recommended per 100 gal.	Grams of actual toxicant per gal.	Grams of formulation used per gal.
DDT, DDD methoxychlor	50W	2.0	4.54	9.1
			2.27	4.5
			1.14	2.3
dieldrin	25W	1.0	0.57	2.3
	50W	0.5	0.57	1.1
			1.14	2.3
			2.27	4.5
			3.40	6.8
aldrin	25W	1.0	0.57	2.3
parathion	15W	1.5	1.02	6.8
malathion	25W	2.0	1.14	4.5
		4.0	2.27	9.1
Aramite	15W	1.5	1.02	6.8
ovex	50W	1.0	2.27	4.5
lead arsenate	97W	4.0	17.70	18.1
sulfur	95W	6.0	25.87	27.2
ferbam	76W	1.5	5.17	6.8
captan	50W	2.0	4.54	9.1

LOCATION AND DESCRIPTION OF FIELD PLOTS.

The area of the Waltham Field Station provided an excellent opportunity to obtain controlled application conditions. The treatments were applied for apple pest control investigations by the Station staff efficiently and with consideration for the objectives of this project. Three areas were of most importance.

The " Main Orchard" consisted of 25 rows of 6 trees each. Every two succeeding rows was planted to one variety. Spray blocks consisted of the first or last three trees in each of four rows. Thus one block consisted of two varieties. At least two blocks contained the same varieties. The illustration in Fig. 14 shows the location of trees and varieties. The position of the blocks varied from year to year. The treatments in the spray blocks were either the same during the seasonal spray program or were changed between materials tested for plum curculio control and apple maggot control.

The "Dwarf Orchard" was more effectively planted for test purposes. Four rows of approximately

20 trees were divided into 4 blocks of about 20 trees. Since each row was a different variety each block contained 5 trees of 4 varieties. Fig. 17 shows the placement of the trees.

The "New Orchard" was used in 1954 for studies on young, non-bearing trees. The trees consisted of several varieties and ranged from 7 to 9 feet in height. They were left unsprayed and were used only for this project.

Commercial orchards were made available by certain growers. A block of Starking trees in the Assabet Orchards, Hudson, Mass was used for seasonal observations of mites and Stethorus during June, July and August of 1953 under conditions of regular pest control treatments.

For some studies with young trees three plantings were used in addition to the "New Orchard" in Waltham. A portion of "Block E" at the University orchards in Amherst, consisting of Early McIntosh was used. Four rows of 12 trees each were divided into two blocks of 16 trees. In East Warren, Mass., a block of young non-bearing Early McIntosh was made available by the grower. In Groton, Mass., five blocks were available. Early McIntosh was used most extensively and was interplanted with Golden Delicious.

In addition to orchards, a backyard planting of raspberries and blackberries was used for some observations on the two-spotted mite and *Stethorus* since it had been treated with parathion. In Amherst, a number of white willows (*Salix alba* L.) were treated by Dr. William B. Becker for control of the imported willow leaf beetle, *Plagiodera versicolora* (Laich.). Since the trees were also infested with the willow mite *Schizotetranychus schizopus* (Zacher), seasonal observations were taken to determine the effect of the sprays on the lady beetle *Stethorus* which fed upon the mites.

DATA COLLECTED IN FIELD TESTS.

It was necessary to determine the abundance of prey as well as the presence or absence of coccinellids since the occurrence of predators is relative to a source of prey or food. In addition, the amount of growth which could support aphids was recorded in some areas. On young trees the length of new growth in the current season was measured.

The number of new shoots was noted also since it was directly related to the total abundance of aphids which could be expected in a given tree.

Determination of Aphid Abundance.

An aphid index was used to indicate levels of populations. It was obtained by estimating the degree of infestation on 3 upright shoots or water sprouts on young trees and 5 branches on older trees for each of 3 or 4 trees per block. The same branches on each tree were examined throughout the season. A numerical index was used in order to average the observations by block or treatment. The ratings are as follows:

0	none	
1	light	Only the very tips including two partly developed leaves and the stem infested with moderate numbers, or a number of older leaves with a very few aphids near the base of older leaves

2	moderate	The new developing leaves at the tip and about 2 to 3 inches of stem densely covered with aphids, or several older leaves only partially infested
3	heavy	The new developing leaves at the tip, the newly formed stem and 2 to 3 older leaves heavily infested
4	very heavy	The new leaves and stem and most old leaves heavily infested. This type of abundance was considered for these studies to be a maximum. Only one exception to this was noted during the studies. During a very wet period when the trees were growing most rapidly, aphids increased to levels where foliage throughout the tree and fruits supported large numbers of aphids. Fig. 3 shows a typical terminal branch.

An "aphid index" was calculated by: 1) adding the estimate of each branch for all trees and dividing by the number of branches to obtain an average, or 2) dividing the sum of all observed estimates by the highest total which was possible to obtain a "percent of maximum" index. As far as is known, this method has not been described heretofore and constitutes a new procedure for estimating the abundance of aphids in apple orchards.

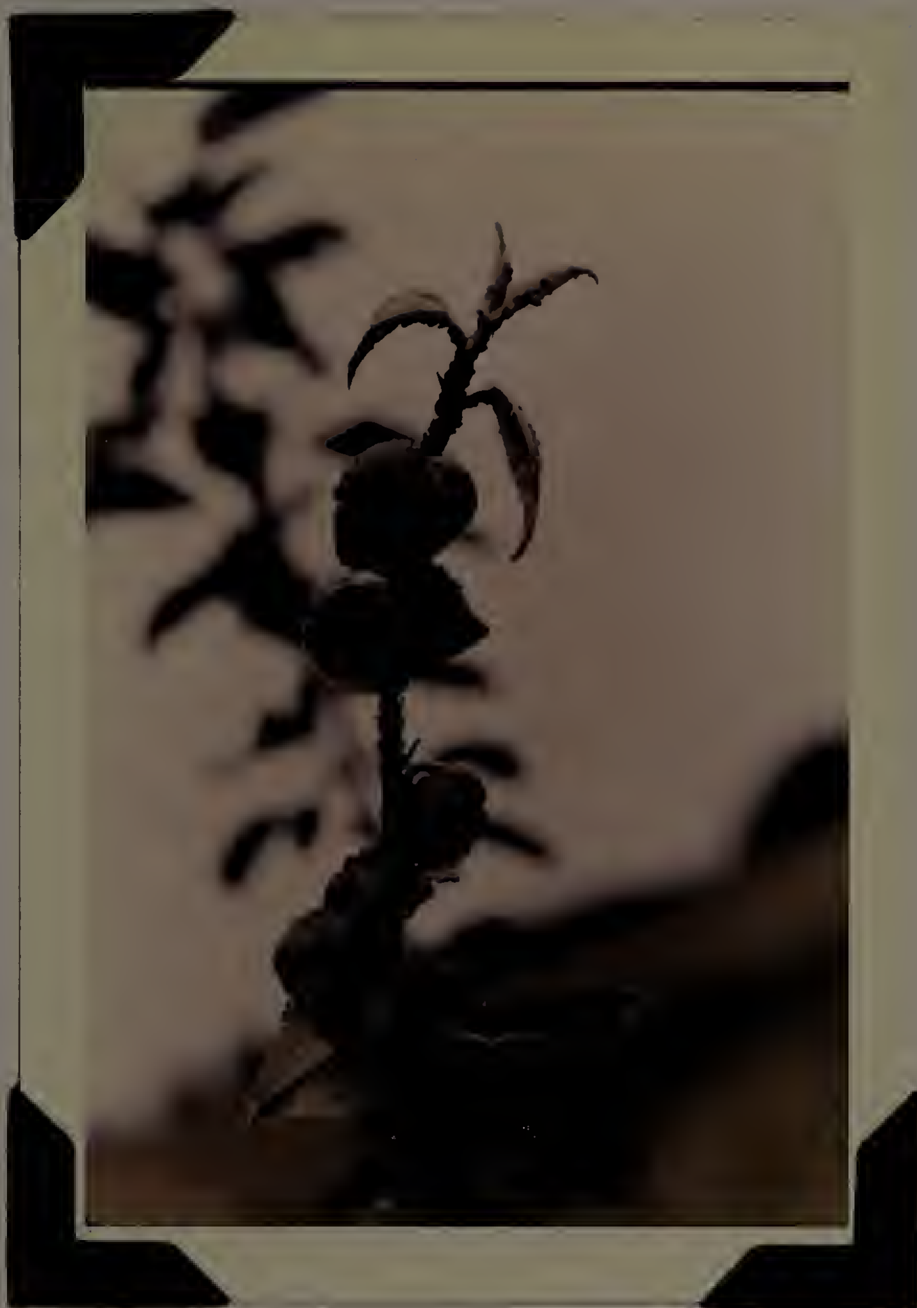


FIGURE 3

Water sprout terminal of apple showing a heavy infestation of aphids.

Determination of Mite Abundance.

The standard practice of counting individuals found on an arbitrary number of leaveswas used in these studies for making mite estimates. Leaf samples were selected at random from replicated trees in each block and examined. All stages including eggs were observed.

Estimates were made by selecting 10 leaves at random from 3 trees in each block. Up until the latter part of 1953, the leaves were examined under a microscope and the numbers of each stage present for each species of mite including the European red mite, Panonychus ulmi (Koch.), the two-spotted spider mite, Tetranychus telarius (L.),and the predacious Typhlodromus spp., were recorded separately.

In orchards away from Waltham, sampling was done in the field. No more than 10 leaves were picked at one time to insure accuracy and prevent loss of mites. When leaves were to be brought into the laboratory for counting, they were placed in waxed sandwich bags in the field and kept in a portable ice-box until counts were made.

In 1953, a mite-brushing machine (Fig. 4) was purchased from H. Gearing, California and used to make larger leaf samples from test blocks. From each of four trees in one treatment, 25 leaves were selected at random and brought into the laboratory for brushing. Mites brushed onto the adhesive-coated glass plates were uninjured and could be stored satisfactorily up to three weeks, which permitted large numbers of samples to be taken. Unfortunately, the machine was not obtained until late in the season.

Methods for Sampling Coccinellids.

The techniques which were used to obtain counts depended upon the type of prey which the lady beetles selected and each will be discussed separately. Generally, methods which disturbed the predators, such as jarring and insecticidal treatment, were avoided because they tended to upset field populations. Lady beetles usually move from place to place if frequently disturbed.

Acarinophagous coccinellids.

The most satisfactory procedure for sampling

FIGURE 4

The Henderson-McBurnie mite-brushing machine showing the brushes, movable metal sides and revolving truntable below.

populations of Stethorus punctillum was a modification of the timed, visual inspection method used by DeBach et al. (1950), Clancy and Pollard (1948, 1952), and MacPhee and Sanford (1953). Larvae, pupae, and adults, without being disturbed, were easily seen especially on the foliage, where most predator activity was confined. Apple trees selected for sampling were observed from beneath, or inside, for a period of 5 minutes per tree. With this method a much larger proportion of the tree could be scanned than with the previously-tried method of examining a given length of branch. Counts of eggs, larvae and pupae were taken also at the time foliage was sampled for mites as a supplement to tree counts. The number observed in both were combined, and the sum total of all on count trees in each block was used to indicate the abundance of the predator for a given sampling date.

The effect of pesticidal treatments was determined from fluctuations in the predator population from one sampling date to another. Counts were plotted graphically on a chart to illustrate the seasonal and induced changes in population levels. The data on the prey made it possible to distinguish fluctuations due to variations in food supply from those caused by treatments.

On low-growing plants such as raspberry, counting was much more difficult. Although supplemental observations were made by scanning the undersides of leaves on a uniform number of canes, in each plot, counts were based primarily on larvae and pupae recorded when the leaves were sampled for mites.

In orchards where the ground cover was sampled, all predator counts were taken when the leaves were examined for mites.

Aphidophagous coccinellids.

Bright-colored adults and dark, contrasty leaves were easily observed among colonies of aphids. Since aphids are more restricted in their location on the trees, sampling was based on the number found on terminals rather than by timed visual inspection as for mite predators. Either 5 or 3 branches were tagged, depending on whether mature or young non-bearing trees were used. Usually water sprouts were selected. In the trees at Waltham, trees had been "open-top" pruned and new succulent sprouts in the tops were also tagged and reached by climbing the trees.

Adults of all species of lady beetles were recorded separately and not pooled as most workers have done. _A. bipunctata_ was the only dominant species found in apple orchards. Larvae and pupae were recorded as _bipunctata_ and others. Eggs are much more difficult, if not impossible, to identify to species. They were recorded as "small," presumably _bipunctata_, but possibly _Cycloneda munda_ or _Coccinella perplexa_; and "large," presumably _Coccinella transversoguttata_, _Hippodamia convergens_ or _Anatis 15-punctata_.

The total number of each stage and each species on each sampling date was used as an indication of population levels and compared to the aphid index. By plotting bi-weekly counts for the whole season, the effects of pesticides could be determined from fluctuations in the relative abundance of the predators and prey.

Another method was used to determine the toxic effects of sprays on lady beetles. Counts before and after treatment were made of dead beetles on ground cloths which had been spread under the trees during spring drop to collect curculio-stung apples in other tests. Plots treated with materials such as malathion or TEPP, which produce immediate toxicity, were satisfactorily tested with this method.

In order to determine the effect of direct sprays on individual lady beetles, adults were placed in wire mesh screen cages and hung in apple trees to be sprayed with a high pressure hydraulic machine. After the exposure, the beetles were transferred to clean cages, placed in a temperature cabinet and observed for several days.

RESULTS OF LABORATORY INVESTIGATIONS

THE TWO-SPOTTED LADY BEETLE.

Test cages were sprayed at dilutions normally recommended in apple spray programs (see Table 6). Counts are based on three replicates of 10 adults each which were exposed to the residues.

Malathion residues killed all of the adults within 4 hours, whereas those exposed to parathion, methoxychlor, and DDT residues died within 2 days (Fig. 5). Mortality was only moderate among beetles exposed to dieldrin and DDD during the first two days. Although 90 percent of the beetles were dead after 4 days in the DDD cages, about half of the beetles remained alive which were exposed to dieldrin. By the fourth day, the dieldrin mortality was not appreciably different from the untreated checks. Lead arsenate residues did not cause appreciable mortality.

Acaricidal materials are compared in Figure 6. The two phosphates, malathion and parathion

FIGURE 5

The effect of two-day-old residues of seven insecticides on adult two-spotted lady beetles

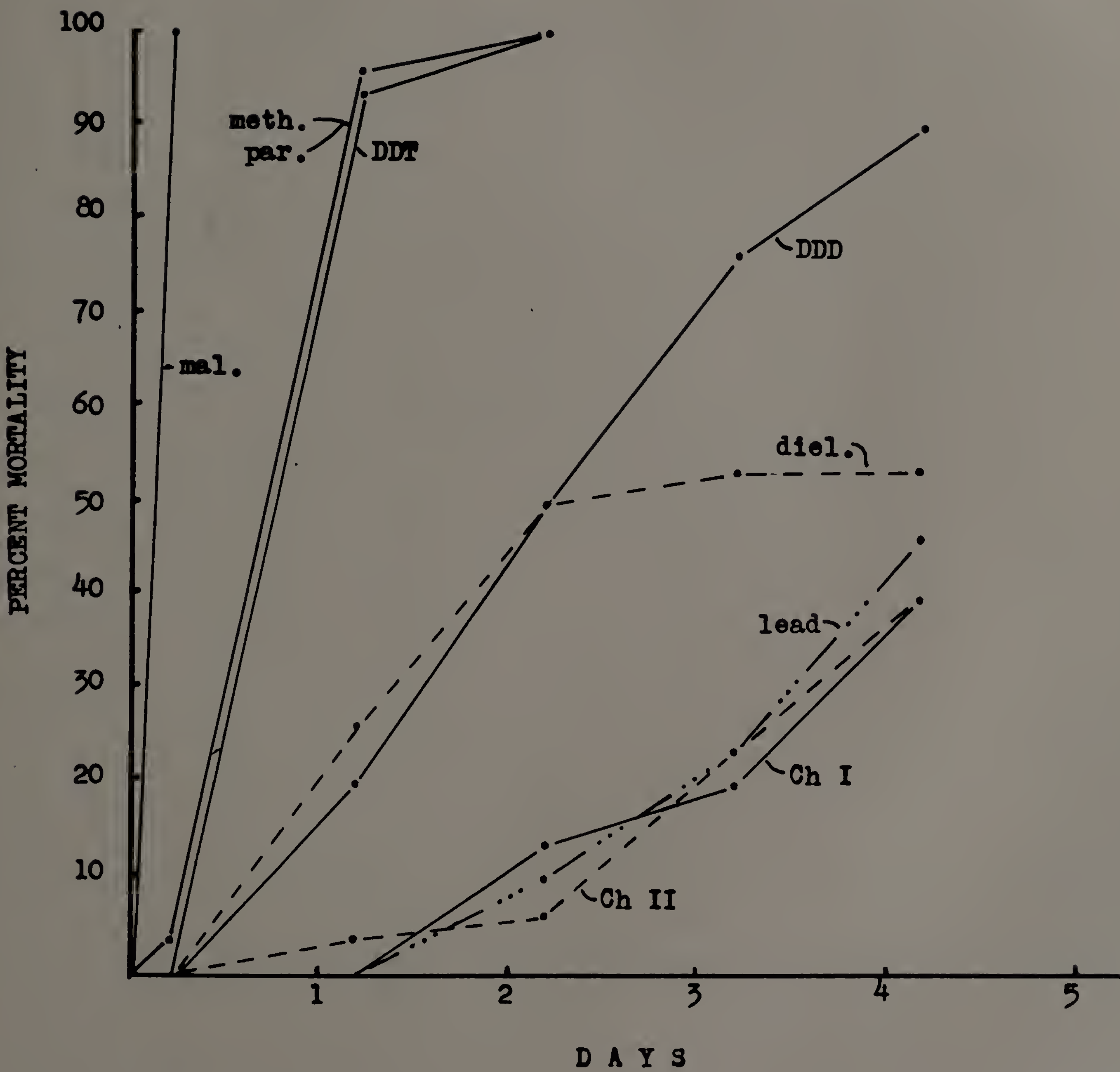
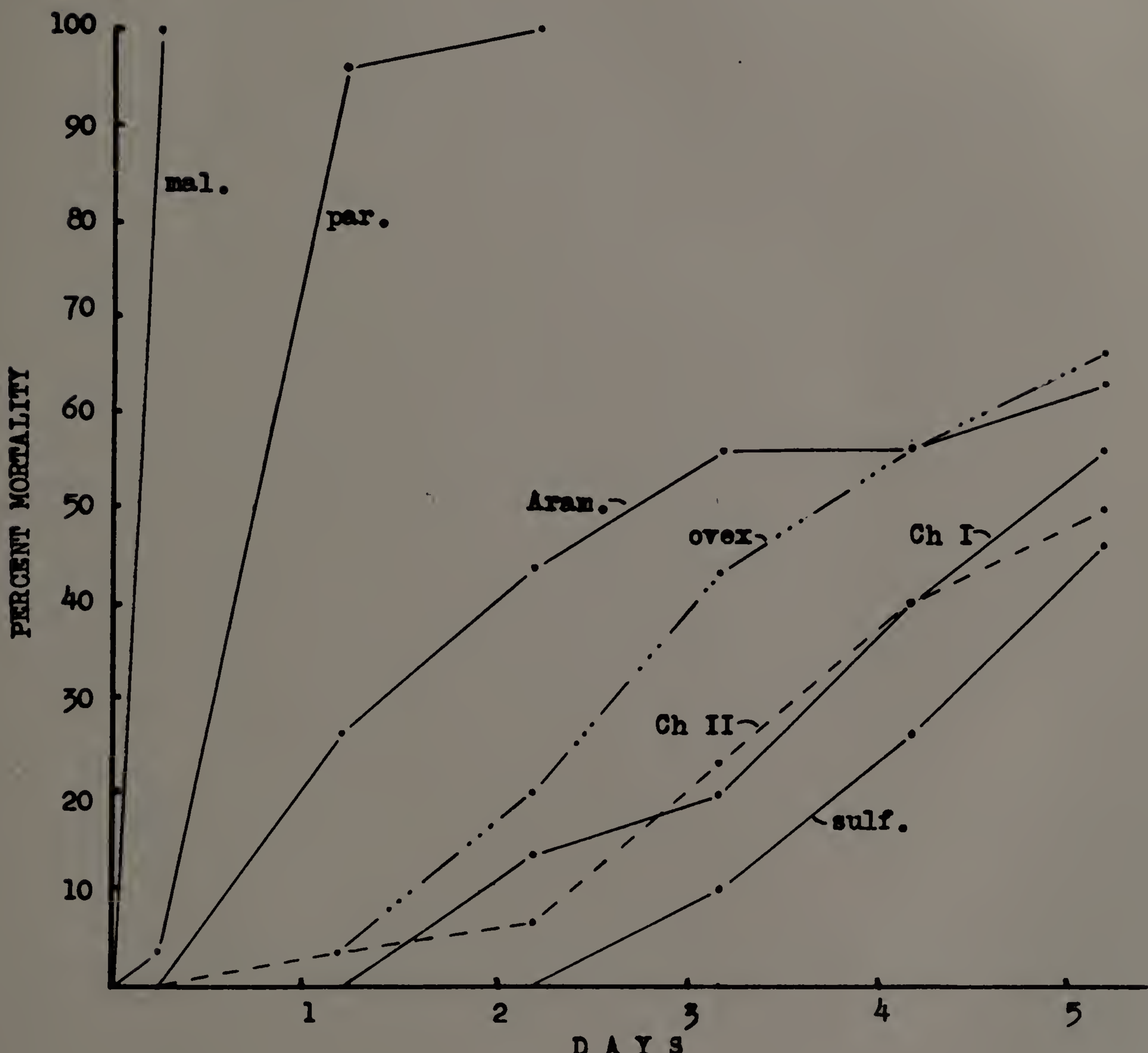


FIGURE 6

The effect of two-day-old residues of five acaricides on adult two-spotted lady beetles



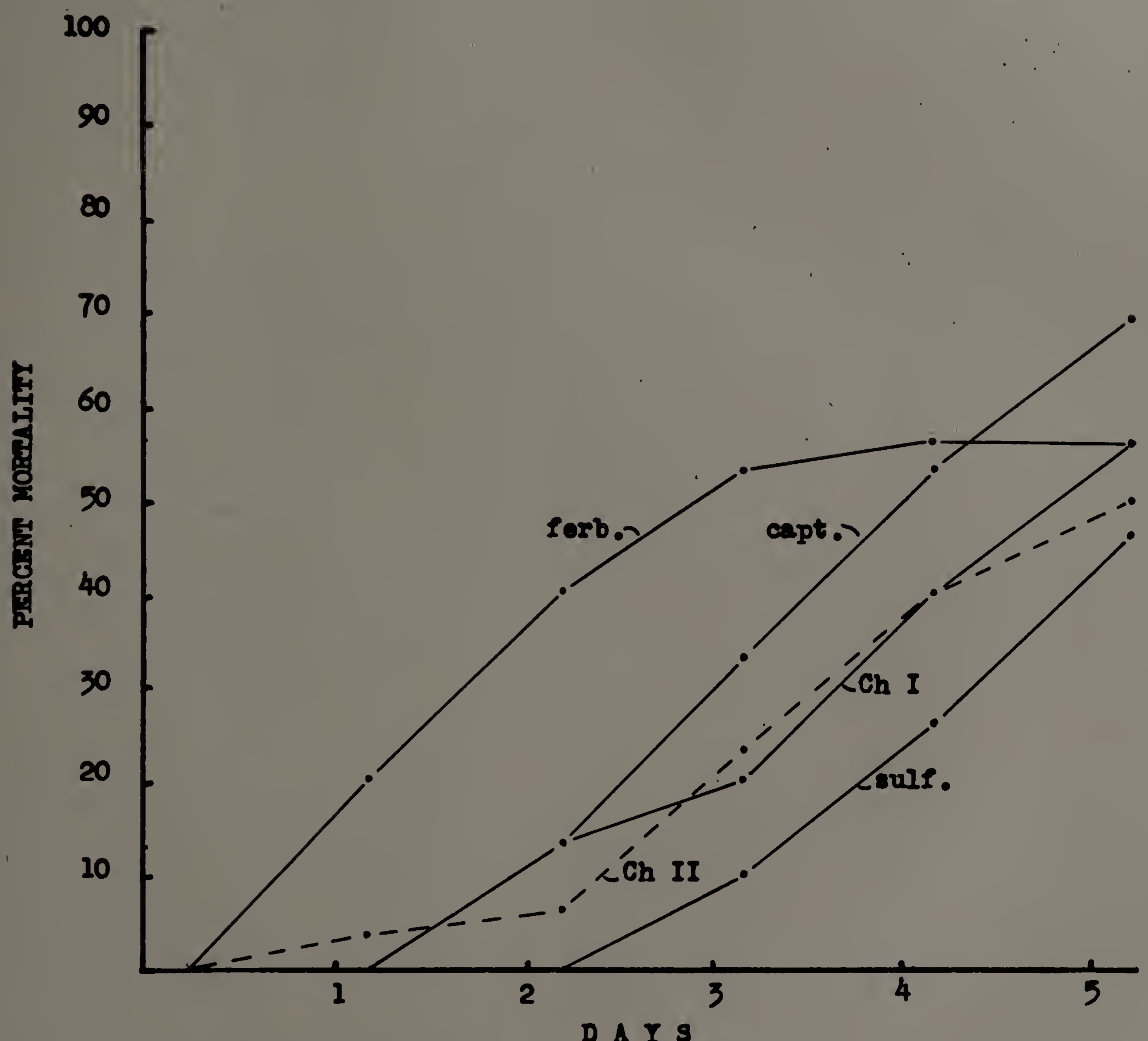
(carried over from Fig. 5) were highly toxic, killing all adults, whereas ovex and Aramite were only slightly to moderately toxic, compated to the untreated checks. Sulfur, sometimes considered acaricidal, showed no indication of toxicity to the two-spotted lady beetle.

The effects of fungicidal residues is shown in Figure 7. Sulfur and captan apparently had no toxic effect on the adults. Ferbam produced 53 percent mortality by the third day, but had little effect after that time. At the end of the test there was little difference in the number alive between the treated and the untreated.

Methoxychlor, which is highly toxic to lady beetles, was applied to test cages at the recommended rate of 2 pounds of 50 percent WP per 100 gallons, and at one-half and one-fourth that rate. Dieldrin, which gave low percent kill in other tests, was applied to test cages at the recommended rate of 0.5 pound of 50 percent WP per 100 gallons, and at 2 and 4 times that amount. Three replicates of 10 beetles each were exposed to

FIGURE 7

The effect of two-day-old residues of three fungicides on adult two-spotted lady beetles.



each treatment, and observations were made daily of the percent killed for 4 days.

Methoxychlor residues from sprays one-fourth and one-half the recommended concentrations were just as toxic in these tests as the residues from sprays at the recommended concentration (Fig. 8). In one day, 96 percent mortality occurred in all methoxychlor treatments. All beetles were dead on the second day.

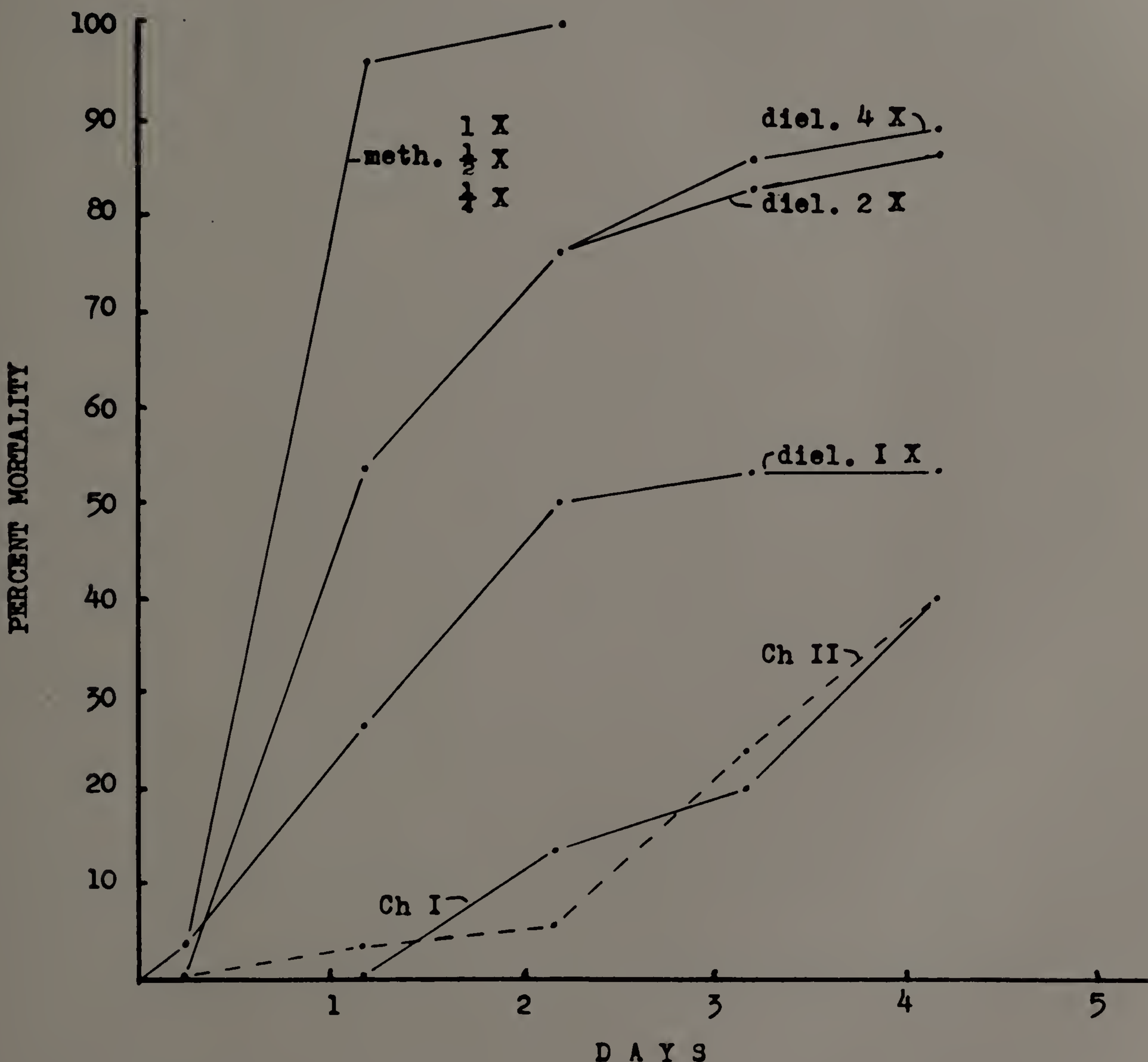
The higher concentrations of dieldrin, as residues, gave higher percent kill of the adult beetles, but 15 percent or more were alive and apparently normal at the end of the test. The data for the recommended concentration of methoxychlor and dieldrin in Figure 8 are the same used in Figure 5 for purposes of comparison in this test.

THE CONVERGENT LADY BEETLE.

Beetles obtained from California were used for all tests with this species. Three replicates of 10 adults each were used in each treatment. Unless stated otherwise, each treatment consisted of residues

FIGURE 8

The effect of three methoxychlor and three dieldrin residues on adults of the two-spotted lady beetle.



obtained by spraying test cages at dilutions of wettable powders normally used in apple spray programs (see Table 6).

The effect of one-day-old residues of 8 insecticides and 1 fungicide is shown in Figure 9. All of the beetles died in the parathion, methoxychlor, and DDT treatments. The toxic action of methoxychlor was slower than that of parathion, but both killed the beetles sooner than did DDT. Beetles which were alive in the DDT cages, however, were moribund by the second day. Thirty-five percent or more of the beetles survived in cages treated with DDD, dieldrin, aldrin, lead arsenate, and ferbam. The fungicide, ferbam, and DDD showed moderate mortality during the first three days, but the percent killed did not increase much after that time. Dieldrin, aldrin, and lead arsenate produced only a slight mortality as compared to the untreated check.

In Figure 10 the effect of four acaricidal residues is shown. The counts for parathion are

FIGURE 9

The effect of one-day-old residues of eight insecticides and one fungicide on adults of the convergent lady beetle.

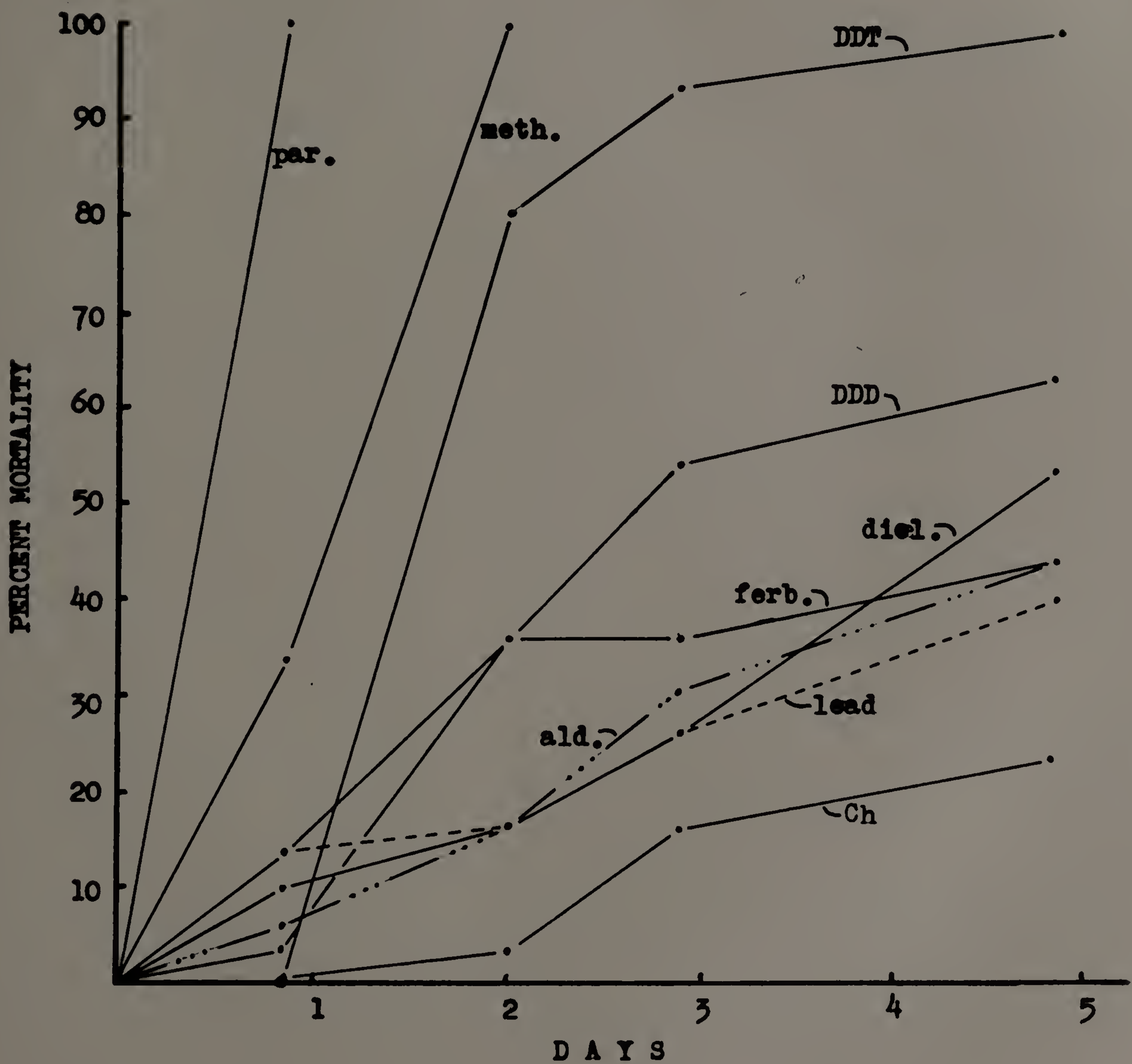
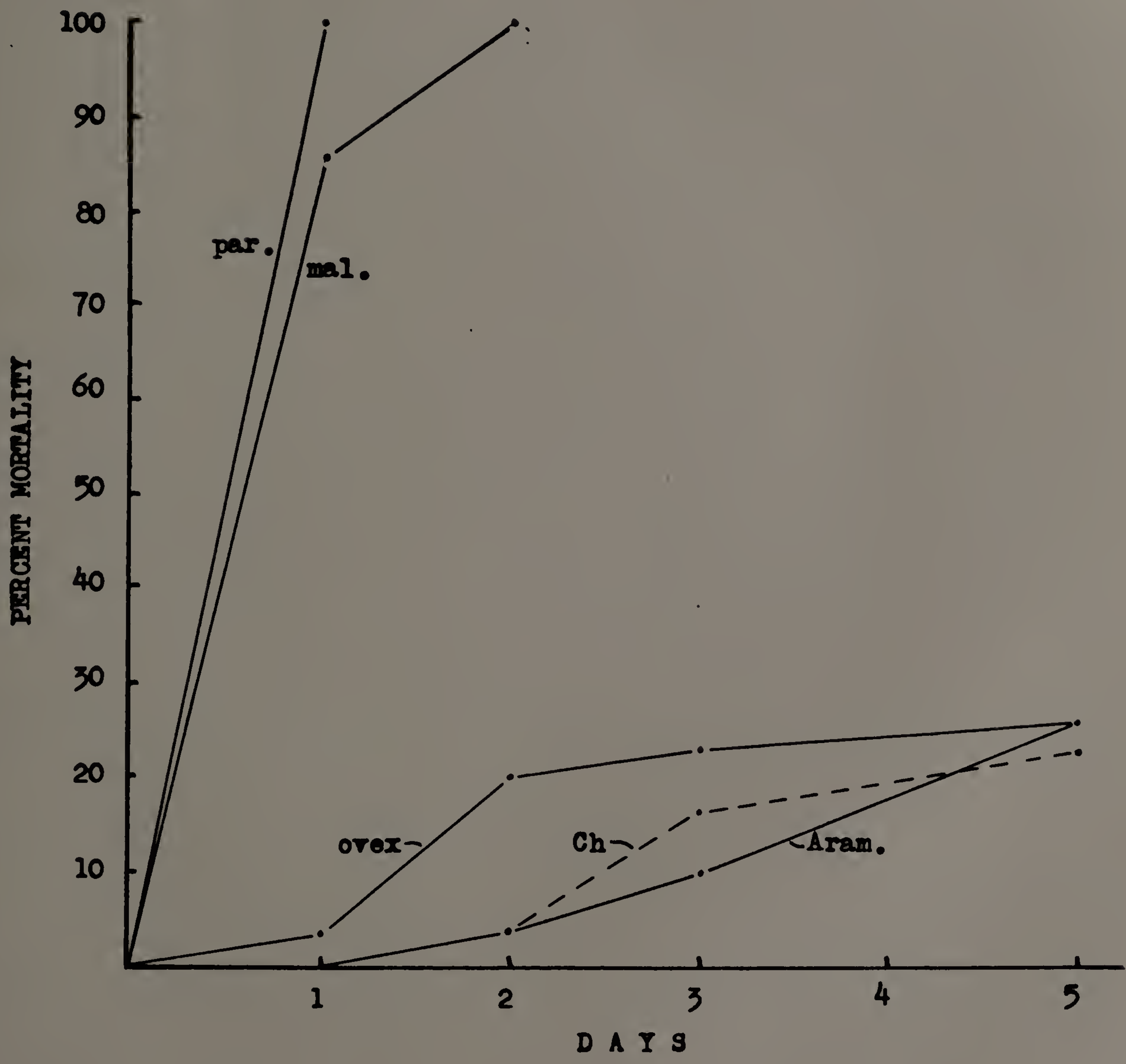


FIGURE 10

The effect of four acaricidal residues
on adults of the convergent lady beetle.

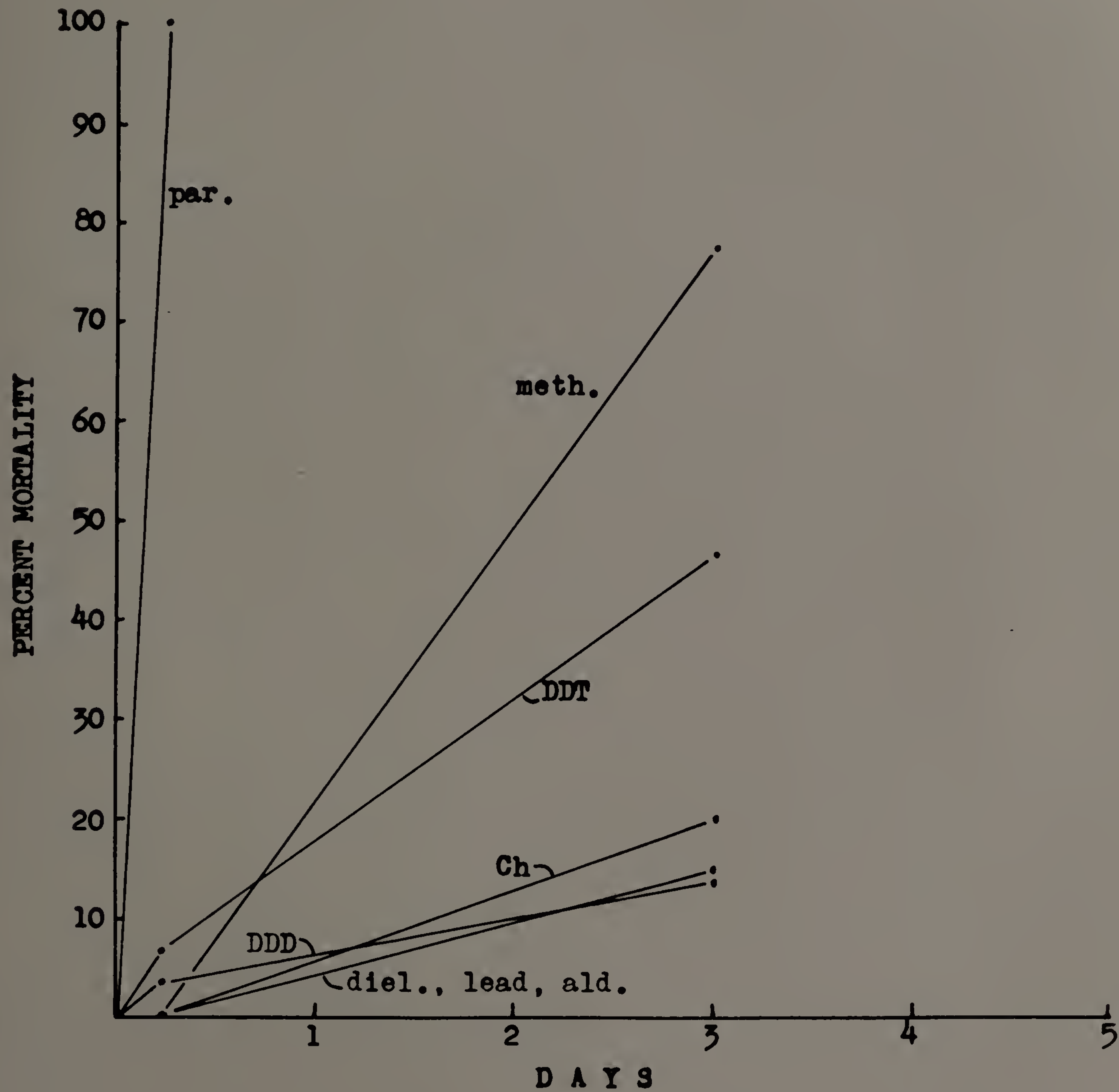


taken from Figure 9. The two phosphates parathion and malathion, killed all of the beetles. Ovex and Aramite were non-toxic in this test, varying only slightly from the check in percent mortality.

The spray suspensions used to treat cages for residue tests were applied directly on groups of adult lady beetles. Figure 11 shows the percent mortality of beetles for each treatment. Parathion eliminated all of the adults within 4 hours. More than 20 percent of the beetles were still alive on the third day following spraying with methoxychlor and over 50 percent were alive which had been sprayed with DDT. No toxic effect was indicated for dieldrin, aldrin, DDD, or lead arsenate as compared to the untreated check. The test indicates that the insecticides as direct sprays, except for parathion, had less toxic effects on the beetles than did the residues. Considerable run-off of the spray material was observed when the beetles were sprayed. Spray which remained on the beetles when they were removed to clean cages was in the form of a few large droplets. Apparently, the beetles have only a slight

FIGURE 11

The effect of direct applications of seven insecticidal spray suspensions on adult convergent lady beetles.



exposure to the insecticides when sprayed directly.

Numbers of treated cages, which had been stored for 19 days because no beetles were available, were used in a series of tests. The residues had aged but not weathered since the cages were closed and kept in a dry room at approximately 75 degrees F. The mortality data shown in Figure 9 shows that the residues were of the same order of toxicity as one or two-day old residues except that the beetles did not die as quickly. Methoxychlor, parathion, and DDT residues were highly toxic, whereas aldrin, dieldrin, DDD, lead arsenate, and ferbam residues were only slightly, if at all, toxic in this test.

Using DDT and methoxychlor at the recommended rate of 2 pounds of 50 percent WP per 100 gallons, test cages (three per treatment) were sprayed for 1, 2, 4, 6, and 10 seconds to determine if the amount of residue deposited had an effect on the mortality of the beetles exposed. Table 7 gives the percent mortality observed for each treatment. Residues resulting from sprays of 4 seconds or more

Table 7. Mortality of convergent lady beetle adults when exposed continuously to residues in cages sprayed with methoxychlor and with DDT for 1, 2, 4, 6, and 10 seconds.

TREATMENT	NO. SEC. SPRAYED	PERCENT MORTALITY 1 DAY	2 DAYS	3 DAYS
DDT (2.0 lbs. of 50% WP)	1	3.3	26.6	63.3
	2	0.0	53.3	60.0
	4	3.3	36.6	86.6
	6	0.0	44.1	91.1
	10	6.1	50.0	100.0
methoxychlor (2.0 lbs. of 50% WP)	1	3.3	16.1	93.5
	2	3.3	29.3	100.0
	4	6.1	46.6	100.0
	6	3.3	36.6	100.0
	10	0.0	40.0	100.0
UNTREATED	-	0.0	6.1	18.3

caused complete mortality of adults in the methoxychlor treatments and high mortality in the DDT treatments. The residues were 19-days old when used. On the basis of the delayed toxic effect of older residues (Figure 12), a spraying time of only one or two seconds, produced a sufficient deposit for test purposes. The general uniformity of replicates in this and other tests as measured by the mortality observed leaves little doubt that adequate and uniform deposits were obtained by the application methods used.

A number of groups of adults were exposed to 19-day old residues of DDT and methoxychlor for periods of 10, 30, and 60 minutes, 10 and 24 hours, and 3 or 5 days, the period of the test, to determine if the length of exposure time had an effect on the mortality which occurred. It was found that short periods of exposure to the residues resulted in high mortality (see Table 8). Beetles which walked on methoxychlor residues for 30 minutes died in two days. Eighty-three percent of those which had

FIGURE 12

The effect of 19-day-old residues of eight pesticides on adults of the convergent lady beetle.

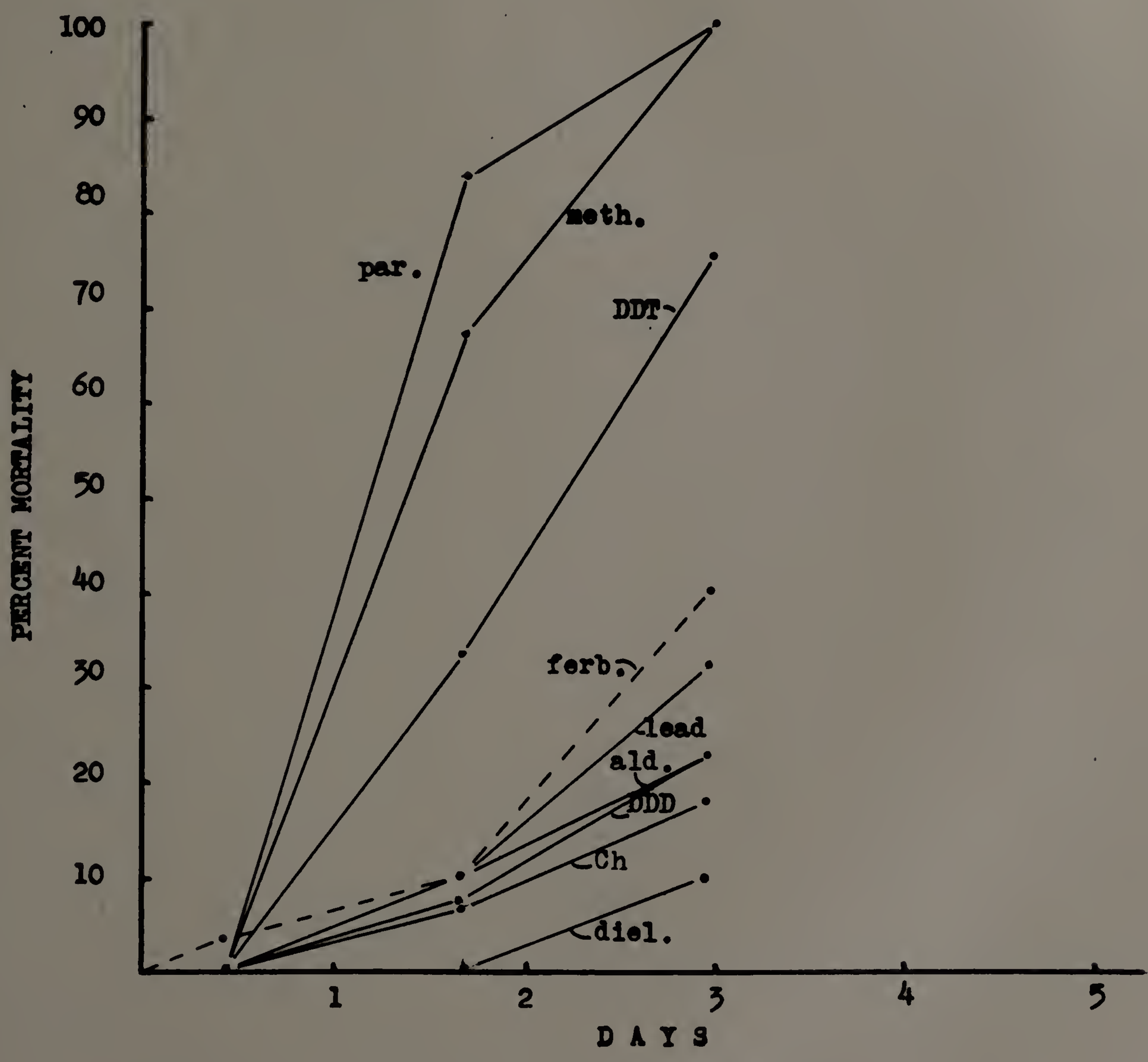


Table 8. The effect of DDT and methoxychlor residues when adult convergent lady beetles were exposed for six different periods of time.

EXPOSURE TIME	PERCENT MORTALITY					
	methox. 2 lbs. 50%W/100			DDT 2 lbs. 50% W/100		
	1 DAY	2 DAYS	3 DAYS	2 DAYS	3 DAYS	5 DAYS
10 min.	--	69.5	83.3	23.3	33.3	--
30 min.	--	100.0	--	36.6	53.4	--
1 hour	39.9	100.0	--	56.7	63.3	73.4
10 hours	43.2	100.0	--	56.7	76.7	90.0
24 hours	56.7	100.0	--	63.3	96.6	100.0
3-5 days	33.3	100.0	--	80.0	93.4	100.0
Check I	0.0	3.3	16.6	3.3	16.6	23.3
Check II	--	0.0	6.6	0.0	6.6	--

been exposed only 10 minutes were dead by the third day. DDT which in other tests showed slower toxic action, produced 53 percent mortality of the beetles in three days. Exposures of 10 hours gave 90 percent mortality in five days.

Convergent lady beetle adults were exposed to residues obtained by treating test cages with sprays at the recommended concentration, one-half the recommended concentration, and one-fourth the recommended concentration of methoxychlor wettable powder. Other beetles were exposed to residues of dieldrin sprayed at the recommended concentration of 1 pound of 50 percent wettable powder per 100 gallons, and 2, 4, and 6 times that concentration. The residues were 2 days old when the test was started.

The mortalities which were observed over a 5-day period are shown in Table 9. Residues of all concentrations of methoxychlor produced 100 percent mortality of adults in the test. Even at 6 times the normally recommended concentration of dieldrin, residues of sprays were only moderately toxic to adult

Table 9. Mortalities of H. convergens adults exposed continuously to 2-day old residues of methoxychlor and dieldrin applied as sprays of different concentrations.

INSECTICIDE	CONCENTRATION	PERCENT MORTALITY*			
		1 day	2 days	3 days	5 days
dieldrin (X = 1 lb. 25W per 100 gal.)	1 X	10.0	16.6	26.6	53.4
	2 X	6.6	10.0	13.3	36.6
	4 X	3.3	26.6	33.3	56.7
	6 X	3.3	23.3	53.4	66.6
methoxychlor (X = 2 lb. 50W per 100 gal.)	1 X	--	100.0	--	--
	0.5 X	--	46.7	100.0	--
	0.25 X	--	46.7	83.3	100.0
Untreated	--	0.0	3.3	16.6	23.3

*Based on 3 replicates of 10 adults each.

beetles. The results are similar to those obtained in a test with the two-spotted lady beetle, indicating that methoxychlor is very highly toxic and dieldrin is of low toxicity to lady beetles, despite the fact that both are chlorinated hydrocarbons.

THE TRANSVERSE LADY BEETLE.

In some early tests, the amount of pesticide needed to obtain a 1 to 1600 concentration by weight was mixed with 1 gallon of water for spraying test cages (Table 10). Residues of equivalent spray concentrations produced mortalities as shown in Figures 13 and 14. The data in Figure 13 are based on three replicates of 8 adults whereas the data in Figure 14 are based on three replicates of 7 adults.

Parathion killed all beetles in one-and one-half days. Methoxychlor and DDT were less toxic in these tests. The amounts of formulation used in the sprays were half the concentration at 1 to 1600 of those recommended in spray programs. DDD, Aramite, lindane, and lead arsenate produced no toxic effect compared to the untreated checks. Toxaphene gave

Table 10. Amounts of pesticide formulation to obtain 1-1600 spray suspensions.

PESTICIDE	FORMULATION	LBS./100 GAL. RECOMM. CONC.	GMS./GAL AT RECOMM. CONC.	GMS./GAL FOR 1-1600 DILUT.
DDT	50WP	2.0	9.1	4.5
methoxychlor	50WP	2.0	9.1	4.5
DDD	50WP	2.0	9.1	4.5
toxaphene	40WP	2.0	9.1	5.7
lindane	25WP	1.0	4.5	9.1
aldrin	25WP	1.0	4.5	9.1
dieldrin	25WP	1.0	4.5	9.1
Aramite	15WP	1.5	6.8	15.2
parathion	15WP	1.5	6.8	15.2
lead arsenate	97WP	4.0	18.1	2.3

FIGURE 13

The effect of two-day-old residues of six pesticides on adult transverse lady beetles.

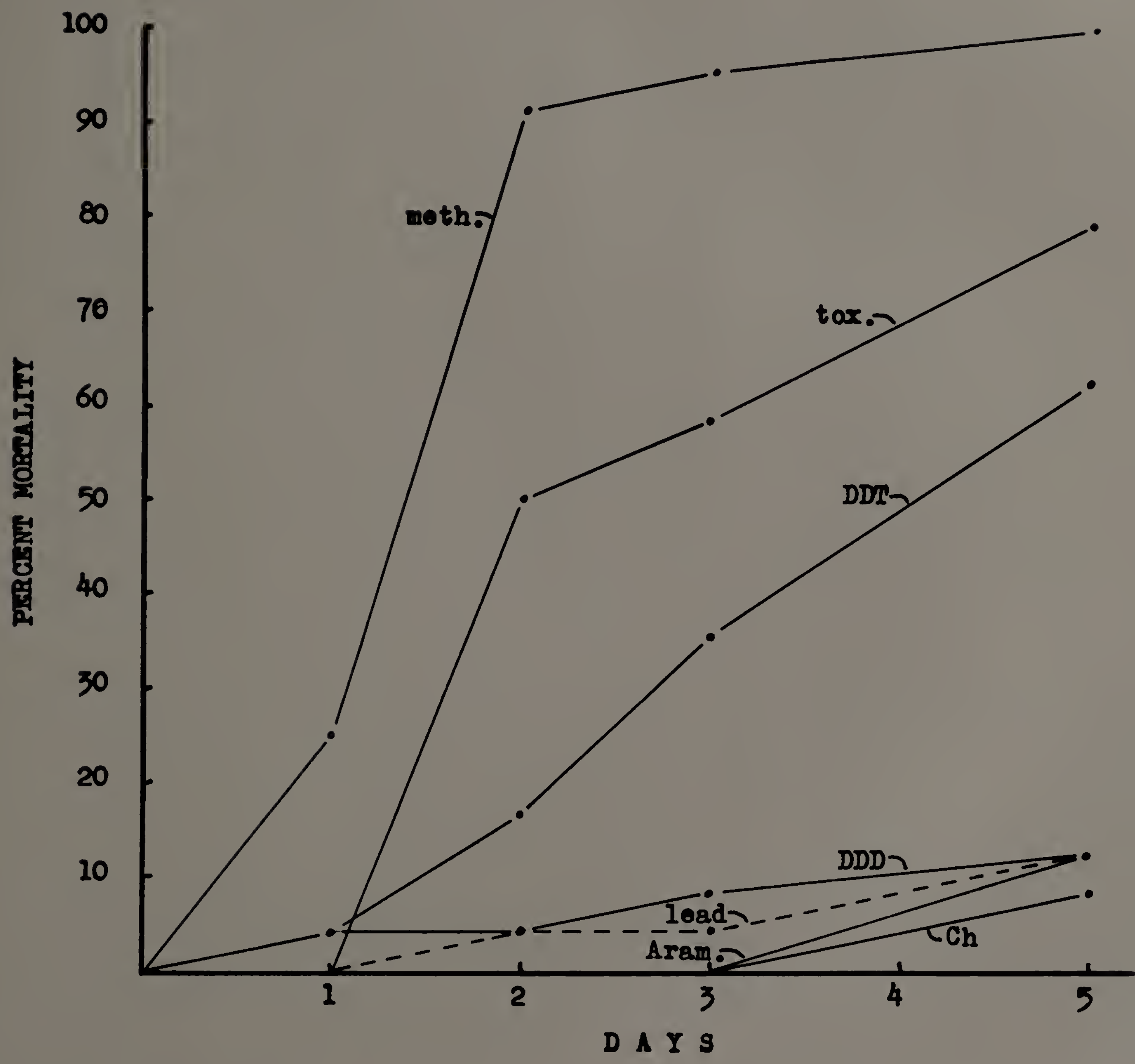
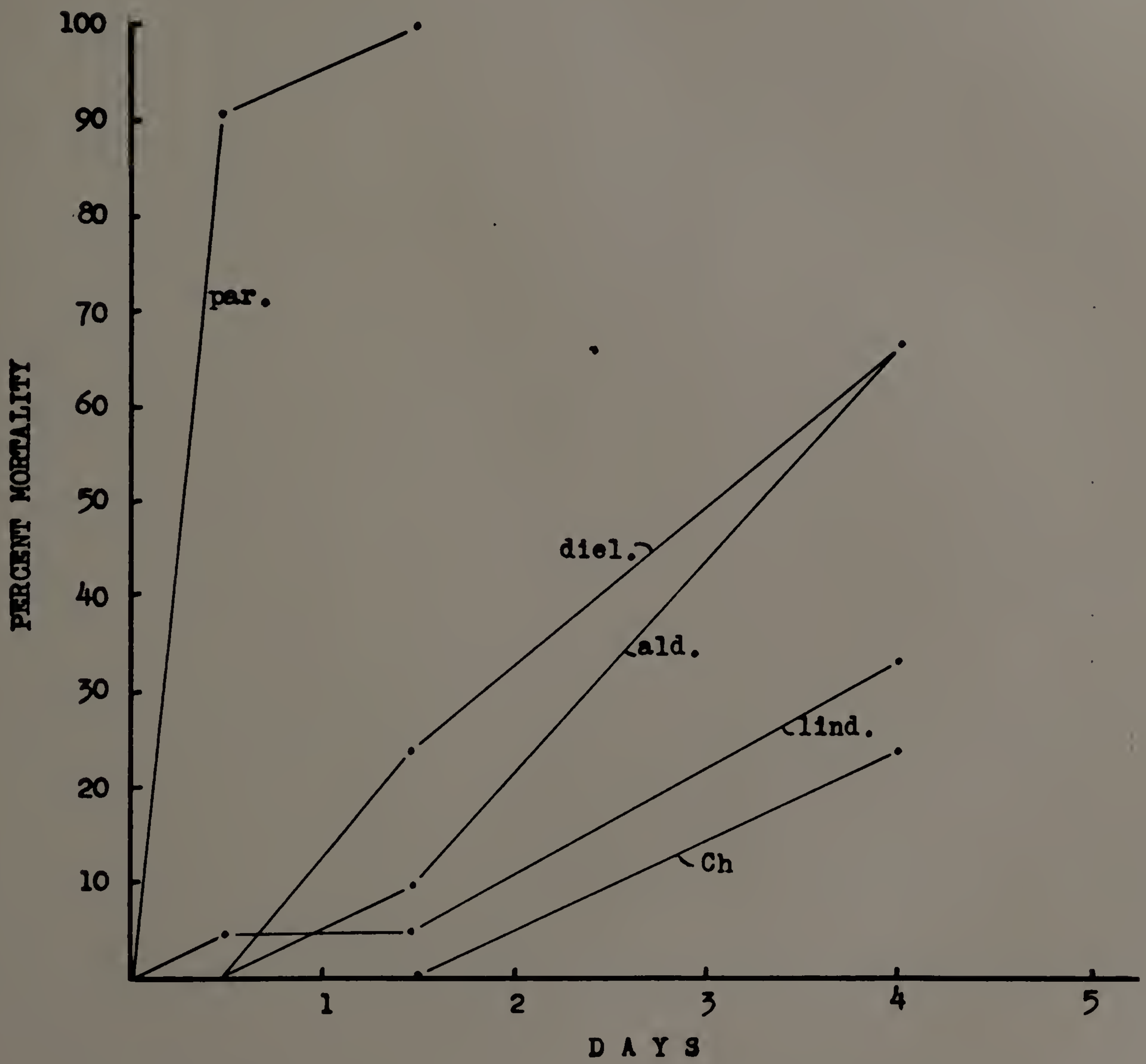


FIGURE 14

The effect of two-day-old residues of four insecticides on adult transverse lady beetles.



moderate toxicity. Dieldrin and aldrin sprays at 1 to 1600 dilutions were twice as concentrated as at the recommended concentration (Table 10), and produced moderate toxicity of the adults.

Table 11 shows the mortality which resulted in two days when 5 adults in each of 3 replicates were exposed to residues of different concentrations (as indicated in the table) of DDT and dieldrin. The results were similar to those of other tests with the two materials. Dieldrin at the higher concentrations caused moderate mortality, but most surviving beetles appeared normal. Even the low concentrations of DDT caused moderate mortality and all the surviving beetles were moribund.

Adult beetles were sprayed directly with the same suspensions used to treat test cages in the previous experiment. Table 12 shows that no mortality of any consequence occurred in any treatment. There was excessive run-off of the spray material from the beetles, and since they were

Table 11. Mortality of banded lady beetle adults after two days of exposure to six day old residues of three concentrations of both DDT and dieldrin.[1]

Insecticide	Concentration	Percent Mortality in two days
DDT (X is 2 lbs. 50% WP / 100 gal.)	1 X	40.0 [2]
	1/2 X	26.6 [2]
	1/4 X	33.0 [3]
	check	0.0
dieldrin (X is 1 lb. 50% WP / 100 gal.)	2 X	26.6
	3 X	13.3
	4 X	40.0 [4]
	check	6.6

1 Based on 15 adults per treatment.

2 Moribund, unable to stand.

3 Uncoordinated but able to walk.

4 Slight trembling in 3 or 9 live beetles, others normal.

Table 12. The effect on adult transverse lady beetles of direct sprays of three concentrations each of DDT and dieldrin.

Insecticide	Concentration	Percent Mortality		
		0.5 day	1.5 days	3.5 days
check	--	0.0	0.0	0.0
DDT	X	0.0	0.0	11.1
(X is 2 lbs. 50% WP/100)	1/2 X	0.0	0.0	0.0
	1/4 X	0.0	0.0	5.5
check	--	0.0	0.0	0.0
dieldrin	2 X	0.0	0.0	0.0
(X is 1 lb. 50% WP/100)	3 X	0.0	0.0	0.0
	4 X	0.0	0.0	5.5

removed immediately to clean cages, little exposure occurred. In each of three replicates, 6 adult beetles were sprayed while confined to wire-mesh, screen cages.

Field-collected larvae of the transverse lady beetle and the 9-spotted lady beetle were exposed to wettable powder residues of 11 pesticides obtained from sprays diluted at the rate of 1 to 1600 by weight (see Table 13). Large numbers of green apple aphids were placed in the test cages with the lady beetles to minimize cannibalism. Although care was taken to select larvae which were in the last instar, variation in the age of the individuals occurred. Records were taken 1, 2, 4, and 7 days after the larvae were introduced into the cages. The number of dead and live larvae, moribund larvae, the percent of larvae which pupated, the number of pupae, adults, and live adults are given for each treatment in Table 13.

The results of the test are not well defined due to the transformation of some during the period

Table 13. Observations of mortality, pupation, adult emergence and adult survival of the transverse and 9-spotted lady beetles exposed to residues of 11 pesticides.

PESTICIDE*	PERCENT MORTALITY 1 day	2 days	4 days	7 days	Percent Pupating	No. Pupae	No. Adults	No.live Adults
Lindane**	42.8	80.9	90.5	95.2	9.5	2	1	1
parathion**	57.1	85.7	85.7	100.0	14.3	4	0	0
toxaphene**	0.0	19.0	52.4	100.0	38.1	8	7	0
dieldrin**	9.5	33.3	52.4	95.2	38.1	8	5	1
methoxychlor	19.0	33.3	66.6	66.6	33.3	7	7	7
lead arsenate	0.0	14.3	71.3	85.7	28.6	6	3	3
DDD	4.7	4.7	47.6	76.1	52.4	11	6	5
DDT	0.0	4.7	38.1	47.6	52.4	11	9	9
Aramite	0.0	4.7	42.8	61.9	52.4	11	7	7
nicotine	0.0	4.7	57.1	66.6	33.3	7	7	7
aldrin	0.0	0.0	19.0	66.6	61.9	13	5	5
Check I #	0.0	0.0	52.4	76.1	38.1	8	7	5
Check II ##	0.0	0.0	38.1	71.3	57.1	12	4	4

* all were diluted at the concentration of 1 to 1600 (see Table

** all aphids either were dead or moribund when daily counts were made 1 day after aphids were placed in cages.

\# this check for the lindane, dieldrin, aldrin, parathion and nicotine treatments.

\## this check for the methoxychlor, DDT, DDD, toxaphene, lead arsenate, and Aramite treatments.

of the test. There are several indications, however, which are evident. Lindane and parathion were highly toxic to the larvae, killing them before more than a few pupated. One adult emerged. Toxaphene caused 100 percent mortality by the end of the test. Methoxychlor was not as highly toxic to the larvae. The dieldrin treatment showed very high mortality. It should be noted, however, that all of the aphids supplied for food were dead in the dieldrin, as well as the lindane, parathion, and toxaphene treatment. Nearly all of the adults which emerged in these four treatments died, whereas those with healthy aphids lived. The test illustrates the difficulties which are involved in testing coccinellid larvae. Such known factors as cannibalism, effect of food supply, and active development through instars cause variability in the results. The two check treatments varied considerably in results.

THE STETHORUS LADY BEETLE.

The techniques used for exposing the larger, aphidophagous coccinellids were not satisfactory for residue tests with the small mite-eating _Stethorus punctillum_. The major reasons for the difficulty were: 1) the beetles tended to fly when cages were opened for observation and when transparent specimen boxes were substituted for test cages, residues prevented seeing inside; and 2) there was very high mortality in the untreated checks within 1 or 2 days after the beetles were introduced.

Laboratory tests with this species were inconclusive, although there was an indication that parathion and DDT were very highly toxic to the adults.

RESULTS OF FIELD INVESTIGATIONS

THE OCCURRENCE AND PREVALENCE OF COCCINELLIDS IN MASSACHUSETTS.

Observations in the field showed that certain lady beetles predominate in some areas and other species do not. In general distribution, the following were most numerous: *Stethorus punctillum* Weise; *Adalia bipunctata* Muls.; *Coccinella transversoguttata* Fald.; and *Ceratomegilla fuscilabris* Muls. The following species were moderately abundant: *Coccinella novemnotata* Herbst.; *Hippodamia convergens* G. - M.; *Hippodamia tredecimpunctata* L.; and *Anatis quinquepunctata* Oliv. The following species were found only occasionally and in very small numbers: *Cycloneda munda* Say; *Coccinella perplexa* Muls.; and *Hippodamia parenthesis* Say. The following species were found only rarely: *Adalia frigida humeralis* Say; *Brachyacantha ursina* Fab.; *Hippodamia glacialis* Fab.; *Chilocorus stigma* Say [= *bivulnerus* Muls.]; *Scymnus* spp.; and *Cleis picta* Rand. All of the observations pertained to lady beetles in association with mite and aphid colonies.

Some species of aphidophagous lady beetles were found to predominate in one habitat more than in others, although most are considered to feed on a wide variety of aphids, and to be non-selective of prey.

A. bipunctata was the only species present in large numbers in apple orchards, on shade trees, especially Norway maple, on spirea, and on horse nettle. It was found only in small numbers on vegetable and other low-growing plants.

The most abundant species on vegetable crops such as cabbage, broccoli, cucurbits, and lettuce was C. transversoguttata. Moderately abundant were H. convergens, H. tredecimpunctata and C. novemnotata. All of these species remained on vegetables which grew next to apple orchards, with little migration between the two areas. A. bipunctata also remained on the apple trees. Even after the vegetable crops were plowed under, C. transversoguttata did not move to the apple trees, but to weeds and flowers.

C. fuscilabris was the most common lady beetle on corn, Sudan grass, and other field crops which were infested with aphids. It was seen occasionally on vegetables, but rarely on apple, shade trees, or garden crops. When several hundred marked adults of *C. fuscilabris* were placed at breast height in apple trees, all but a few crawled down the trunk into the grass within one hour. After one day none were found in the trees. On the other hand, the two-spotted lady beetle was observed to crawl upward usually on apple trees and remain on terminals if aphids were present.

S. punctillum, a species introduced from Europe, was the only lady beetle found which fed exclusively on mites. Dr. E. A. Chapin of the United States National Museum identified several series of beetles as that species. *S. punctum* Lec., a native species, was not found. Putman (1955) stated that in Ontario, *punctillum* apparently has replaced *punctum*, since all records from 1940 to date have proven to be *punctillum*.

The stethorus lady beetle was found in great numbers where mites were abundant enough to cause damage: apple (see Fig. 16A), willow, oak, maple, arborvitae, hemlock, spruce, rose, raspberry, phlox, corn, dandelion, dockweed, and other plants. The appearance of stethorus lady beetle populations apparently is associated with abundance of mites rather than calendar dates. Large colonies of the predator were found in different stages of development in the same local area and were associated directly with the time when mites began to build up. Putman (1955) found that the adults have a long ovipositional period and lay large numbers of eggs where mite infestations begin to develop.

THE EFFECT OF EIGHT PESTICIDES ON PREDATORS WHEN APPLIED IN THE FIFTH COVER SPRAY, MAIN ORCHARD, WALTHAM, 1951.

Eight blocks of apple trees were sprayed during 1951 for control of plum curculio and apple maggot and two rows of Baldwins were left unsprayed (Table 14). No coccinellids had been present in early summer, except for some in Block V and the Check. The interval between earlier sprays was shorter and aphids which had started to increase were treated with an aphicide on June 26. As aphids began to build up again and cover sprays were put on less frequently, coccinellids migrated into the test blocks.

Actual counts of lady beetles and syrphid larvae and estimates of aphid infestation were recorded 2 days before and 4 days after the fifth cover spray which was applied on July 26. The treatments throughout the season as well as those applied in the fifth cover spray are given in Table 15.

ROW	A	B	C	D	E	F	
	TREE						
1	*	*	*	*	*	*	MCINTOSH
2	*	*	*	*	*	*	
3	*	*	*	*	*	*	R.I.GREENING
4	*	*	*	*	*	*	
5	*	*	*	*	*	*	WEALTHY
		II			I		
6	*	*	*	*	*	*	
7	* b	*	*	* a	*	*	BALDWIN
		CHECK			CHECK		
8	* d	*	*	* c	*	*	
9	*	*	*	*	*	*	MCINTOSH
10	*	*	*	*	*	*	
		IV			III		
11	*	*	*	*	*	*	GRAVENSTEIN
12	*	*	*	*	*	*	
13	*	*	*	*	*	*	NORTHERN SPY
14	*	*	*	*	*	*	
15	*	*	*	*	*	*	RED DELICIOUS
16	*	*	*	*	*	*	
17	*	*	*	*	*	*	RED SPY
18	*	*	*	*	*	*	CORTLAND
19	*	*	*	*	*	*	MIXED VARIETIES
		V I			V		
20	*	*	*	*	*	*	
21	*	*	*	*	*	*	EARLY MCINTOSH
22	*	*	*	*	*	*	MCINTOSH
23	*	*	*	*	*	*	GOLDEN DELICIOUS
24	*	*	*	*	*	*	KENDALL
		VIII			VII		
25	*	*	*	*	*	*	MACOUN

↓ N

Table 14. Location of varieties, trees, and blocks, Main Orchard, Waltham Field Station, 1951.

Table 15. Spray materials applied to experimental plots in 1951 for apple pest control tests, Main Orchard, Waltham Field Station

PLOT	VARIETY	CALYX THROUGH SECOND COVER			THIRD TO THE FIFTH COVER		
		pesticide*	formulation	pounds/100	pesticide*	formulation	pounds/100
I	Wealthy	toxaphene	40 W	2			
		DDT	50 W	1	same as earlier sprays		
II	"	EPN	25 W	0.5	same as earlier sprays		
III	McIntosh	methoxychlor	50W	1	same as earlier sprays PLUS		
	Gravenstein	lead arsenate	97W	2	Aramite	15 W	1.5
IV	"	methoxychlor	50 W	2	same as earlier sprays PLUS		
		lead arsenate	97 W	1	Aramite	15 W	1.5
V	mixed	dieldrin	15 W	1	DDT	50 W	2
					lead arsenate	97 W	2
					malathion	25 E.C.	1 pt.
VI	"	aldrin	25 W	2	DDT	50 W	2
					lead arsenate	97 W	2
					Genite	25 W	2
VII	G. Delicious	methoxychlor	50 W	2	DDT	50 W	2
	Kendall				lead arsenate	97 W	2
	Macoun				Aramite	15 W	1.5
VIII	"	DDT	50W	2	DDT	50 W	2
		lead arsenate	97W	2	lead arsenate	97 W	2
					Aramite	15 W	1.5

* All plots received 2% superior oil in delayed dormant and a fungicidal treatment with sulfur (5 lbs./100 gal.) and ferbam (3/4 lb/100 gal) as prepink and pink sprays. Sulfur (4 lbs./100 gal.) and ferbam (1/2 or 3/4 lb./100 gal.) was applied with each spray thereafter: calyx - May 14; 1st cover - May 22; 2nd cover - May 28; 3rd cover - June 20; 4th cover - July 10; and 5th cover - July 26. Exceptions: no sulfur, but ferbam alone at 1 lb./100 in 4th and 5th cover sprays; aphid spray of nicotine sulfate 1 pt. per 100 gal. on June 26.

All of the treatments eliminated the coccinellids and reduced the number of syrphid larvae (Table 16). Not a single lady beetle was found in the treated blocks. Since each treatment contained DDT or methoxychlor, the observations are in agreement with findings in the laboratory tests in which residues of both materials killed lady beetles.

In all blocks, aphids were abundant enough to support lady beetles before treatment. Following the sprays, aphids were light in Blocks III, IV, and VII, and of questionable abundance for supporting lady beetles.

In the untreated check, aphids were numerous, but a sharp decrease in coccinellids was noted following the sprays in adjacent treated blocks. Syrphids were slightly, if at all, affected. During the application of sprays in the fifth cover, there was considerable drift of the spray material. The effect of drift on the lady beetles was also observed earlier on the same trees. Counts taken

Table 16. Coccinellid adults and larvae and syrphid larvae in eight sprayed and one unsprayed blocks before and after the fifth cover spray. Main Orchard, Waltham, 1951.

BLOCK	NO. TREES OBSERVED	PESTICIDES*	COCCINELLIDS July 24	COCCINELLIDS July 30	SYRPHIDS July 24	SYRPHIDS July 30
I	2	DDT, toxaphene	1	0	17	5
II	2	EPN	0	0	13	9
III	3	meth.,ld.,Aram.	2	0	17	17
IV	3	"	1	0	15	10
V	3	DDT, ld., mal.	2	0	42	7
VI	3	DDT, ld., Genite	6	0	33	4
VII	3	DDT, ld., Aram.	0	0	23	6
VIII	3	"	2	0	23	11
TOTALS	22		12	0	183	69
CHECK	3	none	36	10	57	56
Ave. no. per sprayed tree			0.54	0.0	8.3	3.1
Ave. no. per unsprayed tree			12.0	3.3	19.0	18.3

*Applied July 26. See Table 15 for rates of application.

from June 27 to July 16 on every tree in the unsprayed Baldwins, showed a total count of 243, or an average of 20.2 lady beetles per tree the day before the fourth cover spray. Two days after adjacent blocks were sprayed there was a total count of 28, or an average of 3.3 lady beetles per tree.

Observations in the untreated Baldwin trees showed that outside sources of lady beetles are important in relation to the coccinellid abundance in orchards. It was noted that the eastern half of the two rows of Baldwins had many more lady beetles than the western half. Check bd counts were 193 on July 10, whereas Check ac counts totaled 50. A total of 5 observations from June 27 to July 16 gave 241 and 64 for each half respectively. Survey data in areas surrounding the orchard revealed that A. bipunctata, the only species of consequence in the in the apple trees, was very numerous on spirea, horse nettle, and crab apple. In late June adults were emerging in numbers at those sites and migrating to the orchard, occupying trees nearest to the source from which they had come.

THE EFFECT OF FOUR PESTICIDE COMBINATIONS ON PREDATORS IN APPLE TREES.

In the "Dwarf Orchard" at the Waltham Field Station, four insecticidal treatments in combination with fungicides were applied from the calyx to the sixth cover spray to blocks of 20 trees each. Counts of all predators and estimates of aphid infestation were made on the same branches at intervals from June 20 to July 29, the period including the fourth, fifth, and sixth cover sprays.

The location of trees, varieties, and blocks, the treatments, and the dates of application are given in Table 17. Only a single insecticide was used in each block for the entire season, and the fungicides were the same in all blocks, thus the insecticides can be compared directly in relation to their effects on predators.

The abundance of aphids during the observation period was unaffected by the treatments and was sufficient to support lady beetles. An estimated level of 40 percent or more out of a

Table 17. Location of varieties, trees, and plots in the Dwarf Orchard, Waltham, 1952, with a list of treatments and spray dates.

	block A	block B	block C	block D
BALDWIN	* * * * *	* * * * *	* * * * *	* *
GOLDEN DELICIOUS	* * * * *	* * * * *	* * * * *	* * *
MACOUN	* * * * *	* * * * *	* * * * *	* * * *
STARKING	* * * * *	* * * * *	* * * * *	

↑ N

BLOCK	PESTICIDE	FORMULATION	POUNDS / 100 GAL.
A	dieldrin	25 WP	0.5
	sulfur*	95 WP	3.0
	ferbam*	76 WP	0.75
B	lead arsenate	97 WP	4.0
	sulfur *	95 WP	3.0
	ferbam *	76 WP	0.75
C	dieldrin	25 WP	1.0
	sulfur*	95 WP	3.0
	ferbam*	76 WP	0.75
D	sulfur*	95 WP	3.0
	ferbam*	76 WP	0.75

* after the 3rd cover, sulfur was omitted and ferbam was used alone at 1 lb./100.

SPRAY	DATE
Calyx	May 19
1st cover	May 28
2nd cover	June 3
3rd cover	June 11
4th cover	June 23
5th cover	July 8
6th cover	July 25

possible maximum or very heavy infestation is considered adequate to support lady beetle populations. The aphids declined in numbers in all blocks except A during the latter part of July. A heavy infestation of the European red mite in Block B, C, and D in the middle of July led to cessation of new succulent growth and the gradual disappearance of the aphids, especially in C and D.

The effect of each treatment on lady beetles is discussed below followed by the effect of each on other predators. The adults and larvae of the coccinellids are used to indicate the abundance, while the egg counts are included to show the activity of the adults in oviposition.

In Block A, which was treated with dieldrin at 0.5 pound per 100 gallons plus fungicides, coccinellids were numerous. Prior to the fourth cover spray, the number of larvae was high because of two groups of recently hatched eggs (Table 18). The decrease from June 20 to June 23

Table 18. The estimated aphid abundance given as the percent of a theoretical maximum infestation in four blocks of apple trees, Dwarf Orchard, Waltham, 1952.

DATE OBSERVED	Estimated aphid infestation (percent)*			
	BLOCK A	BLOCK B	BLOCK C	BLOCK D
6-20	75	73	40	51
6-23	86	84	40	53
6-24	84	82	37	55
7-1	91	80	37	57
7-7	100	93	55	66
7-10	86	86	55	64
7-15	46	82	37	31
7-18	60	64	26	20
7-29	60	42	6	7

*Calculated by adding the ratings of estimated aphid abundance on all count branches and dividing that by the highest possible total if all branches were completely infested.

to June 24 resulted mostly from cannibalism and dispersion of the larvae over the tree. The decrease in numbers after the fourth cover spray was not greater than that which occurred when no sprays were applied. Counts after the fifth cover spray were higher than those made before the application. After the sixth cover, counts were low in this as well as all blocks due to the natural seasonal decline of lady beetles. No eggs were laid in any trees after July 15. Dieldrin did not eliminate the lady beetles nor prevent a population from developing in the trees.

In Block B, which was treated with lead arsenate at the rate of 4 pounds per 100 gallons, large fluctuations in the number of adult and larval lady beetles are evident as in Block A, but are not associated with the treatments. Counts after the fourth cover spray are lower, but the decrease of adults was not greater than that which occurred earlier when no sprays were applied. The high egg counts show that adults were active in the block despite the treatment. Larvae increased in numbers following the fifth cover spray. The drop from 5 to 3 adults is not considered as a result of the spray, since adults actively move about in the trees.

In Block C, which was treated with twice the concentration of dieldrin used in Block A, coccinellids increased in numbers following the fourth cover spray and were only slightly lower after the fifth cover. The number of eggs increased indicating that the adults were active in ovipositing in spite of the treatment.

In Block D, which received only fungicide applications and no insecticide, there were fewer larvae and adults after the fourth and fifth cover sprays than before, but the change was not significant on the basis of the known habits of the beetles in moving about on the trees. More eggs were laid in this block than in any of the other three.

The two-spotted lady beetle and the few

individuals of other species were not eliminated by any of the treatments. The total number observed in each block is large and little variation is shown which can be attributed to treatments (Table 19 and Figure 15).

No direct comparison was made with other pesticides in this test, but observations in apple trees at other times showed that malathion, methoxychlor, and DDT completely eliminated lady beetles and no populations developed, although aphids were abundant.

Counts of the stethorus lady beetle were made during regular collection of field data, in the same blocks described for aphidophagous lady beetles, when a mite infestation developed in July. Mite counts were not made, but gross relative estimates were noted. Block A had the lightest infestation and Block C, the heaviest. Stethorus lady beetles were most numerous in the most heavily infested areas and were unaffected by the treatments applied (Figure 16). As many as 14 and sometimes

Table 19. Numbers of eggs, larvae, and aphids of coccinellids observed in four blocks of apple trees during the period of the fourth, fifth and sixth cover sprays.*

	6-20	6-23	6-24	7 -1	7 -7	7-10	7-15	7-18	7-29	TOTAL
	BLOCK A (dieldrin at 0.5 lb. 50W/100 gal.)									
Eggs	6	12	12	16	30	0	0	0	0	76
Larvae	35	22	10	11	5	10	12	9	1	115
Adults	6	2	1	5	0	6	0	3	2	25
Tot. A & L	41	24	11	16	5	16	12	12	3	140
	BLOCK B (lead arsenate at 4.0 lb. 97W/100 gal.)									
Eggs	0	37	56	24	19	37	0	0	0	157
Larvae	13	14	7	7	14	18	24	11	3	111
Adults	6	2	0	0	5	3	1	6	0	22
Tot. A & L	19	16	7	7	19	21	25	17	3	133
	BLOCK C (dieldrin at 1.0 lb. 50W/100 gal.)									
Eggs	6	17	8	0	20	47	12	0	0	110
Larvae	6	4	5	11	15	11	19	15	6	92
Adults	5	0	4	3	7	3	1	1	2	26
Tot. A & L	11	4	9	14	22	14	20	16	8	118
	BLOCK D (fungicides only)									
Eggs	0	24	60	12	25	64	0	0	0	188
Larvae	0	10	8	28	23	23	11	9	0	112
Adults	0	5	4	1	6	0	0	3	0	19
Tot. A & L	0	15	12	29	29	23	11	12	0	131

* The fourth cover spray was applied on June 23, the fifth on July 8, and the sixth on July 25.

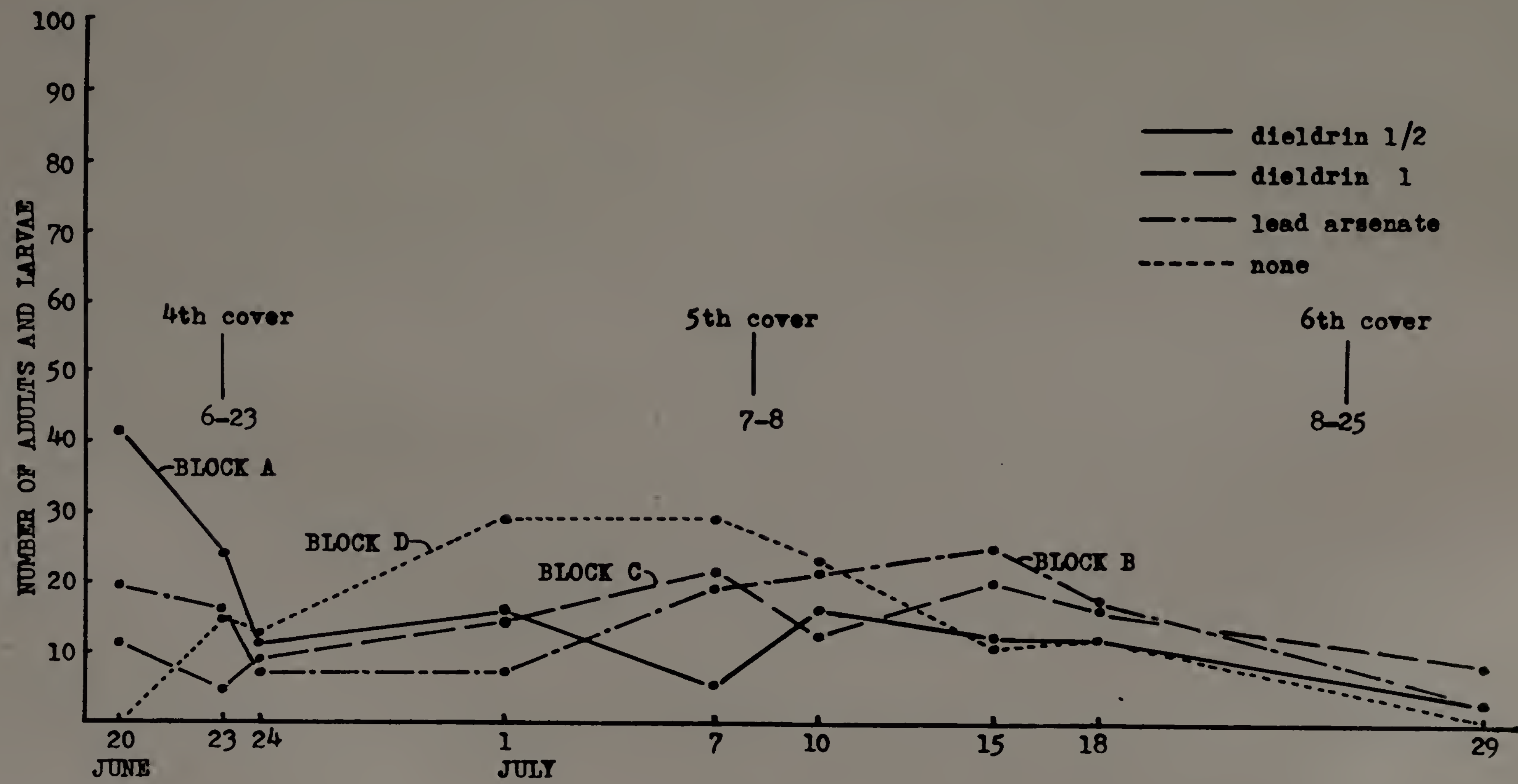


FIGURE 15

Total numbers of adult and larval coccinellids during the period of the fourth, fifth, and sixth cover sprays in four blocks of apple trees, Dwarf Orchard, Waltham, 1952

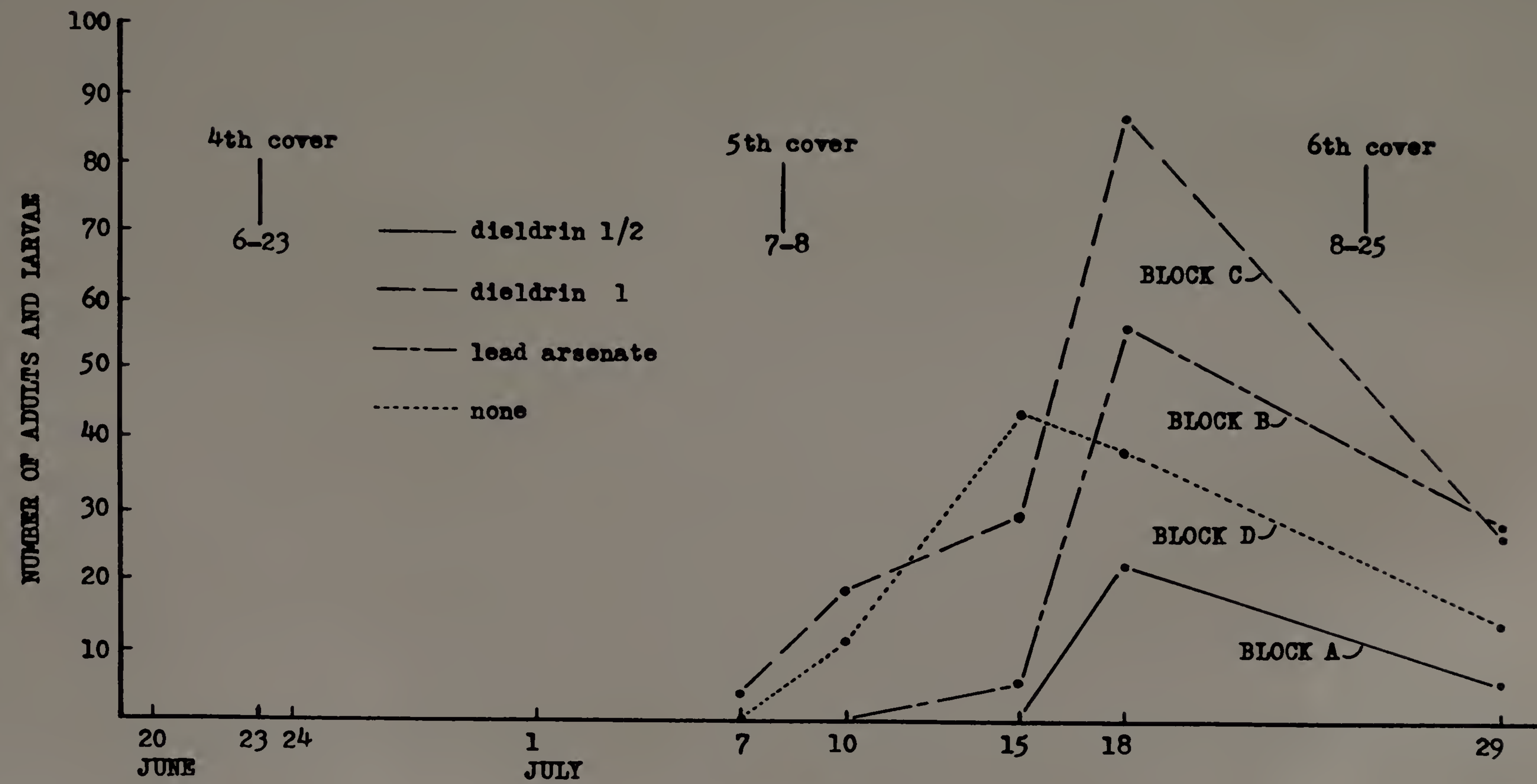


FIGURE 16

Total numbers of adult and larval Stethorus during the period of the fourth, fifth, and sixth cover sprays in four blocks of apple trees, Dwarf Orchard, Waltham, 1952.

FIGURE 16 A

Larvae and pupae of Stethorus punctillum Weise clustered in a naturally-occurring group for pupation on an apple leaf (1.5X). (Photograph by J. A. Weidhaas) more larvae were found on each leaf feeding and pupating. The low numbers of predators on July 29 in all blocks resulted from the depletion of mites rather than the spray treatments.

The counts of syrphid larvae made in the same plots are shown in Figure 17. Although it appears from the graph that the heavier concentration of dieldrin had a deleterious effect on the syrphid larvae, the level of aphid infestation is indicated in Table 18 to be low in that block. Whereas the blocks receiving insecticidal treatments showed lower syrphid counts than the check on July 1, they showed higher counts than the check on July 10, following the fifth cover spray. Thus it is evident that the sprays had only slight effects on the predators. It should be pointed out that exposure to sprays is not so likely with syrphids as with coccinellids. The syrphid larvae are sluggish and do not so actively move about on the plants. They usually are found along veins and in curled leaves where they are at least partially protected.

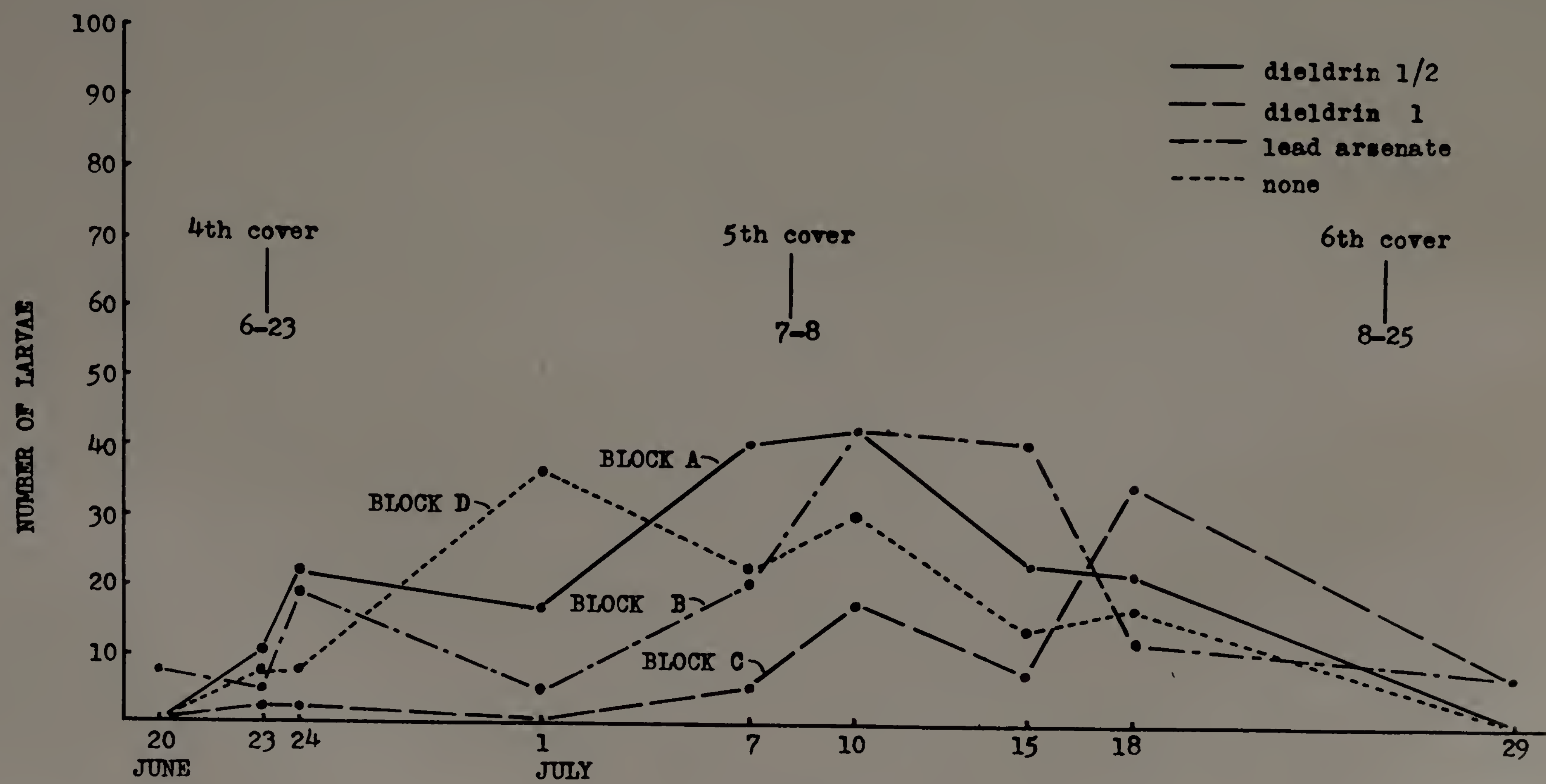


FIGURE 17

Total numbers of syrphid larvae observed during the period of the fourth, fifth, and sixth cover sprays in four blocks of apple trees, Dwarf Orchard, Waltham, 1952.

The total number of predators of all types in the four blocks is shown in Figure 18. The data include larvae of the Neuroptera (lacewing flies). Predators moved into the orchard blocks and developed sizeable populations in spite of the application of the fourth, fifth, and sixth cover sprays (Figure 18). There may have been a depressing effect of the sprays which included insecticides up through the fourth cover spray. However, the increase in all blocks following the fifth cover show that the sprays were not highly toxic to the predators. It is possible that the peaks of predator abundance may have occurred earlier in July and reached higher levels, but data from plots receiving no treatment were unavailable.

THE EFFECT OF COMMERCIAL SPRAY APPLICATIONS ON THE STETHORUS LADY BEETLE AND ITS PREY, ASSABET ORCHARD, HUDSON, MASS., 1953.

A block of Starking apple trees was selected for studies in 1953, when large numbers of *S. punctillum* were found preying on the two-spotted

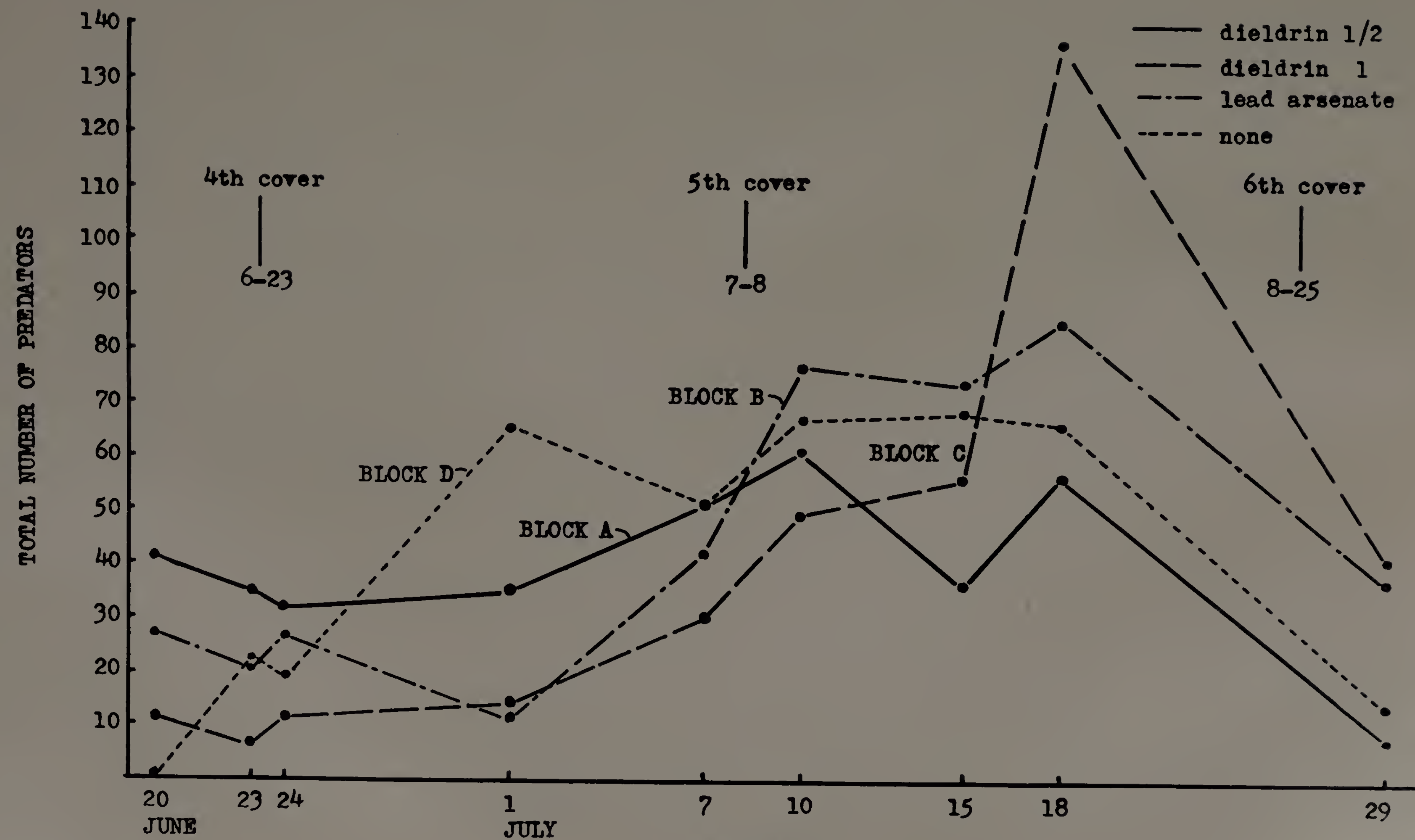


FIGURE 18

Total numbers of active predators observed during the period of the fourth, fifth, and sixth cover sprays in four blocks of apple trees, Dwarf Orchard, Waltham, 1952.

mite infesting dandelion ground cover. Observations were recorded from May through August to determine the interaction between the predator and the mites in relation to the effect of commercial spray operations.

Three trees were selected which were uniform in size, growth habit, vigor, density of foliage, and dandelion ground cover. Mite populations were sampled by counting the various stages of the two-spotted mite on 15 dandelion leaves and the European red mite on 30 leaf samples from the trees. Stethorus counts were obtained by the timed visual-inspection method to which were added the larvae observed when mite counts were made. Also recorded were the number of predacious mites and thrips.

The sprays were applied by the grower as follows; at rates of application given in the Apple Spray Schedule for Massachusetts, 1953:

April 6, 10	sulfur dust
April 24, 30	ferbam spray
May 5	sulfur dust
May 9, 15	ferbam spray
May 19, 25, June 1	methoxychlor, lead arsenate, ferbam
June 12, 28, July 8	DDT, lead arsenate, TEPP, ferbam

The effects of the spray must be considered in relation to the levels of mites as well as the predators, their location on the ground cover or the trees, and the timing of the treatments. The data graphed in Figure 19 is also given with supporting data in Table 20. Both are necessary to explain the occurrence and abundance of the lady beetle.

On May 27 there were mites infesting the apple trees in the plot but few Stethorus were present. No acaricidal materials had been applied to the trees, but methoxychlor had been included in sprays from May 19 through June 1. In spite of the applications of methoxychlor, which is highly toxic

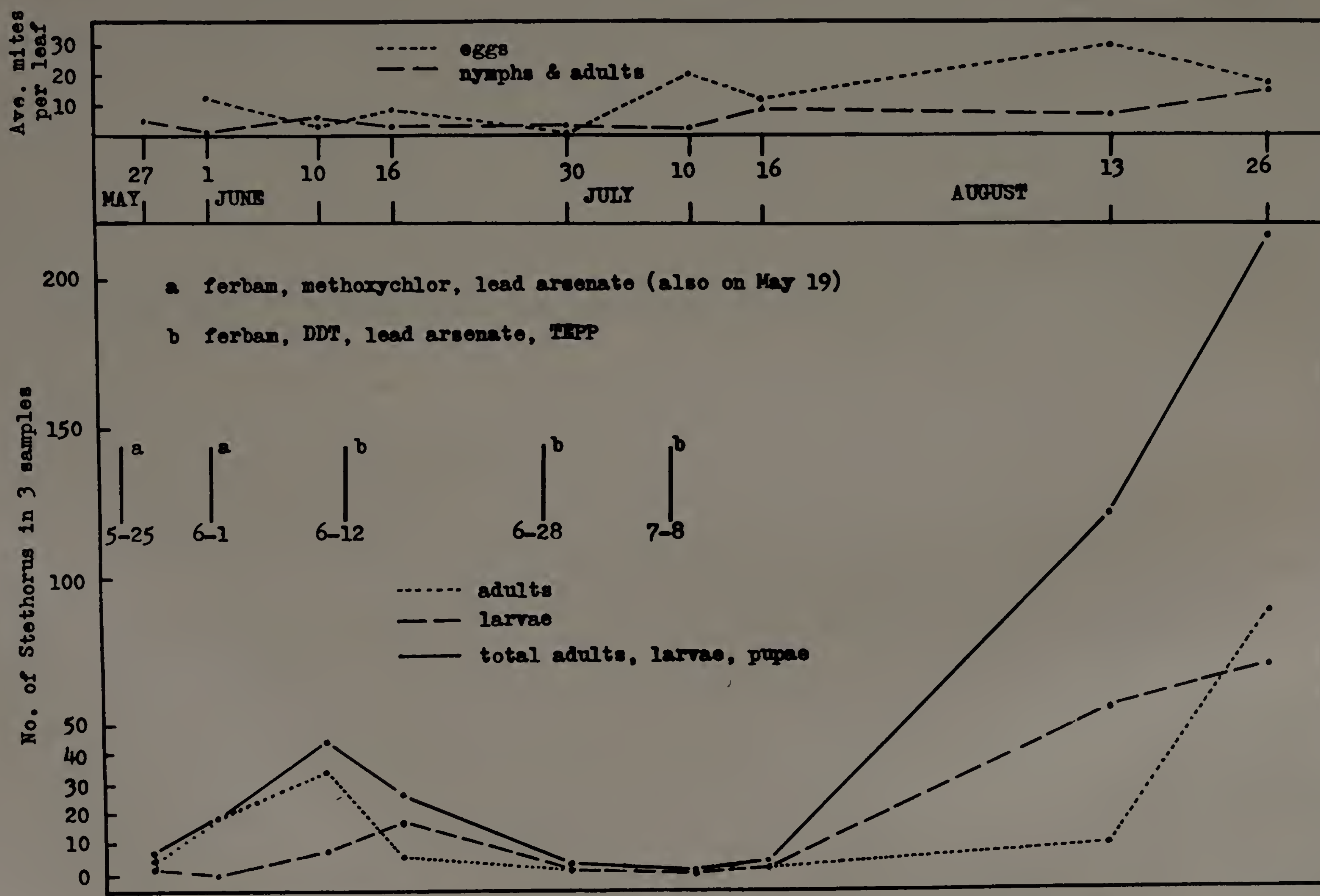


FIGURE 19. Estimates of abundance of the European red mite and <u>Stethorus punctillum</u> in a Starking block, Hudson, Mass., in relation to five commercial spray applications, May through August, 1953.

Table 20. Observations of mites and predators in a block of Starking apple trees during one season of commercial pesticide schedule, Assabet Orchards, Hudson, Mass.

		5/5	5/27	6/1	6/10	6/16	6/30	7/10	7/16	8/13	8/26
		AVERAGE NUMBER OF MITES PER LEAF BASED UPON 30 LVS. FROM EACH OF 3 TREES									
Metatetranychus ulmi	EGGS	-	-	11.2	2.2	7.5	0.1	19.6	11.4	29.1	17.1
	ACTIVE STAGES	-	4.9	0.6	4.8	2.6	1.7	0.2	8.1	6.4	13.6
Tetranychus telarius	EGGS	-	0.0	0.0	0.0	-	0.0	0.2	0.0	0.0	0.0
	ACTIVE STAGES	-	0.0	0.0	0.0	-	0.2	0.0	0.4	0.0	0.0
		AVERAGE NUMBER OF MITES PER LEAF BASED UPON 3 GROUPS OF 5 DANDELION LVS.									
Tetranychus telarius	EGGS	250.0	90.0	33.0	0.0	-	-	-	-	-	-
	ACTIVE STAGES	65.0	88.0	62.0	0.05	-	-	-	-	-	-
		TOTAL NUMBER OF PREDATORS COUNTED ON THREE TREES AND ON GROUND SAMPLES									
Stethorus punctillum GROUND	A	-	1	1	0	-	-	-	-	-	-
	L	-	9	44	0	-	-	-	-	-	-
Stethorus punctillum TREES	A	-	5	19	35	6	1	0	2	20	179
	L	-	2	0	8	17	2	0	1	113	142
	P	-	0	0	2	4	0	1	1	111	109
TOTAL STETHORUS		-	17	64	45	27	3	1	4	244	430
PHYTOSEIIDAE	N & A	-	0	2	0	0	1	-	63	161	-

to *Stethorus*, numbers of the lady beetle increased up until June 10. Table 20 shows that the *Stethorus* larvae on the dandelion transformed to adults and migration of the adults to the trees took place, accounting for the increase at the time sprays were applied. When the treatments which started on June 12 included TEPP, the mites were killed as well as the predators which had little prey on which to feed. When spraying ceased after July 8 the mites began to increase, and *Stethorus* once again became numerous. Although the two-spotted mite had been a problem late in the season in previous years on the same trees, only a very few were found in the trees and no spray was necessary to control them. The early buildup of the stethorus lady beetle, its subsequent dispersal, and its repopulation account for the low numbers of European red mite in August and the absence of two-spotted mites in the block on apple trees.

OBSERVATIONS ON THE EFFECT OF PARATHION ON *STETHORUS PUNCTILLUM* WEISE NATURALLY PREYING UPON AN INFESTATION OF *TETRANYCHUS TELARIUS* L. IN PLANTINGS OF *RUBUS IDEAUS* L.

In a backyard planting of red raspberry, the owner had applied a spray of 15 percent parathion wettable powder at the rate of 1.5 pounds per 100 gallons of water to control the two-spotted mite. Following the treatment on July 25, 1953, observations were recorded of predator abundance at four intervals until August 25. Mite counts were made on two of the dates.

In two sprayed plots and one untreated plot, mite counts were obtained by sweeping 10 leaves from each plot with a mite brushing machine (Henderson and McBurnie, 1943) as illustrated in Figure 3. The numbers of *Stethorus* were determined by counting adults and larvae during a 5 minute observation period in each plot.

Parathion gave reasonably good control of the mites, although some reinfestation occurred at least 3 weeks later (Table 21). Stethorus was eliminated in plots by parathion. Dead larvae and adults of Stethorus were found on the treated plants. Several pupae were collected the day after treatment and brought into the laboratory for observation. After 5 days 3 adults emerged from the pupae collected in the untreated plot, whereas no adults emerged from 9 pupae taken on sprayed leaves. Dead pupae were also observed in field counts (Table 21). They remained black as is normal for live pupae, but gradually became dried in appearance and no emergence occurred.

THE EFFECT OF METHOXYCHLOR ON STETHORUS PUNCTILLUM.

In Amherst, on the University campus, several white willow trees, Salix alba L., which supported populations of the willow mite, Schizotetranychus schizopus (Zacher) and large numbers of Stethorus were sprayed, in June 1952, to control the imported willow leaf beetle. The effect of the treatments on the mite and on Stethorus was determined for this project.

Table 21. Mites and predators observed on red raspberry plants following treatment with parathion wettable powder on July 25, 1953.

DATE	UNSPRAYED		SPRAYED	
	Ave. no. mites/leaf	No. *Stethorus* adults & larvae	Ave. no. mites/leaf	No. *Stethorus* adults & larvae
July 26	-	16	-	0
Aug. 6	68.0	8	0.0	0*
Aug. 20	69.8	38	18.8	2
Aug. 25	-	26	-	3

*Found 11 dead pupae, 3 dead larvae in mite counts.

Mites and predators were sampled by taking 3 groups of 10 leaves to obtain an average mite count and by examining three sections of branch about 1 yard long for counts of larval and adult *Stethorus*. The spray treatment consisted of 1 quart of 24 percent methoxychlor emulsifiable concentrate per 100 gallons and was applied on June 4 with a Friend hydraulic sprayer operated at 700 p.s.i.

The mites in trees A and C reached approximately the same proportions by the latter part of June, while lower population levels existed in tree B. *Stethorus* beetles had started populations in all three trees (Table 22), but the sprays applied to B and C eliminated them for the first part of June. In the unsprayed tree, *Stethorus* was effective in maintaining lower populations of mites in contrast to tree C, where many adult mites were present to lay large numbers of eggs late in June. The methoxychlor treatment came at a most critical time in relation to the life cycle of the mite. Also, the treated blocks

Table 22. Seasonal observations of the willow mite and Stethorus predators in relation to methoxychlor sprays applied to control the willow leaf beetle, U. Mass., Amherst.

DATE	Ave. no. mites per leaf and total adult and larval Stethorus					
	Untreated		Treated*			
	TREE A		TREE B		TREE C	
	MITES	STETH	MITES	STETH	MITES	STETH
May 28	8.5	9	0.8	4	4.0	6
June 9	-	11	-	0	-	0
June 23	46.3	14	9.0	1	48.0	0
June 29	58.0	22	35.0	4	190.0	3
July 7	65.0	11	49.0	10	230.0	6
July 14	40.2	40	33.5	16	35.7	18
July 21	29.6	55	25.4	24	40.2	24
July 29	6.4	47	0.04	0	0.0	0
Seasonal Total Stethorus		209		59		57

* 1 qt. 24 percent emulsifiable per 100 applied June 4.

did not show a sizeable increase in the numbers of the predator until nearly three weeks later than in the unsprayed. Consequently a very highly significant number of Stethorus was obtained as a total seasonal sum.

EFFECT ON THE TRANSVERSE LADY BEETLE OF DIRECT EXPOSURE TO THE ORCHARD APPLICATIONS SPRAYED WITH A HARDIE HYDRAULIC MACHINE.

To determine the effect of direct orchard spraying on lady beetles, caged C. transversoguttata adults were placed in wire-mesh screen cages and hung in trees just prior to the application of the fifth cover spray on July 21 in the Dwarf Orchard and July 25 in the Main Orchard, Waltham, 1952.

Three adults in each of three cages were placed in each of 14 plots, all but one of which received sprays. The treatments were made with a Hardie hydraulic power sprayer operating at 800 p.s.i. Immediately after the sprayer had passed the trees, the cages were removed to the laboratory where the beetles were placed in clean cages and observed for three days.

Methoxychlor and EPN killed the beetles in one day, except in one instance where they died the second day (Table 23). Dieldrin at 0.5 and 1.0 pounds of 25 percent WP per 100 gallons and lead arsenate at 4.0 pounds per 100 gallons produced no mortality, as in the untreated checks. In tests four days earlier with acaricides, Sulphenone and ovex were slightly toxic, while Aramite and Chlorobenzilate produced mortalities lower than those of the check.

THE EFFECT OF DIRECT APPLICATIONS OF FOUR PESTICIDES ON COCCINELLIDS.

Immediately after the fourth cover spray had been applied, beetles were collected from each of 4 plots in the Dwarf Orchard, placed in clean cages, and observed 1 and 3 days later.

Malathion killed all lady beetles within the first day after the exposure. Perthane and Compound 1189 killed all of the two-spotted lady beetles, but only 50 and 25 percent respectively,

Table 23. Mortalities of the transverse lady beetle resulting from direct exposure to field applications of orchard pesticides applied with a Hardie hydraulic sprayer, at 800 p.s.i., Main and Dwarf Orchards, Waltham Field Station, 1952.

PLOT	MATERIAL*	FORMULATION	POUNDS/100	NO. EXPOSED	PERCENT MORTALITY 24 hours	PERCENT MORTALITY 72 hours
I	EPN	25% WP	1.5	9	100	-
II	methoxychlor toxaphene	50% WP 50% WP	2.0 2.0	9	100	-
III	methoxychlor	50% WP	2.0	9	89	100
V	methoxychlor	25% EC	1.5 qts.	9	100	-
VIII	methoxychlor lead arsenate	50% WP 97% S	2.0 2.0	9	100	-
IX	dieldrin	25% WP	0.5	9	0	0
X	lead arsenate	97% S	4.0	9	0	0
XI	dieldrin	25% WP	1.0	9	0	0
XII	none	-	-	9	0	0
II	none	-	-	9	11	22
III	ovex	50% WP	2.0	9	11	33
IV	Aramite	15% WP	2.0	9	0	0
VII	Chlorobenzilate	25% EC	1.5 pts.	9	0	11
VIII	Sulphenone	50% WP	3.0	9	33	44

*In all but the second Plot II, fungicides were included with the insecticides as given in the 1952 spray schedule, Main Orchard, for the Fifth Cover.

of the other species. No beetles died which were sprayed with fungicides only.

MORTALITY OF LADY BEETLE ADULTS EXPOSED TO APPLE FOLIAGE TREATED IN FIELD APPLICATIONS.

Apple leaves from around the periphery of orchard trees and from water sprouts in the center of the trees were placed in cages and _C. transversoguttata_ adults were exposed to them to determine if the spray deposits from regular field applications were toxic. From the outer parts of the branches, 5 medium-sized leaves were selected. From the water sprouts, sprout tips with 2 to 4 leaves were taken. The latter were infested with aphids.

Figure 20 shows that methoxychlor - TEPP - ferbam spray residues on peripheral leaves killed all of the beetles. High mortality resulted among beetles on leaves from water sprouts. DDT - lead arsenate - ferbam residues on outer leaves produced 100 percent mortality, but those from water sprouts caused none. Beetles exposed to foliage from inside

Table 24, The effect of direct spray applications of 4 pesticide combinations on lady beetle adults, Dwarf Orchard, Waltham Field Station, 1953.

BLOCK	PESTICIDE	FORMULATION	AMT. PER 100 GAL.	SPECIES EXPOSED	NO. EXPOSED	PERCENT MORTALITY 1 day	3 days
X	malathion, ferbam	25% EC 76% WP	1.5 pts. 1.0 lbs.	*A. bipunctata*	9	100	-
				others*	3	100	-
XI	Perthane captan	50% WP 50% WP	4.0 lbs. 2.0 lbs.	*A. bipunctata*	8	100	-
				others*	6	50	50
XII	Comp. 1189 ferbam	** 76% WP	1.0 lb.	*A. bipunctata*	8	100	-
				others*	4	25	25
XIII	ferbam sulfur	76% WP	0.75 lb. 3.0 lbs.	*A. bipunctata*	10	10	10
				others*	10	0	0

* Others included: Block X - *C. transversoguttata*, *A. 15-punctata*, *C. munda*; Block XI - *C. novemnotata*, *C. transversoguttata*, *C. munda*; Block XII - *C. transversoguttata*, *C. munda*; Block XIII - *C. novemnotata*, *C. transversoguttata*, *C. munda*.

** General Block chemical experimental insecticide, formulation and amount used not known.

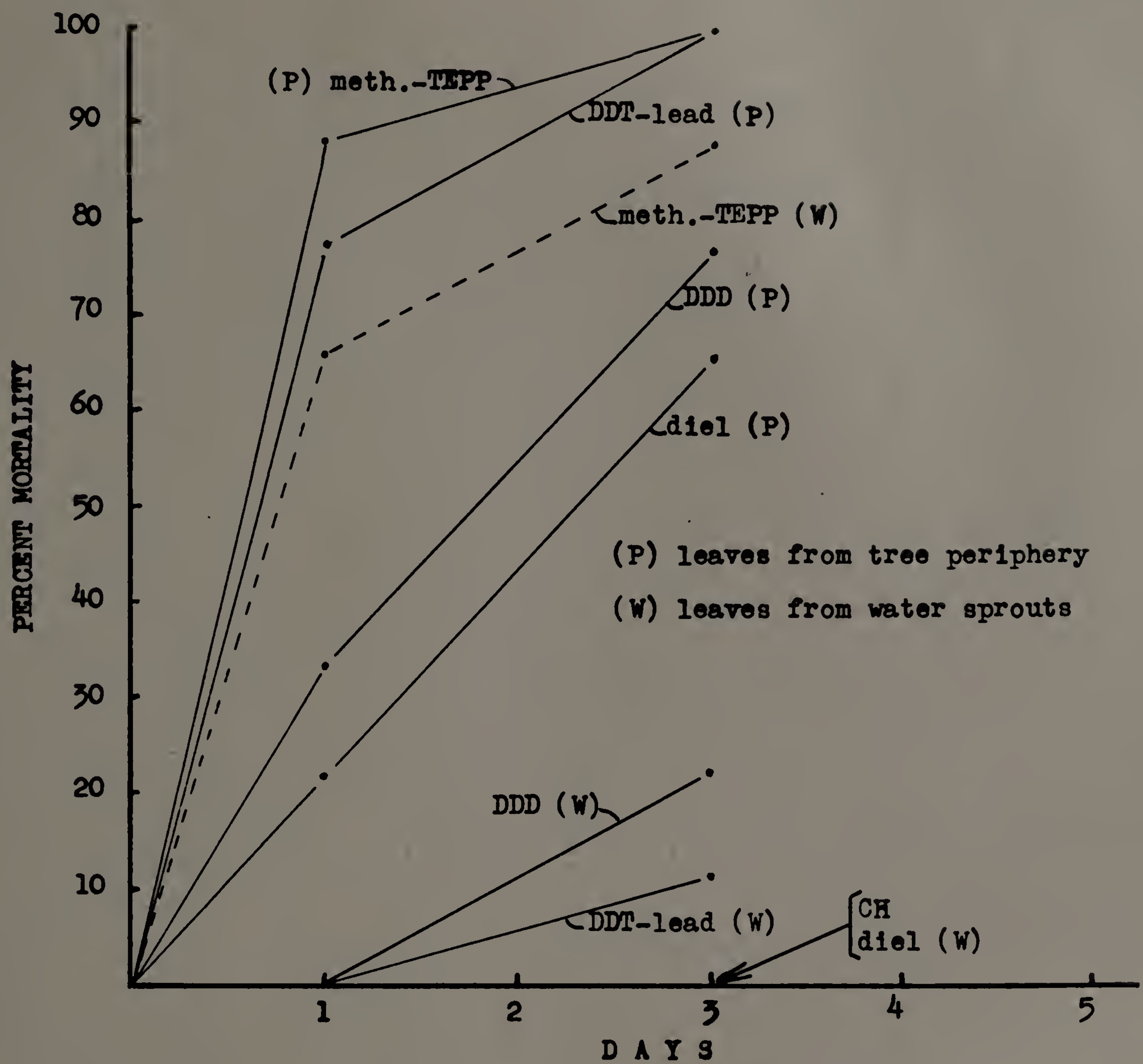


FIGURE 20

Mortality of adult transverse lady beetles exposed to treated leaves from the tree periphery and water sprouts in the centers of trees sprayed with three pesticide combinations.

the tree sprayed with DDD - ferbam, fieldrin - ferbam - sulfur, and ferbam - sulfur combinations had slight or no effect on the lady beetles. DDD and dieldrin did produce moderate toxicity as residues on outer leaves, whereas the fungicidal residue alone did not.

GENERAL OBSERVATIONS OF THE OCCURRENCE OF COCCINELLIDS IN YOUNG APPLE ORCHARDS AND THE EFFECT OF SPRAY TREATMENTS APPLIED ONCE.

Studies were conducted to determine the occurrence and abundance of lady beetles in young, non-bearing apple orchards, since aphids are often important pests and since few pesticides are applied except to insure maximum growth. Such orchards offer promise for the application of integrated biological and chemical control.

A survey of blocks of Early McIntosh trees in Amherst, East Warren, and Groton, and McIntosh in Waltham showed that the occurrence of lady beetles varies in different locations. Table 25 shows that only 5 lady beetles were found on 16

Table 25. The relative abundance of lady beetle species in four young, non-bearing apple orchards widely separated in Massachusetts, 1954.

SPECIES	NUMBER OBSERVED* WALTHAM	WARREN	GROTON	AMHERST	TOTAL
Adalia bipunctata	34	2	4	13	53
Hippodamia convergens	4	0	3	4	11
Coccinella transverso-guttata	4	1	1	9	15
Coccinella novemnotata	6	0	0	5	11
Cycloneda munda	1	2	0	4	7
Hippodamia tredecimnotata	1	0	0	1	2
Hippodamia parenthesis	1	0	0	1	2
Coccinella perplexa	0	0	1	0	1
TOTAL COCCIN. OBSERVED	51	5	9	36	101
No. trees observed	5	16	20	8	49
Ave. no. coccin. per tree	1.70	0.05	0.07	1.13	2.03

*Numbers represent the total counted in 6 visits to each orchard except in Amherst, which is the sum of 4 visits.

trees in Warren although no sprays were applied except one experimental treatment. Observations in surrounding areas suggested that few beetles were present in the entire area which was mostly wooded and pasture. In Groton few lady beetles were observed, but investigations in other trees showed that the effects of malathion sprays applied at frequent intervals throughout the summer killed lady beetles and some eggs which were laid. In Waltham and Amherst, large coccinellid populations were available and the trees were not sprayed except for one test in Amherst. The abundance of coccinellid species in surrounding areas on vegetable and garden plants was found to contribute to the general abundance of lady beetles over the whole general area.

In Amherst and East Warren, groups of 4 trees arranged in the orchard in Latin Square design were sprayed with pesticides to determine: 1) the effect of residual, non-aphicidal type materials, and 2) the effect of non-residual, aphicidal types. The sprays were applied with a 5-gallon Indian-type knapsack sprayer at dilution rates recommended in apple spray schedules. Counts of lady beetles and estimated of prey before and at two intervals after treatment are shown in Table 26. Records of plant growth and incidental biological data were recorded also. Although insufficient numbers of coccinellids were present during the test at East Warren, the counts are shown for two purposes: 1) in the few instances where lady beetles were found, the majority occurred in the dieldrin treatment, supporting other data elsewhere that dieldrin is not highly toxic; and 2) the effects of TEPP, malathion, and nicotine sulfate on aphids is apparent. In the tests at Amherst, where sufficient lady beetles were present, DDT and methoxychlor eliminated the lady beetles whereas dieldrin did not. None of the three reduced the aphids appreciably. TEPP, malathion, and nicotine sulfate caused extensive reductions in the aphids but did not kill the lady beetles

Table 26. Abundance of coccinellids on young trees in an apple orchard before and after treatments of three non-aphicidal and three aphicidal insecticides, Amherst and Warren, Mass.

TREATMENT #	AMHERST					WARREN				
	Ave. aphid index		No. coccinellids			Ave. aphid index		No. coccinellids		
	before	after	before	1 day after	4 days after	before	after	before	1 day after	9 days after
none	1.9	2.3	7	10	3	2.2	2.5	0*	0**	0
DDT	2.5	2.1	9	0	0	2.2	1.8	0	0	0
methoxychlor	2.1	2.2	11	2*	0	2.2	2.5	0*	0	0
dieldrin	2.2	2.4	11	8	3	2.5	2.3	0*	1	10
none	2.8	3.1	6	12	3	2.1	2.4	0	0**	4*
TEPP	2.8	1.2	5	3	0	3.0	0.8	1	0	0*
malathion	3.0	1.6	4	1	0	3.4	0.9	0	0	2*
nicotine	2.8	1.1	5	2	0	2.2	1.0	0	0	4*

Treatments were mixed at the same concentration as in the laboratory tests and were equivalent to recommended dosages in the apple spray schedule.

*Ants were present in the plots, in one or two of four trees.
**Ants were present in all of the trees in each plot.

as residues. The lady beetles were affected indirectly over a longer period by the reduction of the prey. Counts 4 days after treatment show that lady beetles had left due to lack of prey.

A DISCUSSION OF THE PROBLEM AND THE RESULTS OF INVESTIGATIONS

Studies of the effects of pesticides on entomophagous coccinellids are complicated by certain factors not ordinarily encountered in investigations with phytophagous insect pests.

The first factor is the predator-prey relationship. The location and density levels of aphids and mites determine the presence and abundance of lady beetles whether or not pesticides are applied. Prey populations may fluctuate because of poor host condition, natural migration of aphids to their alternate hosts, feeding activities of predators, the application of pesticides and for other reasons. Such fluctuations must be considered when interpreting the effect of pesticides on coccinellids in field plots.

A second complication lies in the interpretation of mortality. When insecticides are used against phytophagous pests, reduction in abundance of the pests in treated plots is usually assumed to result from mortality caused by the insecticides.

With entomophagous species, a similar assumption cannot be made. Although the reduction may be due directly to the toxicity of the insecticide, it may also be due to the natural or insecticide-induced starvation of the lady beetles or to their migration to other areas in search of prey.

A third complication is the inadequacy of standard testing procedures. In laboratory tests, techniques for screening insecticides such as the minimum lethal dosage (MLD) or dosage necessary to kill 50 percent of a population (LD50) are of little value. The problem is to determine the mortalities produced by the standard recommended dosage used in spray programs, not the dosages which produce a given mortality. In field tests, the standard technique for counting individuals is in itself inadquate. Estimates of prey must be included also and plots must be large enough to make it possible to observe the development and fluctuations of both predators and their prey in relation to the long term as well as short term effects of chemical treatments.

The laboratory methods used in these investigations, for exposing coccinellids to heavy residues which they could not avoid, gave uniform results with replications and consistent results over a three-year period, even when test specimens were obtained from various sources. The method, used by other workers, of confining lady beetles in cages with treated foliage was found to be inadequate.

THE DIRECT EFFECTS OF PESTICIDES ON COCCINELLIDS.

The pesticides can be grouped into three categories: highly toxic, moderately toxic, and slightly or non-toxic.

Pesticides Found Highly Toxic.

This group includes parathion, malathion, TEPP, methoxychlor, and DDT. The residues of the organic phosphates, malathion and parathion killed all adults of *A. bipunctata*, *H. convergens* and *C. transversoguttata* and *S. punctillum* within 4 hours to 2 days. Sprays of wettable powders applied directly to the beetles also resulted in 100 percent mortality. Sprays of TEPP applied directly caused high mortality. TEPP leaves no toxic residue. Both residual phosphates completely eliminated all species of lady beetles, including _S. punctillum_ in treated plots. _Stethorus_ pupae were also killed by parathion. These results are in agreement with those of other workers, who have conducted tests with _H. convergens_ and other species not found or not common in Massachusetts. The evidence indicates that lady beetles are killed and populations are eliminated by the phosphates, malathion and parathion.

Lady beetles were very highly susceptible to methoxychlor, moreso than to any other chlorinated hydrocarbon tested. No beetles survived exposures to residues, even when reduced to one-half and one-quarter the concentration recommended in spray schedules. Adults of the convergent lady beetle all died when exposed for only 30 minutes. Of those which walked on residues for only 10 minutes, 83 percent died within three days. When beetles were sprayed directly with water suspensions, mortalities were lower. No evidence has been found in the literature on the effects of methoxychlor on lady beetles. These tests clearly show that it is very highly toxic. In field plots of apple at Hudson and on willow trees in Amherst, no populations developed and beetles migrating into sprayed areas were killed.

In literature, most reports of pesticidal effects on lady beetles are in reference to DDT and pertain to field observations incidental to other studies. No data are available on the two-spotted or transverse lady beetles.

From the residue tests reported here, DDT was highly toxic to _A_. _bipunctata_, _H_. _convergens_, and _C_. _transversoguttata_, at concentrations recommended in spray schedules. However, an occasional adult survived. At reduced concentrations and when beetles were exposed for 10 hours or less to residues, less mortality occurred and more beetles survived, recovering from the mild trembling symptoms produced by DDT. Apparently DDT is not so highly toxic to lady beetles as is methoxychlor, although in field plots treated regularly with DDT no lady beetle populations developed.

The possibility that DDT has a repellent effect on the beetles was indicated in limited tests. Adults were observed less frequently on treated than untreated surfaces and mortalities were lower than in the check. Repellency has also been suggested by Yothers and Carlson (1948).

Pesticides Found Moderately Toxic.

DDD was moderately to highly toxic to the two-spotted lady beetle and moderately to slightly toxic to the convergent lady beetle. The results with the transverse lady beetle are not strictly comparable to those for the first two species, since only the 1 to 1600 dilution was tested. Slight mortality of the transverse lady beetle was observed. DDD as aged residues and as direct sprays was only slightly, if at all, toxic in all tests. In those tests where some mortality occurred with DDD, the beetles died within the first two days, after which only a few died. At the end of the tests, there was about the same mortality as in the checks.

Toxaphene was moderately toxic, but was included in only a few tests since it is seldom recommended in spray schedules for Massachusetts.

Aldrin was moderately to slightly toxic in these tests. It was not tested as extensively as most of the other materials.

There was more variation in the mortalities with materials that caused moderate mortality than with those showing high toxicity. The convergent lady beetle appeared less susceptible than other species to the toxic effects of the insecticides in this group.

Pesticides Found Slightly Toxic or Non-Toxic.

Dieldrin produced some mortality of the two-spotted lady beetle adults during the first two days of exposure to residues, but after 3 to 5 days there was about the same mortality as in the untreated check. The convergent lady beetle tests showed only slight mortality. With all species tested, there was no mortality from exposure to aged residues or direct sprays. When concentrations of dieldrin were increased to 4 and 6 times the recommended amount beetle mortality from residues was only moderate. The increased mortalities were consistent with the increased dosage. All beetles which survived any treatments with dieldrin appeared normal at the end of the tests and recovered from mild symptoms observed occasionally. In orchard tests, dieldrin sprays applied over an entire spray season did not prevent the two-spotted and stethorus lady beetles from becoming established and increasing in numbers.

Dieldrin is considered one of the most long-lasting and most highly toxic insecticides when used against many pests. In apple orchards it has given as effective, if not better, control of plum curculio than methoxychlor, which in turn is more effective than DDT. In relation to lady beetles, these studies show that while methoxychlor and DDT are highly toxic to lady beetles, dieldrin always produced only slight or moderate toxicity, depending upon the concentration used. The differential toxicity between the materials for lady beetles is particularly important in light of the interchangeability of all three of those chlorinated hydrocarbons for control of certain pests, especially in orchards.

Although some preliminary evidence has been reported of low toxicity of dieldrin to other species in California and the convergent lady beetle on cotton, this is the first conclusive evidence of the effects of dieldrin on the species of coccinellids in Massachusetts.

The acaricides, ovex and Aramite, as residues did not produce mortalities greatly different from that of the untreated check. In some instances there was slightly more mortality in the first 2 or 3 days. In field studies, ovex applied for the control of the spruce mite did not reduce the stethorus population through toxic action, but only indirectly by removal of the prey.

The fungicides ferbam, captan, Phygon, and sulfur gave the same general results as did the acaricides. Little, if any, toxicity was suggested. Occasionally ferbam showed slightly more mortality early in the tests. Little data were found in the literature on the effects of fungicides on lady beetles. These studies, including extensive field tests with ferbam, show that fungicides are generally non-toxic to lady beetles.

The effects of lead arsenate, nicotine sulfate, and TEPP are difficult to evaluate from these studies. Lead arsenate leaves a long lasting residue, but its mode of action is that of a stomach poison rather than a contact insecticide. A few beetles died in some of the laboratory tests, moreso than in untreated checks, but how the residue affected the beetles is not understood. In the field it is possible that beetles may drink from water droplets containing arsenic from the residues. Adults were observed to take water after long storage periods without food, but were never seen drinking water in the field, presumably since they obtain adequate moisture from their aphid prey. In laboratory tests there was no source of water in the cages, because residues were dried thoroughly before the beetles were introduced.

The toxic effects of nicotine sulfate and TEPP are of very short duration, since they leave no residue. No mortalities resulted in laboratory tests when cages were treated with these materials. Neither is considered to be important in keeping down lady beetle populations but some temporary reduction might result when direct sprays kill beetles before they oviposit or kill larvae.

THE INDIRECT EFFECTS OF PESTICIDES ON PREDACIOUS COCCINELLIDS.

The elimination of prey, at critical times, by pesticides indirectly affects the abundance and development of lady beetles. Lady beetles either starve so that local populations are decimated or migrate so that they are widely dispersed.

In field studies, nicotine sulfate depleted aphids, and ovex and Aramite depleted mites, without apparent harm to coccinellids which had become established in the prey colonies. TEPP and malathion eliminated both the predators and the prey. The prey usually became re-established whereas the predators did not because they had either died from pesticides, lack of food, or had moved to other areas.

Chemical sprays may have indirect beneficial effects on coccinellids. There is better foliage, maximum new growth, little competition from other phytophagous pests and in general, the most ideal food conditions for all plant-eating pests. In unsprayed orchards, however, very poor plant conditions were observed. Leaves were severely damaged by apple scab and by leaf-feeding insects, an unfavorable environment for prey and subsequently for predators.

Predators such as lady beetles have an abundance of food in sprayed orchards. If the sprays do not contact or are not toxic to the predators, then larger populations of the beneficial species would exist than where no sprays were applied. This condition was observed in two field plosts. In Hudson, where large mite populations were present on dandelions, Stethorus beetles not exposed to spray drip reached remarkable numbers early in the season. The dieldrin plots in Waltham showed that where aphids increased on sprayed trees and lady beetles were not killed, they built up in numbers and effectively reduced the aphids.

Large aphid and mite populations attract coccinellids into orchards where the predators are killed by pesticides not toxic to the prey. DeBach and Bartlett (1951) have referred to this as "trap effects."

FACTORS WHICH ALTER THE EFFECT OF PESTICIDES ON COCCINELLIDS.

Timing and Frequency of Application of Sprays.

It has been observed often that home-owners

and spray

operators apply acaricides too late to prevent damage from the spruce mite. The mite population usually had begun to subside because the mites destroyed most of their food supply and large numbers of the stethorus lady beetle were present. The use of chemicals highly toxic to lady beetles at such a time killed both the mites and the predators. The proper timing of those sprays, such as malathion, when mites are just beginning to develop, give control before the predators become established. Early treatments thus prevent damage from the mites and cause little if any harm to the beneficial insects.

Sprays not toxic to the stethorus lady beetle, applied before the larvae have completed development, caused high losses of the predator due to starvation and the inability of larvae to migrate to other distant mite-infested areas. If sufficiently abundant to effect some mite control, the predators should be allowed to complete development before the sprays are applied. This can be done when the mite infestation has been discovered too late to prevent damage. Proper timing of sprays to prevent mite buildup and damage would minimize the harmful effects on the predators.

The frequency of spraying is also important. Highly toxic pesticides applied at short intervals for control of plum curculio in apple orchards was found to eliminate coccinellids. However, lady beetles were able to live for longer periods, feed for some time on aphids, and occasionally complete development to the adult stage during the period of "cover sprays" because the interval between applications was greater.

The Proper Selection of Pesticides.

The selection, where possible, of a material which has the least harmful effects to beneficial insects offers the most promise of integrating biological and chemical control.

In apple orchards there is a choice of dieldrin or methoxychlor for control of plum curculio in early season sprays. Both give excellent control, but dieldrin does not eliminate lady beetles and permits them to work effectively in sprayed plots whereas methoxychlor is very highly toxic.

For control of the spruce mite and other species, when stethorus lady beetle adults are present, the use of acaricides such as ovex which are of low toxicity to the predator, would permit the beetles to survive and establish themselves elsewhere.

Where pests can be controlled with non-residual materials such as nicotine sulfate and TEPP, lady beetles can migrate into sprayed orchards very soon after treatment without being adversely affected to feed on those aphids not killed by the treatment.

Workers, such as Ripper _et_ _al_. (1949, 1950, 1951) and Ahmed (1955), have shown that systemic insecticides exhibit a high degree of selectivity for pest species while not being harmful to their predators.

Effects of Predator Abundance Near Sprayed Areas.

Where populations of the two-spotted lady beetle and the stethorus lady beetle occurred near orchards, the toxic effects of orchard sprays were minimized by the migration of adults into the trees when spraying was stopped. Where no such outside sources existed, the local population was decimated by the sprays and few other beetles were present to establish new colonies. Some workers have suggested establishing suitable plants for prey in marginal areas so that predators and parasites would be available to repopulate sprayed areas (Marcovitch, 1935 and Geijskes, 1938).

In these investigations, the willow mite, which is host specific, was found to support large numbers of the stethorus lady beetle. Such trees planted near orchards and infested artificially with mites could provide large numbers of predators with no threat to infestation on the crop trees.

SUMMARY

A review of the available literature has shown that no studies have been conducted to determine the extent to which commonly used pesticides affect the lady beetle predators of aphids and mites in northeastern United States. The available data pertain to other species and are based on observations supplementary to pest control experiments.

Laboratory tests were devised and conducted to determine the relative toxicities of pesticidal residues, in formulations and concentrations used by growers, to adult coccinellid species found in Massachusetts. Exposures of beetles under controlled conditions showed that pesticides such as most phosphates, methoxychlor and DDT were very highly toxic, that others were only moderately toxic, and still others including dieldrin, some acaricides and fungicides were slightly if at all toxic.

Field tests were conducted in orchards primarily and data on predators, prey, and spray

treatments were analyzed to determine the effect of pesticidal applications on predator populations under field conditions. Malathion, methoxychlor, and DDT eliminated lady beetles in apple orchards. Dieldrin at 0.5 pounds actual per 100 gallons did not eliminate lady beetles; these increased in treated plots and reduced aphid and mite infestations.

CONCLUSIONS

The common statement that pesticides eliminate natural enemies of pests is a generalization which needs clarification. In these studies, certain spray materials were found to be highly toxic to beneficial Coccinellidae and others were moderately, slightly, or non-toxic as residues. The principal conclusions are:

1) Lady beetles are one of the most important groups of predators of aphids and mites on apple trees in Massachusetts. Two species predominate: the two-spotted lady beetle, *A. bipunctata* Muls. and the stethorus lady beetle, *S. punctillum* Weise. *Stethorus* was found to be a major mite predator on many types of plants where mites were abundant.

2) Parathion, malathion, methoxychlor, and DDT as residues and direct sprays of wettable powder formulations were highly toxic to adults of *Adalia bipunctata* Muls., *Coccinella transversoguttata* Fald., *Hippodamia convergens* G.-M., and *Stethorus punctillum* Weise in laboratory and field tests.

3) Toxaphene, aldrin, and DDD residues were moderately toxic to adult lady beetles in laboratory tests.

4) Dieldrin was only slightly toxic to the lady beetles tested in the laboratory. In apple orchards, coccinellids, including the stethorus lady beetle, were abundant and increased in numbers where repeated applications of dieldrin were made during an entire spray season.

5) The acaricides, ovex and Aramite, and the fungicides, sulfur, ferbam, captan and Phygon, were only slightly if at all toxic to lady beetles in residue tests.

6) Non-residual aphicides and acaricides non-toxic to lady beetles adversely affect coccinellid populations indirectly by eliminating their prey.

7) Coccinellids can be favored by the proper selection of pesticides and timing of applications.

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APPENDIX I

ANNOUNCEMENT OF FELLOWSHIP

At The

WALTHAM FIELD STATION OF THE UNIVERSITY OF MASSACHUSETTS

Through the generosity of the Massachusetts Society for Promoting Agriculture, a fellowship is available to study the Effect of New Organic Pesticides on Beneficial Insects.

Objective - To determine the extent to which the new pesticides kill parasitic and predatory beneficial insects and spiders when used in modern control practices.

Justification - Reports indicate that red spider, aphis, and similar pests of fruit trees, shade trees, and perennial plants have increased following sprays with DDT and other organic pesticides because the natural enemies of the pests have been killed. There is little definite information that this occurs, or, if so, to what extent and under what conditions.

Procedure - Beneficial insects, such as ladybird beetles, leatherwing beetles, lacewing flies, syrphus flies, bumble bees, and some internal parasites will be exposed to normal residues of DDT, methoxychlor, chlordane, lindane, parathion, dinitro compounds, fermate, sulfur, and similar pesticides.

Anticipated Results - To secure information showing that some pesticides are less harmful to beneficial insects; and to develop a pest control program which will utilize the optimum benefits from both pesticides and natural enemies.

Personnel - A graduate student working for advanced degrees is preferred. It is desirable that the student be registered in the Graduate School of the University of Massachusetts, Amherst, Massachusetts, which is one of the few schools in eastern United States having accredited graduate courses in Entomology. According to the terms of the fellowship, the summer field work must be done at the Waltham Field Station, Waltham, Massachusetts.

Duration - The fellowship will be available for at least three years. The advisability of continued work would be determined from progress reports.

Financial Support - Approximately, one thousand dollars ($1,000) is available in the first year to equip a laboratory and supply materials. A grant of eighteen hundred dollars ($1,800) is available annually for three years for personal service, maintenance, and travel. If registered in the Graduate School, the student must pay the regular tuition fees.

May 1, 1951.

APPROVED BY:

Dr. Frank R. Shaw, Thesis Chairman
Professor of Entomology

Dr. Ellsworth H. Wheeler
Extension Entomologist

Dr. Constantine J. Gilgut
Extenstion Plant Pathologist

Dr. Henry N. Little
Professor of Chemistry

Dr. Walter D. Weeks
Assistant Professor of Pomology

Prof. Warren D. Whitcomb, Project Director
Professor of Entomology

Dr. Charles P. Alexander
Head, Entomology Section
Department of Entomology and Plant Pathology

Dr. John H. Lilly
Head, Department of Entomology and Plant Pathology

APPROVED DATE: May 26, 1959