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CONTROL OF DIABROTICA, OR WESTERN SPOTTED CUCUMBER BEETLE, IN DECIDUOUS FRUIT ORCHARDS

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CONTENTS

CONTROL OF DIABROTICA, OR WESTERN SPOTTED CUCUMBER BEETLE, IN DECIDUOUS FRUIT ORCHARDS[1]

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INTRODUCTION

THE WESTERN spotted cucumber beetle, *Diabrotica 11-punctata* Mann., is one of the most destructive native insects in California. This insect is most commonly known in California as "diabrotica." In order to avoid the frequent use of the more cumbersome name, the term diabrotica will be used in this bulletin. It attacks a great many cultivated crops and both the larvae and adults injure plants. The adults, however, are the more important and each year large sums of money are expended trying to control them. They are particularly destructive to some of the cucurbits, to beans, corn, and other truck crops. Under certain conditions deciduous fruits are seriously attacked. The degree of attack varies not only from year to year but between districts. Under severe conditions nearly all the ripening fruit may be injured. The beetles not only damage the fruit by direct feeding, but the injuries are a portal of entry for the brown rot organism. Request for the investigation of this pest as it affects deciduous fruits was made following the serious outbreak of 1938. The study was undertaken late that season and has been continued up to the present time. A preliminary report on the early work has been published (Michelbacher and associates, 1941).[5] The investigation has now progressed to a point where considerable information on life history, habits, and control has been accumulated, and is summarized in this bulletin.

In this publication diabrotica is considered only from the standpoint of its destructiveness to deciduous fruits, and the control measures given pertain to orchard crops only.

SYSTEMATIC POSITION

Diabrotica 11-punctata Mannerheim (1843)
Galleruca 11-punctata Eschscholtz (MS)
Diabrotica soror LeConte (1865)

The genus *Diabrotica* is one of the largest genera in the family Chrysomelidae. Many of its species are of economic importance. When *D. 11-punctata* was collected by the Russians in California, it was determined as *D. 12-punctata* (Fabr.). However, Eschscholtz in a letter to Mannerheim called it *Galleruca 11-punctata.* Later Mannerheim (1843) clearly distinguished it, but considered it a variety of *D. 12-punctata* and recorded it from California. LeConte (1865) described *D. soror* from specimens collected by John Xantus at Fort Tejon in 1857–58. The western spotted cucumber beetle has generally

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[5] See "Literature Cited" at the end of the bulletin for full data on citations which are referred to in the text by author and date of publication.

been known under the name *D. soror* LeConte (1865). As pointed out by the present authors (1941), however, the older name *D. 11-punctata* Mannerheim is available.

HISTORICAL SUMMARY

This beetle was first collected in California by the early Russian exploring expeditions. Eschscholtz took it in 1824 and later Tschernikh collected it on the expedition of 1833–1835 (Essig, 1931). This native insect must have been a pest of agriculture from early times although the first published record of it as a pest does not occur until 1877. In January of that year a letter from H. G. Newton of Pasadena, California, was published in the Pacific Rural Press complaining of injury to oranges and roses. The reply by the editor indicated that the insect had been a pest many times before.

The earliest report of injury to deciduous fruit was made by Comstock (1880) who reported considerable damage to apricots from Dixon, California. Cooke (1883) also recorded damage to apricots.

Practically no important papers have been published on diabrotica but a large number of isolated notes have been made on life history, habits, and control. Most workers have been content to assume that what applied to the eastern species of *Diabrotica* held true for *11-punctata.* Craw (1892), Lelong (1890), Koebele (1890, 1891), Coquillett (1890), Marsh (1907), Wymore (California Agricultural Experiment Station, 1927, 1929, 1930), Woodworth (1895), Campbell and Nixon (1921), Mote (1926), Besse (1936), Elmore and Campbell (1936), all mention the insect, usually as part of a general treatise. As editor of the *Pacific Rural Press,* Wickson (1877–1923) published a large number of letters reporting damage to various crops by this beetle. The most significant thing brought out by that series of complaints was the great variations in abundance of the beetles.

Doane (1897) was the first person actually to study our western species. He conducted life-history studies and described the egg, larva, and pupa. His brief notes on the habits of the immature forms agree very closely with those obtained by the present authors under controlled conditions.

Chittenden (1910) figured the egg and adult. Marsh (1907, 1908) mentioned considerable damage to cucurbits and other truck crops. Essig (1913) stated that there are two distinct generations whose broods overlap throughout the summer and he gave a partial host list. Later, Essig (1915) gave a brief review of the status of the beetle, figured the injury, gave a host list and control measures. Lovett (1913) drew heavily on the published information concerning the eastern species of this genus in his work on *Diabrotica 11-punctata.* His notes have been repeated many times in later Oregon publications.

Sell (1915) undertook to study the life history of diabrotica but was not very successful and encountered many difficulties. He discussed food habits, migration, enemies and "color phases." He did not obtain any stages beyond the egg. Wilson (1915) reported diabrotica as feeding on the leaves of young almond and apple trees and the fruit of peaches in Oregon.

Urbahns (1926) reported diabrotica as a pest of apricots and early peaches and suggested that the prevalence of these beetles was probably due in part to the late rains coming in June. Mackie (1936) reported the beetles as seriously injuring apricots in 1936. A few notes were made on the habits of the insect in the orchards during the previously reported study by Michelbacher and associates (1941), but no complete study of *D. 11-punctata* has ever been undertaken and, until the work of the present authors, no one had reared the insect through all the stages.

DISTRIBUTION

The genus *Diabrotica* is almost entirely confined to the two American continents and the West Indies. Over 800 species have been described and probably many more yet remain to be described (Weise, 1924). The largest part of the genus is confined to the tropical part of the Americas; a few species occur in the more temperate regions. North of Mexico there are 19 species and several varieties. About two thirds of these are restricted to the most southern regions of the United States, only 2 or 3 species finding their way into the north. Four species of *Diabrotica* occur in California, namely *D. 11-punctata* Mann., *D. trivittata* Mann., *D. balteata* Lec., and *D. 12-punctata* (Fabr.).

Diabrotica 11-punctata is most abundant in California and Oregon. It also extends into Washington, Arizona, New Mexico, and probably Mexico. It has been recorded from Boulder, Colorado (Cockerell, 1924) and doubtfully from Colombia, South America (Toro, 1929). Brisley (1925) is convinced that *D. 11-punctata* does not occur in Arizona and believes that reports to the contrary are incorrect.

HOST PLANTS

The host plants of *Diabrotica 11-punctata* can well be divided into two groups. One includes the plants upon which the larvae feed and the other those plants which serve as food for the adult. The list in both cases is very large and only some of the more important ones are given below. As would be expected, in many cases the same plant is utilized by both the larva and the adult.

ATTACKED BY LARVA

Grains:
- corn
- wheat
- barley

Cucurbits:
- melons
- cucumbers
- squash
- gourds

Legumes:
- alfalfa
- beans
- peas

ATTACKED BY ADULT

Truck and field crops:
- snap beans
- field beans
- corn
- artichokes
- sugar beets
- lettuce
- alfalfa
- sunflower

Fruit and nut crops:
- apricots
- peaches
- nectarines
- cherries
- almond

Flowering garden plants:
- feed on the flowers of most plants found in gardens, especially compositae.

ATTACKED BY ADULT—*Continued*

Cucurbits:
- squash
- melons
- cucumbers
- gourds

Uncultivated plants:
- mayweed (*Anthemis cotula*)
- ground buffalo gourd (*Cucurbita foetidissima*)
- manroot (*Echinocystis*)
- developing heads of both tame and wild grasses, and floral parts of many wild flowers.

Among the uncultivated plants there are several that are very attractive to the adults. Elmore and Campbell (1936) found that ground buffalo gourd attracted the beetles in large numbers. The present writers have observed the beetles concentrating and feeding heavily on manroot. This plant appears to be selected from all others and often suffers nearly complete defoliation. In the spring the pest concentrates in large number on mayweed, where it appears to be attracted to the flowers. The beetles feed heavily upon the petals and probably feed upon the pollen which is rich in protein.

The adults feed extensively upon all of the cultivated crops listed and, while almost any part of the host may be eaten, it is the floral parts that are usually most seriously attacked.

LIFE HISTORY

The larval and pupal stages of *Diabrotica 11-punctata* are spent in the soil. The adults lay their eggs about the bases of the plants just beneath the surface of the soil. The eggs are oval and yellowish but before hatching become dingy in color. The larvae, on hatching, start to feed upon the roots of their host plants. They are tan in color and covered with a scattering of rather long hairs. The head and prothoracic shield, as well as the strongly chitinized posterior end, are dark brown to nearly black. There are three larval stages. The greatest increase in weight occurs during the third larval instar. Upon reaching maturity the larvae construct an earthen cell, and after spending some time in a prepupal condition they pupate. After a varying period, according to the temperature, the adult emerges. The wing covers of newly emerged adults are soft, the spots are barely distinguishable, and the base color is gray. After a few days the wing covers harden, the spots turn black, and the base color becomes green. The stages in the life history of the insect are shown in figure 1.

In the laboratory the beetle was reared under constant-temperature conditions. The temperature in the cabinets did not vary more than 1.5 degrees Fahrenheit. Eggs were usually obtained from individuals collected in the field. A female beetle was placed in a cage made in the following manner. An ordinary 5-inch pie tin was filled with moist sand and covered with a circular piece of green blotting paper. A celluloid cylinder about 4 inches in diameter and 4½ inches high, covered with a piece of fine organdy held in place with masking tape, was placed on the blotter. The insects were fed lettuce, and eggs were readily laid on the blotting paper which was kept moist by adding water to the sand from time to time. The yellow eggs laid either singly or in batches could be readily detected on the green background.

The eggs were transferred to the type of rearing dishes used by Michelbacher (1938) for rearing the garden centipede. These dishes were made by thoroughly mixing 10 parts of plaster of paris, 3 parts finely ground soil, and 1 part animal charcoal. Water was added to the mixture and the whole stirred until the material had the consistency of rather thick cream. This was then

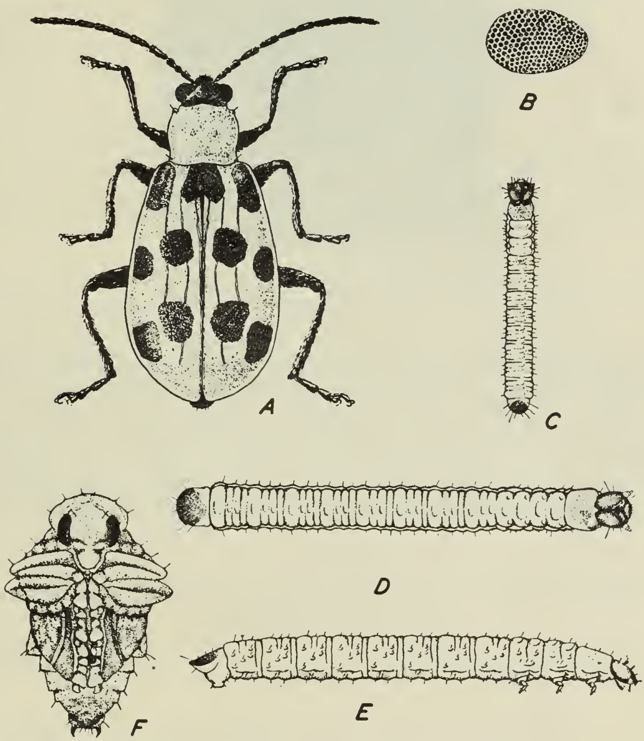

Fig. 1.—Life cycle of *Diabrotica 11-punctata* Mann.: *A*, Adult; *B*, egg; *C*, first instar larva; *D*, dorsal view of last instar larva; *E*, lateral view of last instar larva; *F*, ventral view of pupa. (All × 7, except the egg which is × 30.)

poured into stender dishes to about the depth of ¼ inch and allowed to set. These dishes were found to be very well suited for rearing individual larvae, and made accurate observations possible. The outside dimensions of the two sizes of dishes used were as follows: depth, 22 mm, and diameter, 38 mm; and depth, 30 mm, and diameter, 50 mm.

Upon hatching the larvae were separated, placed into individual dishes, and fed soaked wheat grains. It was found that grain soaked overnight provided an excellent food, and that the larvae fed readily even though the wheat had not germinated. Large larvae consumed the internal contents of several kernels in 24 hours. There was not much tendency for the larvae to bore into the grain and for this reason they could be readily observed during any stage in their development. Fresh food was given the larvae every day, or at least every other day, and moisture was added as needed.

It was found necessary to construct cells in which the full-grown larvae could pupate. When this was not done the larvae failed to pupate and after a

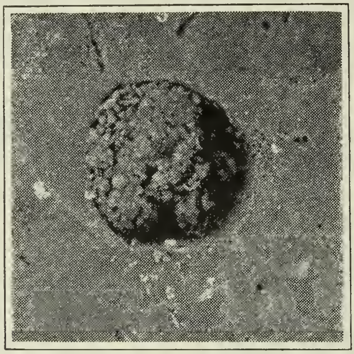

Fig. 2.—Lid constructed over the cell by diabrotica larva. (× 3.)

time died. The circular cells were dug in the "muck plate" with a stiff dissecting needle. They were made about ¼ inch in diameter and about as deep. The larva entered the cell and constructed a lid over it (fig. 2). The covering was made by scraping material from the sides of the cell and cementing it together with a secretion, apparently obtained from the caudal end of the larva. The larva gathered this secretion in its mouth parts and forelegs and built the lid

TABLE 1

NUMBER OF DAYS REQUIRED BY *Diabrotica 11-punctata* TO COMPLETE ITS DEVELOPMENT AT VARIOUS TEMPERATURES

Stage	60° F		68° F		75° F		80° F		85° F	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
	days	*days*	*days*	*days*	*days*	*days*	*days*	*days*	*days*	*days*
Egg	23–30	26.1	6–20	13.2	7–9	8.3	6–9	7.1	5–7	6.4
First instar	10–28	15.6	6–24	10.8	4–10	6.1	3–7	4.5	2–8	3.4
Second instar	9–14	12.0	5–10	7.1	3–7	4.6	2–5	3.6	2–5	3.5
Third instar:										
Feeding period	11–24	15.4	5–18	8.4	4–9	5.9	3–8	4.8	1–9	5.3
Prepupal period	8–17	12.4	4–9	6.9	3–7	4.8	2–5	3.8	1–4	3.0
Total*	24–38	28.1	10–25	15.2	9–24	10.7	6–11	8.5	5–12	8.2
Pupa	15–24	19.6	8–15	11.2	7–9	8.0	5–9	6.6	3–6	5.2
Total days hatch to emergence*	66–97	75.3	34–53	43.1	27–33	29.4	20–27	23.4	18–23	20.3
Number of larvae completing all stages	*14*		*20*		*29*		*33*		*25*	

* Discrepancies in totals are due to differences in numbers of insects used.

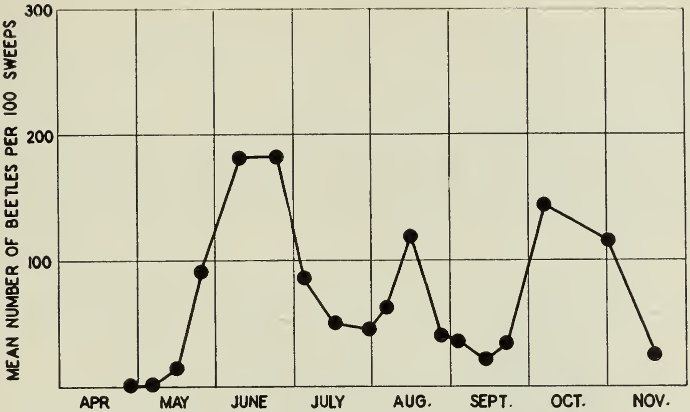

Fig. 3.—Seasonal trend of adult diabrotica population in alfalfa fields in the northwest portion of the San Joaquin Valley in 1941.

with back-and-forward movements of the head. After finishing the lid the larva passed into a prepupal condition and then pupated. Upon emerging, the beetle spent a day or two in its cell before breaking its way out.

The insect was reared at several constant temperatures and a summary of the results is given in table 1. Note that development was most rapid at 85° F. At this temperature the mean length of time for the individual to complete its entire development from egg to adult was 27 days as contrasted with 101 days at 60°; at 68° the mean period was 56 days. In late winter and spring it is possible that the soil temperature in the strata in which the larvae live averages close to 60° and for that reason it is probably safe to assume that around 100 days or more are necessary for the first spring brood to develop. In work conducted in bare soil at Davis, California, Smith (1929) found the soil temperature to average close to 60° at this depth. The soil temperature later in the year in the Brentwood area probably ranges somewhere between 68° and

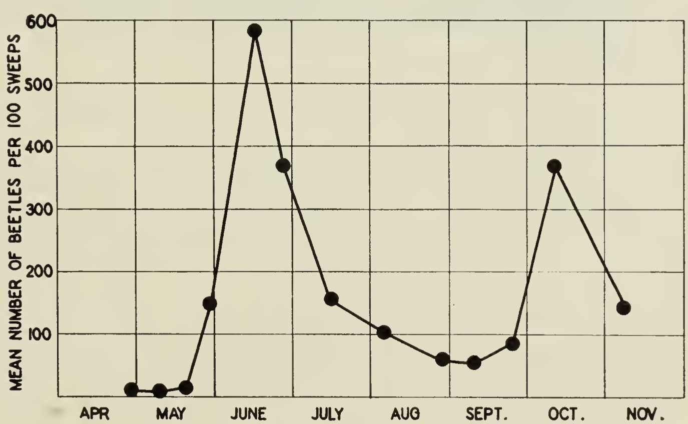

Fig. 4.—Seasonal trend of adult diabrotica population in alfalfa fields in the agricultural region adjacent to San Francisco Bay in 1941.

75°, and if so the developmental period would be expected to range between 37 and 58 days excluding the period necessary for the females to mature their eggs. As far as temperature is concerned there is probably sufficient time for at least three generations to occur in a year.

In the northwest portion of the San Joaquin Valley the seasonal population trend of the adult beetles in alfalfa fields was followed during 1941. The number of beetles collected in 100 sweeps of an insect net was recorded, and on most surveys 10 to 15 fields were examined. The results are shown in figure 3. The points plotted represent the average number of beetles collected per 100 sweeps on any particular survey. The graph shows that there were three distinct peaks; these probably represent broods although there must be consider-

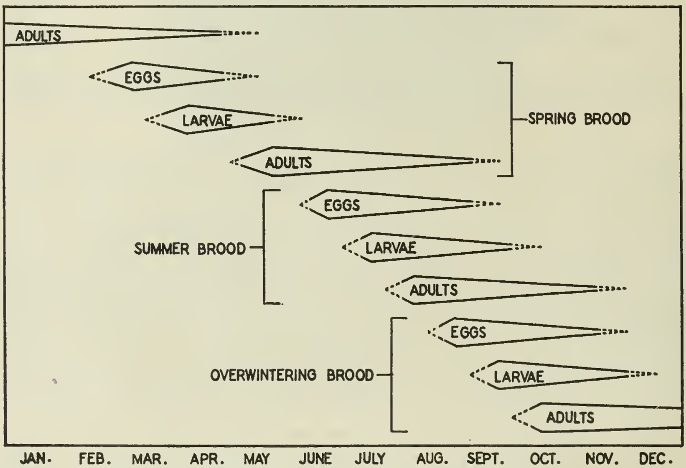

Fig. 5.—Seasonal life history of diabrotica in the lower San Joaquin Valley.

able overlapping. Similar surveys were conducted in the agricultural region adjacent to the San Francisco Bay; on the average many more beetles were collected per field and instead of three peaks only two occurred. The results are shown in figure 4.

The seasonal life history as shown in figure 5 has been constructed from our knowledge concerning the insect, and is what might be expected to occur in a climate such as is found in the lower San Joaquin Valley.

Copulation occurs frequently; and the beetles live for a period of several months. Egg laying may also occur over a long period; one female was recorded as laying 1,784 eggs over a period of 19 weeks in the laboratory. Some of the laboratory-reared females have laid more than 600 eggs, and the average length of life of 20 individuals was 165 days.

The insect passes the winter in the adult stage, although under some conditions it is possible that all stages of the insect might be found during the colder months. Larvae have been taken late in the fall. The only clearly defined brood is probably that which occurs in the spring. Because the beetles may lay eggs over several months the distinguishing of later broods is somewhat difficult.

EXPERIMENTAL METHODS USED

In determining populations in an orchard, five to ten trees were selected at random. Large sheets varying in size from 18×18 feet to 24×24 feet were placed under the trees, as shown in figure 6. To facilitate placing them under a tree a slit was made half way down the middle. To determine the beetle population the trees were dusted with an insecticide containing pyrethrum. This knocked the beetles from the trees and they could be collected from the

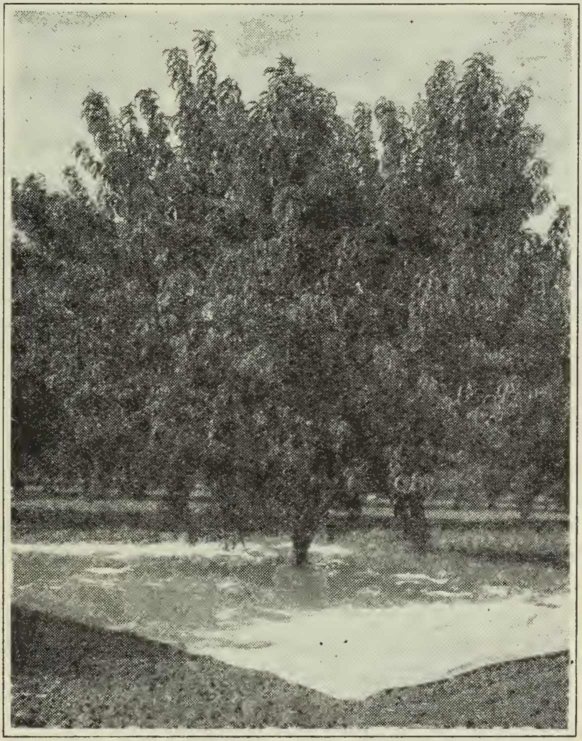

Fig. 6.—Nectarine tree with a sheet spread under it for catching beetles.

sheets and counted. Numerous tests were conducted to determine the efficiency of this method, and it was found that, with proper precautions, practically all the beetles in a tree could be removed. If an effective pyrethrum dust is applied when the air temperature exceeds 60° F, some of the beetles will fly from the tree. For most accurate counts, a temperature of 55° or lower is desirable.

In determining mortality, beetles were picked from the sheets and placed with undusted foliage in paper bags. At the end of 24 hours the beetles were examined. They were divided into three groups: (1) those that were definitely dead; (2) those that showed signs of life but were unable to fly; and (3) those that appeared normal. The last group was counted as fully recovered, the second group was held for further examination, while the first group was used in determining mortality at the end of 24 hours. At the end of 48 hours, or sometimes later, the beetles of the second group were again examined and placed in dead and living groups. The dead were added to the number dead at the end of 24 hours, and the mortality for the 48-hour period determined. The bags containing the beetles were kept in a room where the temperature never became excessive. This means of determining mortality proved to be the most satisfactory of several methods tried. Experiments were run in which the collected insects were caged, together with a branch, in a tree; or placed with foliage in screen cages supported in a tree. With screen cages in the orchard the mortality was slightly higher than where the beetles were placed in bags in the laboratory. The higher mortality may have been due to the direct, hot, sunlight on the cages. There was no satisfactory way to avoid this, and it was found that the most accurate method was to place the beetles in bags and hold them in a room as described above. Caged insects in a tree cannot move about freely and if conditions, where they are caged, became very unfavorable they have no means of escape. The method used probably gave a conservative estimate of the actual mortality in the field.

Insects were always picked up by hand from the sheets for it was found that if they were shaken into the center of the sheet and then poured into a sack, the mortality was increased. This was unquestionably due to the fact that as they were being rolled into a pile they were covered with dust, which resulted in the death of most of the beetles. Hand-picking the beetles from the sheets apparently did not injure them. This was well demonstrated where the dust drift knocked large numbers of the beetles from trees onto the sheets. These were picked up by hand and after 48 hours only 24 were dead out of 1,910 collected. Natural mortality certainly would account for the death of these few beetles. In making field counts either a hand rotary duster or a power duster was used. In making population counts in uncultivated regions or in alfalfa fields an insect sweeping net was used.

The amount of injury done was determined by field counts usually for each of the different fruit pickings, and was based on what was found in the field boxes. Some counts were made in packing sheds. Injured fruit was divided into two categories: (1) primary injury, which included the fruit that had been attacked by the beetle only; and (2) fruit that had been injured by other agencies, although fed upon by diabrotica.

INJURY TO DECIDUOUS FRUITS, AND ECONOMIC IMPORTANCE

Although this beetle feeds on both the foliage and fruit, cases where serious damage is done to foliage are not numerous. This type of injury is likely to be most severe on recently planted trees, and on such trees defoliation may reach a point where control measures become necessary. During the 1941 season at Brentwood the foliage on newly planted almond trees was so heavily attacked that dusting was necessary. It is doubtful whether foliage feeding ever reaches a point where control measures would be justified in an established orchard.

Diabrotica is principally a pest of the fruit, but the very green fruit is not attacked. Usually the fruit is left untouched until it has at least reached the mature-green stage and in most cases it is not attacked until it starts to turn color and ripen. As ripening progresses feeding increases, and in cases of severe outbreaks nearly all the fruit may be damaged by the time the crop is

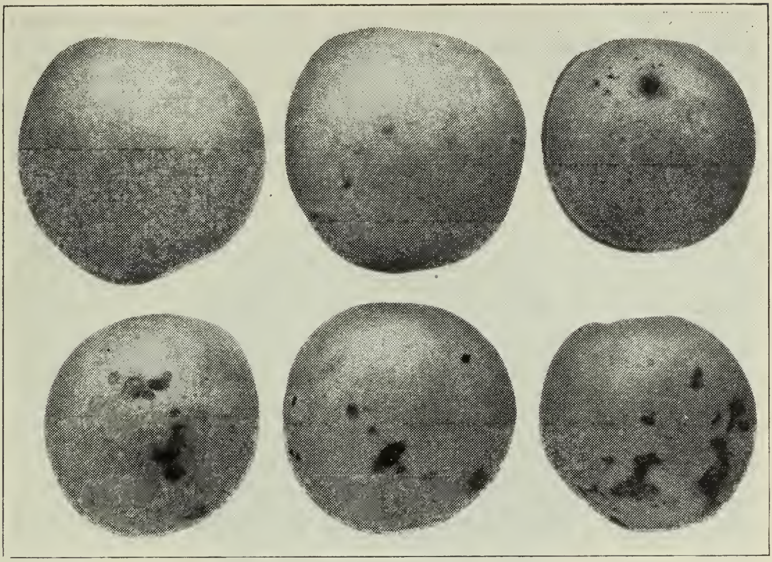

Fig. 7.—Various degrees of primary injury by diabrotica on apricots. An uninjured fruit is shown at the upper left.

Fig. 8.—Primary injury to nectarines by diabrotica.

tree ripe. In 1940 very little of the fruit in the Brentwood area was attacked before it started to turn color. In 1941 feeding started earlier, when much of the fruit was reaching the mature green stage. Apparently this beetle would rather feed upon the foliage than the very green fruit. This is very fortunate for if the pest attacked the fruit in all stages of its development, control would be nearly impossible, or at least the expense would be prohibitive. Control is

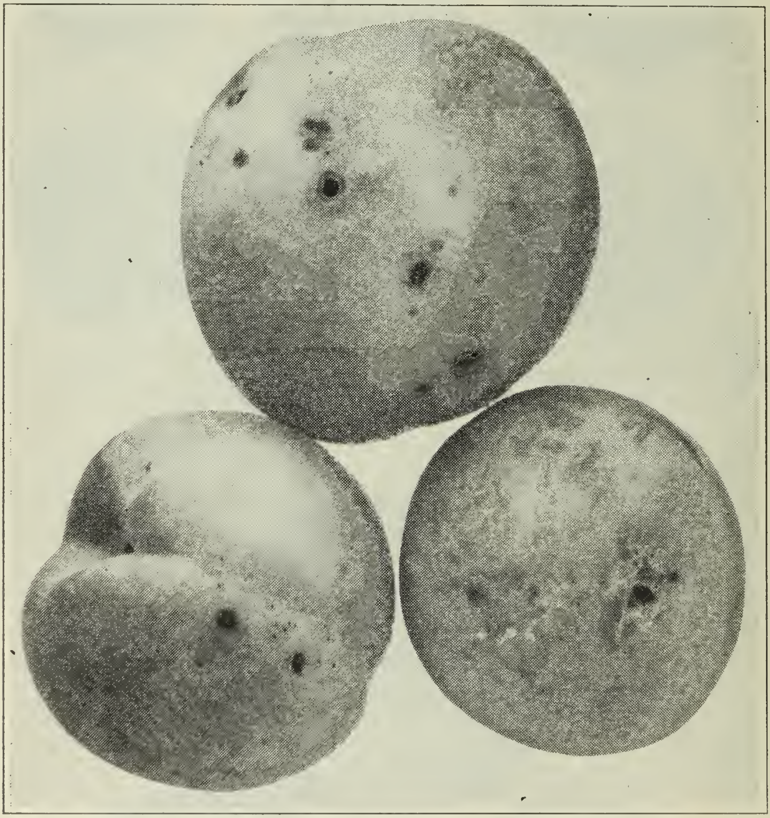

Fig. 9.—Primary injury to freestone peaches by diabrotica.

practical only because the pest confines its attack to the nearly mature fruit. This means that in general the period during which the crop needs protection is hardly ever more than 15 days. This is a relatively short period when it is considered that very large beetle populations may be present in orchards for a period exceeding 2 months.

Diabrotica is very important in spreading brown rot. The beetles feed on infested fruit and carry the spores to sound fruit. Also, feeding injuries, however small, are portals of entry for the brown rot. The loss caused by the insect in spreading this disease is probably as important as the feeding it does.

The injury caused by the beetle can be divided into primary and secondary damage. Primary injury is that which occurs when fruits are only attacked by diabrotica, while secondary injury is that which occurs when the beetles feed on fruit which has been damaged previously by some other agency. Primary damage ranges from extremely small feeding holes to many large and deep cavities completely destroying the fruit. Where fruit is intended for eastern shipment, the smallest puncture renders it worthless because of the danger of brown rot developing. In the case of canning fruit, small punctures or superficial feeding do not render the fruit worthless. Fruit that is too severely

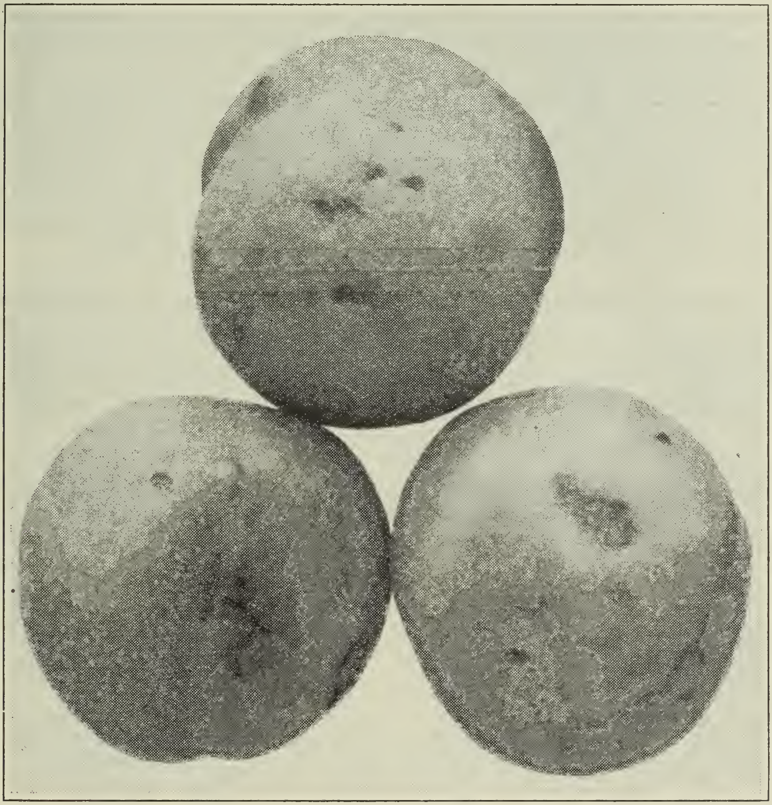

Fig. 10.—Primary injury to clingstone peaches by diabrotica.

injured for canning but not badly infested with brown rot can be utilized for drying or for juice.

Fruit that is being produced for the cannery is usually more severely injured than that intended for the fresh market. This is because such fruit is allowed to become tree ripe before it is picked, while all the fruit picked for eastern shipment is harvested mature green.

Where the beetle population is large and control is not attempted, the entire crop may be destroyed. The population necessary to do this depends upon several factors. Among the important ones are: ripeness of fruit at time of harvest, kind of fruit, number of fruits per tree, and probably orchard temperature. It has been observed that the fruit on the outside of a tree is usually more severely injured than that which is on the inside. This is due in part to the outside fruits ripening the fastest; but there is also some evidence that the beetles feed most heavily in the terminal portions of a tree. It is possible that the beetles are rather heavily concentrated in this part of the tree during the most active feeding period.

In 1940 populations of beetles as low as 100 to the tree in some cases were rather destructive. In 1941 usually much larger populations were present before serious damage resulted. This was true despite the fact that the beetles as a whole attacked greener fruit in 1941 than in 1940. It is possible that with high temperatures the beetles seek and feed heavily on ripe fruit because of the moisture it contains.

Varying degrees of primary injury to apricots are shown in figure 7, injury to nectarines in figure 8, and to freestone peaches in figure 9. In figure 10 is shown the injury done to clingstone peaches. Because of the toughness of the flesh, injury to this type of fruit is rather superficial, which is in marked contrast to the deep feeding cavities that occur on the other kinds of fruit. The only other stone fruit observed being attacked was late cherries.

FACTORS INFLUENCING SIZE OF POPULATIONS IN ORCHARDS

Evidence obtained during the three years that diabrotica has been intensively studied indicates that destructive populations of the beetles arise from sources outside of orchards. When large numbers are found, it is almost certain that they have migrated into the orchards. One of the main sources is the uncultivated land which surrounds many orchard areas. As these regions dry up there is a tendency for the beetles to migrate into irrigated areas. Considerable evidence was obtained in the spring of 1941 to indicate that this is the case. During the later part of April and through the first of June adult beetles were found in abundance in uncultivated regions. At this time the wild vegetation was drying up, while the wild timothy was blooming and maturing seed. In the foothill region surrounding Brentwood large numbers of beetles were found feeding upon the flowering heads of timothy. Many of these beetles

TABLE 2

AVERAGE NUMBER OF DIABROTICA BEETLES COLLECTED IN 1941 PER 100 SWEEPS OF AN INSECT NET, ON TIMOTHY AND MAYWEED IN UNCULTIVATED AREAS

Location	Date	Host	Number collected
4 miles south of Brentwood	May 14	Timothy	200
4 miles south of Brentwood	May 23	Timothy	151
5 miles west of Brentwood	May 28	Mayweed	172
4 miles south of Brentwood	May 28	Timothy	142
8 miles south of Brentwood	May 28	Timothy	108
8 miles south of Brentwood	May 28	Mayweed	800
1½ miles south of Livermore	May 28	Mayweed	128
Morgan Hill	May 29	Mayweed	180
4 miles south of Brentwood	June 3	Timothy	100
5 miles west of Brentwood	June 3	Mayweed	172
5 miles west of Brentwood	June 7	Mayweed	142
4 miles south of Brentwood	June 14	Timothy	10
5 miles west of Brentwood	June 21	Mayweed	20

had only recently emerged, as indicated by their very soft wing covers. In some places most of the thousands of beetles that could be collected were for a certainty less than a week old. During this same period mayweed was blooming and the newly emerged beetles could be found by the millions feeding in the flowers. Near Brentwood and elsewhere, there were stands of mayweed that covered hundreds of acres. The numbers of beetles collected per 100 sweeps

TABLE 3

CLIMATIC CONDITIONS FOR ANTIOCH DURING THE FIRST FIVE MONTHS OF THE YEAR

Year*	Precipitation, January to April inclusive		Temperature, January to April inclusive		Expected abundance of diabrotica in deciduous orchards
	Inches	Deviation from normal	Average of monthly means	Deviation from normal	
			deg. F		
1911	14.47	+7.18	57.4	+4.0	Abundant
1912	4.49	−2.80	52.7	−0.7	Few
1914	10.89	+3.60			Abundant
1915	10.19	+2.90	54.4	+1.0	Abundant
1916	11.90	+4.61	57.7	+4.3	Abundant
1917	4.24	−3.05	57.1	+3.7	Few
1919	7.30	−0.10	51.8	−1.6	Few
1920	4.01	−3.28	54.8	+1.4	Few
1921	6.02	−1.27	53.8	+0.4	Few
1922	8.54	+1.25	51.8	−1.6	Abundant
1923	4.10	−3.19	53.6	+0.2	Few
1924	4.34	−2.95	53.3	−0.1	Few
1925	7.64	+0.35	53.2	−0.2	Few
1926	8.85	+1.56	54.6	+1.2	Abundant
1927	7.74	+0.45	52.5	−0.9	Abundant
1928	5.94	−1.35	53.6	+0.2	Few
1929	2.60	−4.69	50.1	−3.3	Few
1930	8.20	+0.91	53.2	−0.2	Few
1931	5.12	−2.17	54.0	+0.6	Few
1932	5.63	−1.66	51.8	−1.6	Few
1933	5.65	−1.64	50.9	−2.5	Few
1934	3.73	−3.56	56.1	+2.7	Few
1935	8.13	+0.84	50.9	−2.5	Few
1936	9.74	+2.45	53.2	−0.2	Abundant
1937	9.47	+2.18	50.4	−3.0	Abundant
1938	12.72	+5.43	50.8	−2.6	Abundant
1939	4.99	−2.30	52.4	−1.0	Few
1940	14.53	+7.24	53.8	+0.4	Abundant
1941	13.11	+5.82	54.4	+1.0	Abundant

* No data for 1913 and 1918.

of an insect net in different fields and on different dates are given in table 2. As the mayweed matured, there was a migration into the cultivated area, and in the Brentwood region large numbers of beetles entered apricot orchards, causing serious damage in many orchards adjacent to the uncultivated foothill region.

Serious infestations of the beetles do not occur every year in orchards; wet or dry years very definitely affect their abundance. Apparently in the uncultivated regions a build-up of a large population is dependent upon the amount of rainfall or the distribution of the rains in the winter and particularly in the spring. The first or spring brood is in the soil from March to early May and is directly affected by the precipitation, for in the absence of timely or abundant rainfall the vegetation dries up and this brood is largely destroyed.

Table 3 has been prepared to show the important correlation between precipitation and the incidence of diabrotica. Antioch, which is less than 10 miles northwest of Brentwood, was selected as the station. Similar data are available for other stations, for example, Sacramento, Oakland, and Stockton. For each season available from 1910 to date the precipitation from January to April inclusive and the deviation from normal are given. Air temperatures for these months are also included although they do not show any significant correlation with the incidence of these beetles. The fluctuations are small and the soil temperatures would show even smaller differences. When the rainfall at Antioch was 1 inch or more above normal for the period from January to April a serious outbreak in deciduous fruit orchards might be predicted. Judging from notes in the *Pacific Rural Press* and from the amount of investigation devoted to diabrotica, 1914, 1915, 1916, 1922, 1926, 1927, and 1936 were years of serious infestations. As indicated in table 3, all of these outbreaks could have been predicted from the precipitation. There are no records of serious infestations during the years between, which also checks closely with table 3.

Farmers in the Brentwood area and elsewhere remember 1938 as a year of serious attacks and this checks with the information contained in the table. Since this investigation was started in 1938, destructive populations have occurred in 1938, 1940, 1941. In 1939 only a very small population of beetles was present in orchards and no damage resulted. This was a dry year, and in the uncultivated area only a very small population developed. The maximum count in the Brentwood area was 16 beetles per tree in the most heavily infested orchard examined. In 1938 there was a large adult population carried over into the winter. This population was so large that in certain localities sugar beets and spinach planted early in the winter were severely attacked. Yet this population was unable to give rise to a large brood of beetles in the late spring, because of the poor growth of vegetation which resulted from lack of sufficient rain. The number of beetles in the orchards was few, and there was a relatively small carry-over of beetles into the winter of 1940. The spring of that year was wet, and there was a rank growth of vegetation in the uncultivated regions. As a result there were large amounts of food available for the insect during the critical spring period in its development, and the first brood was rather large. Large populations of beetles occurred in the orchard area. The maximum count per tree was 776 and many beetles overwintered. Rainfall and vegetative growth were favorable for the pest in 1941, and a very large spring brood of beetles developed. The infestations that occurred in the years 1938–1941 check closely with the theoretical infestations that would be predicted from table 3. From these observations, it appears that the size of the first spring brood is very largely governed by rainfall, and the largest populations can be expected to occur in years of abundant, well-distributed spring rains.

The 1941 population was larger than that of 1940. This can probably be explained by the relatively small population carried over from 1939 into the winter of 1940 as compared to that of the winter of 1941.

Not all orchards are severely attacked by the pest even in years when the beetles are found in abundance. In fact most orchard sections seem to escape serious attacks. Regions that are most likely to be invaded are, for the most part at least, adjacent to large uncultivated areas. It is those orchard sections bounded by foothills which are most frequently invaded. A few such sections in central California are to be found near Hollister, Fairfield, Winters, and

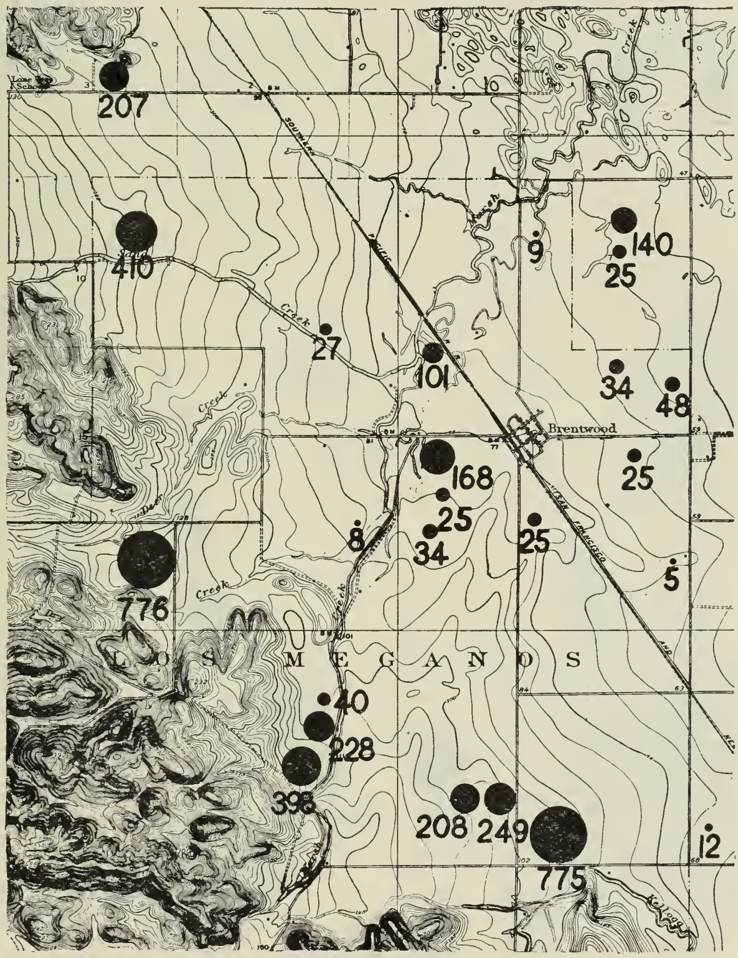

Fig. 11.—Maximum diabrotica population found per tree in different orchards in the Brentwood area, 1940. The figures shown with the dots represent the average number of beetles per tree.

Brentwood. Even in these regions not all orchards are heavily attacked, and the serious infestations are usually adjacent to the foothill areas. Close observations on populations in orchards have been made at Brentwood for the past three years. In 1939, the greatest number of beetles collected per tree in any orchard was 16. This orchard was on the outer fringe, and in other orchards well in from the periphery the number of beetles collected per tree was much less. In 1940 large populations were encountered, and the highest average number collected per tree in any orchard was 776. Surveys made during the summer showed definitely that the highest concentration was confined to the fringe of orchards close to the uncultivated region. This relation is clearly illustrated in figure 11, where the maximum populations encountered in different orchards are presented graphically. The 1941 beetle population was

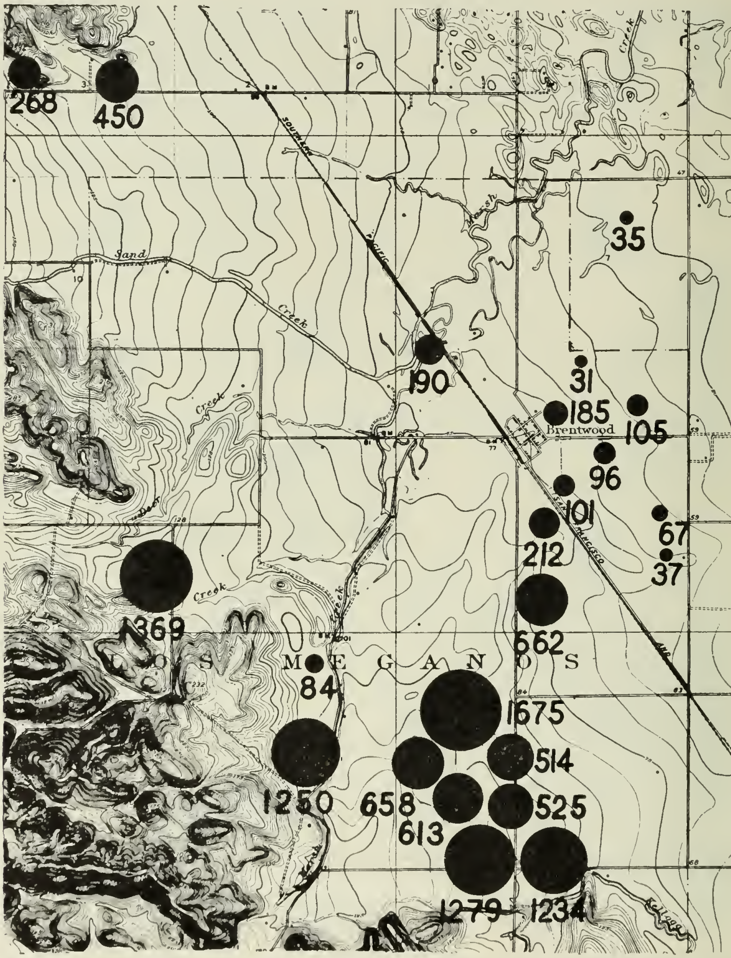

Fig. 12.—Maximum diabrotica population found per tree in different orchards in the Brentwood area, 1941. The figures shown with the dots represent the average number of beetles per tree.

even greater than in 1940, the highest average number collected per tree in any orchard was 1,675. Surveys made during the summer substantiated the results of the previous years and are graphically shown in figure 12. The highest maximum population encountered was found in the same general area in each of the three years that distribution studies have been conducted.

The seasonal distribution of the diabrotica population in orchards is very interesting. There is no marked rise in the orchards until migration takes place from the uncultivated areas which have been discussed above; from this time on, large populations can be found. The seasonal population trends for 1940 in three orchards are shown graphically in figure 13. These show that there was a wide variation in the populations observed in the three orchards. The two orchards with the largest populations were located near the edge of the fruit-growing section, while the third was well in from the periphery. In all cases the orchards were young and the foliage dense, a condition very favorable to this insect. The highest population shown is that found in a peach orchard, while the other two population trends represent conditions found in two nec-

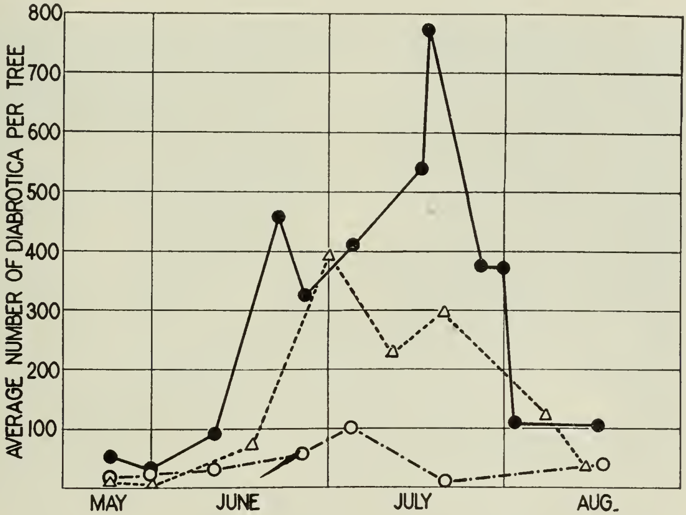

Fig. 13.—Diabrotica population trends in three orchards at Brentwood, 1940. The graph identified by dots represents an isolated peach orchard on the periphery of the orchard area; that marked by triangles represents a nectarine orchard also on the periphery of the orchard area; and the graph indicated by circles represents a nectarine orchard well in from the periphery of the orchard area.

tarine orchards. The seasonal population trends for these same orchards for 1941 are shown in figure 14. Here again the two orchards on the fringe had much the highest population. In these two orchards the beetles did so much damage that it was necessary to dust in order to protect the fruit. For this reason the curve for the end of the season is not a natural one. In the peach orchard, points plotted after July 15 represent the population following dusting and the same is true for the nectarine orchard following July 29. The interesting thing concerning these population trends is that the largest populations occur towards midsummer. This was particularly true in 1941. It hardly seems possible that the beetles which represent these peaks all could be from the spring brood. There is sufficient time for a generation of beetles to complete its development between the time the spring brood migrates into the irrigated areas and the appearance of the midsummer peak. It therefore seems that a second brood is involved. If this is the case, the baffling question is just how do so many of the beetles become concentrated on the periphery of the orchard area? It hardly seems possible that a brood develops on the grasses growing in the orchards. However, in many orchards there is a rank growth of watergrass (*Echinochloa Crus-galli*) and other weeds that might support a large larval diabrotica population. The origin of the beetles that make up this large midsummer brood certainly needs further investigation.

The beetles migrate into deciduous fruit trees because of the favorable conditions that they offer. The leaves give an ample food supply, and the shade afforded allows the beetles to escape from the heat; they are likely to be found most abundant in the trees that have the densest foliage. Even in these trees there is a movement of the beetles towards the shady side as the temperature rises during the hottest part of the day. On many occasions in making popula-

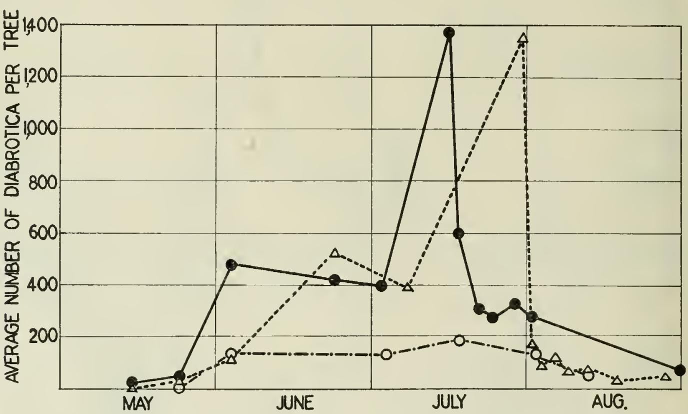

Fig. 14.—Diabrotica population trends for 1941 in the same three orchards as shown in figure 13. The graph identification is the same. Note the drop in population in the two orchards with high diabrotica population, as a result of dusting.

tion counts in early morning, it was noted that many more beetles fell to the sheets on the east side than on the west side of the trees. This distribution beyond a doubt resulted from many beetles moving to the east side of the trees to escape the hot afternoon sun.

Because denseness of foliage is an important factor, peach and nectarine trees generally offer a more suitable environment for the beetles than do apricot trees. This is particularly true of the younger peach and nectarine trees. In the case of the apricot trees the beetle population has always fallen off rather abruptly as soon as the crop is harvested. While the ripe or nearly ripe fruit is still on the trees the beetles find conditions most favorable for their existence. Ripe fruit is probably preferred as food, as it furnishes ample moisture and the feeding punctures can be utilized for protection. Following harvest, apricot trees in their partially wilted and open condition no longer offer a suitable environment and the beetles leave such trees. Nectarine and peach trees on the other hand may furnish a suitable environment for these insects before, during, and after harvest. Before the fruit is ripe, and after harvest, very large populations may be encountered.

CONTROL IN DECIDUOUS FRUIT ORCHARDS

The large diabrotica population of the 1941 season made it possible to extend earlier control experiments. In 1940 considerable evidence was obtained to show that certain dusts containing pyrethrum could be used effectively against this pest. (Michelbacher and associates, 1941). The most effective of these contained 2.00 per cent Lethane 384 (50 per cent β–butoxy, β'–thiocyano diethylether) and 0.15 or 0.20 per cent of pyrethrins in talc. Other dusts that gave promising results contained finely powdered pyrethrum flowers that had

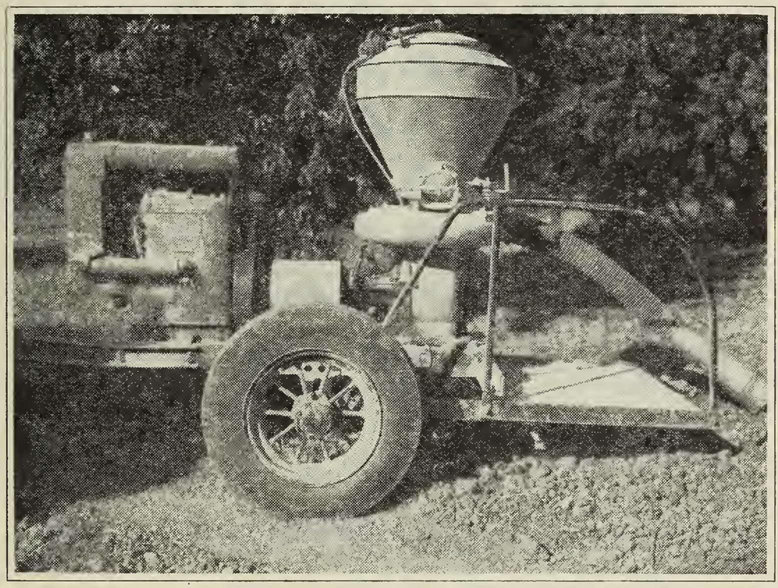

Fig. 15.—Duster used in the experimental work. Note the type of nozzle used.

been treated with special solvents, including highly refined kerosene, Lethane 384, chlorinated volatile petroleum hydrocarbons, and combinations of these solvents. Under favorable conditions mortalities of nearly 100 per cent were obtained with these mixtures. For good control it was found necessary to apply these dusts at the rate of approximately 50 pounds to the acre. The duster used in the experimental work, shown in figure 15, was a self-mixing machine with 3×18 inch fan powered by an 8-horsepower Le Roi, water-cooled engine. The normal fan speed was 3,000 to 4,000 r.p.m., and the nozzle that gave the best velocity and volume had a diameter at the intake of 4 inches, and an outlet diameter of 6 inches. The entire unit was mounted on a two-wheeled trailer, fitted with pneumatic tires. This machine gave satisfactory results, because (1) it developed sufficient velocity to push the dust through the tree, and (2) the volume moved was large enough so that the duster could proceed rapidly through an orchard.

It was found that weather conditions had to be carefully taken into consideration in applying the dusts. For best results the temperature should not exceed 65° F. At higher temperatures many beetles fly from the trees as soon as the dust is applied and it is doubtful whether these receive a lethal dose. It was further found that the direction of the dust drift was a very important factor. It is necessary that the drift be away from the untreated portion of the orchard. This is true because a very small amount of an effective dust will cause the beetles to drop from the trees; these insects do not receive a lethal dose, and as soon as it warms up in the morning they recover and fly back into the trees. Under any condition dusting should be stopped as soon as the direction of the drift changes so that it goes through the undusted part of an orchard. This must be done even though the dusting operation has just been started. The amount of dust in the air from dusting one row if drifted through the orchard is sufficient to knock most of the beetles from the trees. Because the direction of drift is so important, considerable time should be spent in determining this before beginning operations. In early morning the drift may be very variable and within 5 minutes it may shift to any point of the compass. However, on most mornings the drift finally stabilizes in one direction. The direction of drift can be accurately determined by taking a small amount of dust in the palm of the hand and then clapping the hands to create a cloud of dust. Or the drift of tobacco smoke can be noted. If, after a few minutes, it is found that the drift remains constant, dusting can be started. The farmer

Fig. 16.—Diagram of an orchard showing the path that the duster should follow in relation to the direction of the dust drift.

should have other work planned so that the crew can be kept occupied if it is necessary to stop dusting. An ideal dusting arrangement is shown in figure 16.

The time that dusting can be started in the morning is dependent upon temperature. When the temperature drops to 63° F operations can be started, and if the drift is in a constant direction work can be continued until an air

TABLE 4

EFFECTIVENESS OF GROUND PYRETHRUM FLOWERS AND LETHANE 384, IN TALC, AGAINST DIABROTICA ON DECIDUOUS FRUIT TREES; 1940*

Date dusted	Temperature, degrees F	Pounds per acre	Average number of beetles per tree	Number used in determining mortality	Per cent mortality after 24 hours	Per cent mortality after 48 hours
June 13	66	55	292	1,444	73.9	....
June 13	50	45	196	1,387	37.2	65.0
June 18	59	50	228	1,140	55.5	....
June 20	62	50	171	684	89.0	....
June 20	62	80	217	435	100.0	....
June 29	61	50	180	1,266	66.5	97.4
July 5	58	38	238	1,192	86.9	....
July 18	50	50	177	1,238	70.7	84.2
July 19	59	53	434	2,174	90.6	99.7
July 30	58	55	149	1,044	84.7	98.5
July 31	50	60	371	1,855	89.1	97.9

* The dust contained 0.15 per cent pyrethrins, except for applications of July 5 and July 19, which contained 0.20 per cent. All the mixtures contained 2.00 per cent Lethane. The dusts were applied by power duster except for the application of July 18, which was by airplane.

TABLE 5

EFFECTIVENESS OF GROUND PYRETHRUM FLOWERS AND LETHANE 384, IN TALC, AGAINST DIABROTICA ON DECIDUOUS FRUIT TREES; 1941*

Date dusted	Temperature, degrees F	Pounds per acre	Average number of beetles per tree	Number used in determining mortality	Per cent mortality after 24 hours	Per cent mortality after 48 hours
June 24†	54	64	613	3,675	31.4	34.6
July 16	61	45	1,279	6,398	97.5	99.0
July 16	61	45	1,326	4,040	78.0	84.0
July 18	57	50	839	4,197	97.5	98.5
July 29	54	50	1,250	6,252	91.5	95.5
July 29	57	55.5	1,014	4,058	87.0	91.0

* The dust contained 0.15 per cent pyrethrins, except for the application of July 16, which contained 0.20 per cent. All the mixtures contained 2.00 per cent Lethane.
† The trees were very wet from a rain during the night.

temperature of about 65° is reached. Minimum temperatures occur just about daybreak so there is a considerable period before and after sunrise that is suitable for dusting. The morning temperatures at Brentwood where most of the investigations were conducted were usually favorable. During periods of very hot weather, however, the temperature sometimes failed to fall as low as 63°. Other factors that may result in relatively high early morning temperatures are cloudiness and wind.

If rain has fallen during the night and the foliage is not dry by morning, dusting should be delayed a day. Some evidence was obtained that seemed to indicate that an excess of moisture reduced the effectiveness of a contact insecticide containing pyrethrum. Just what action occurs is not known, but it is possible that the excess moisture keeps the insecticide from making maximum contact with the insect.

The two insecticides that were thoroughly investigated were pyrethrum-Lethane 384 in talc dust, and a 5 per cent Pyrocide dust. The former had 0.15

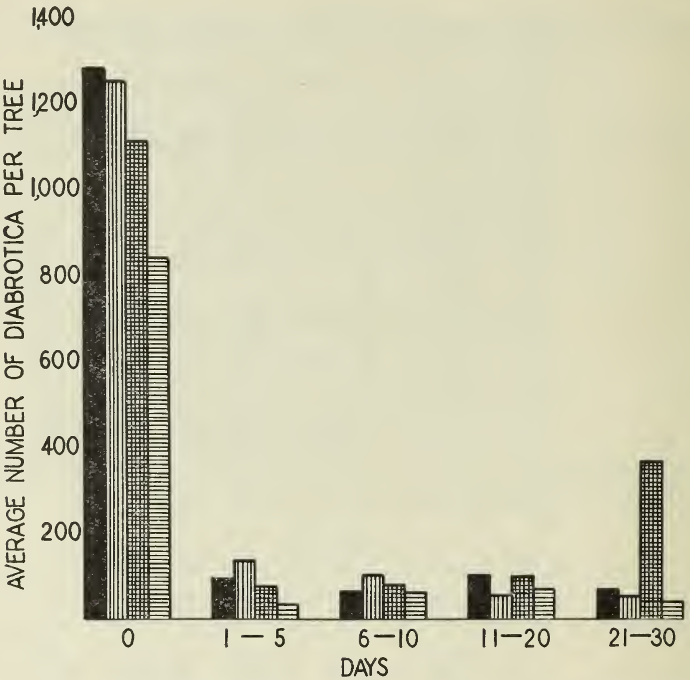

Fig. 17.—Reduction in diabrotica population in four orchards following dusting with ground pyrethrum flowers and Lethane 384 in talc. The four tall bars at the left indicate the populations at the time of dusting; the shorter bars indicate later counts in the respective orchards. The key to the bars, the composition, and rate of application are as follows: The black bar, 0.20 per cent pyrethrins and 2.00 per cent Lethane 384, applied at 45 pounds per acre; the vertically hatched bar, 0.15 per cent pyrethrins and 2.00 per cent Lethane 384, at 50 pounds per acre; the cross-hatched bar, 0.15 per cent pyrethrins and 2.00 per cent Lethane 384, at 50 pounds per acre; and the horizontally hatched bar, 0.15 per cent pyrethrins and 2.00 per cent Lethane 384, applied at 55 pounds per acre.

or 0.2 per cent pyrethrins and 2.0 per cent Lethane. The value of this dust in controlling this pest was thoroughly demonstrated during the 1940 season. The work in 1941 substantiated the results obtained the previous season. When applied under favorable conditions mortalities reach nearly 100 per cent. Some of the results obtained with this dust mixture in 1940 are shown in table 4, and for 1941 in table 5. It should be noted that in most cases very good kills were obtained. In all cases a close correlation was found to exist between mortality counts at time of dusting and reduction in the population as determined by later counts made in the orchards; this is clearly shown in table 6 for five of the orchards dusted in 1941.

In 1941 this type of dust was commercially applied on an experimental basis in four orchards. The results of these dustings are graphically shown in figure 17. All four of the orchards were treated under favorable conditions and very good control was obtained. Both peach and nectarine orchards were dusted and in each case the dust was applied at approximately 50 pounds to

TABLE 6

COMPARISON OF ACTUAL NUMBER OF BEETLES FOUND PER TREE WITH THE EXPECTED NUMBER AS CALCULATED FROM MORTALITY COUNTS AT THE END OF 48 HOURS, FOLLOWING THE APPLICATION OF A PYRETHRUM-LETHANE 384 DUST

Initial population per tree at time of dusting (from table 5)	Per cent mortality at end of 48 hours (from table 5)	Beetles per tree calculated from 48-hour mortality count	Actual number found per tree 72 hours after dusting
613*	34.6	401	435
839	98.5	97	27
1,250	95.5	56	136
1,014	91.0	91	76
1,279†	99.0	13	96

* The trees were very wet from a rain during the night.
† Pyrethrins 0.20 per cent, all others 0.15 per cent.

TABLE 7

EFFECTIVENESS OF 5 PER CENT PYROCIDE DUST AGAINST DIABROTICA ON DECIDUOUS FRUIT TREES; 1941

Date dusted	Temperature, degrees F.	Pounds per acre	Average number of beetles per tree	Number used in determining mortality	Per cent mortality after 24 hours	Per cent mortality after 48 hours
June 21	41	40	300	2,402	37.5	43.0
July 5	62	46	514	4,114	78.0	99.0*
July 15	60	50	1,369	13,692	74.5	78.5
July 26	54	50	658	3,948	84.4	95.5

* Sacks containing beetles were placed in a car exposed to the direct rays of the sun. The car became hot and the high mortality indicated is believed to be due to excessive temperature.

the acre. Because of the stabilized population a single dusting was sufficient to give protection to the ripening fruit during the entire harvest.

A Pyrocide (pyrethrum-impregnated) dust which had a pyrethrins content of 0.1 per cent was also used extensively. This dust was commercially applied on an experimental basis to four orchards. The results of these dustings are given in table 7 and graphically shown for three orchards in figure 18. As with the pyrethrum-Lethane 384 dust, a rather close correlation was noted to exist between the mortality counts at time of dusting and the reduction in the population as determined later by counts in the orchard. This relation is shown in table 8. In all but one case the dust was applied under favorable conditions. In this orchard there was some drift into the nondusted portion of the orchard and thus the mortality was, in general, less than might have been

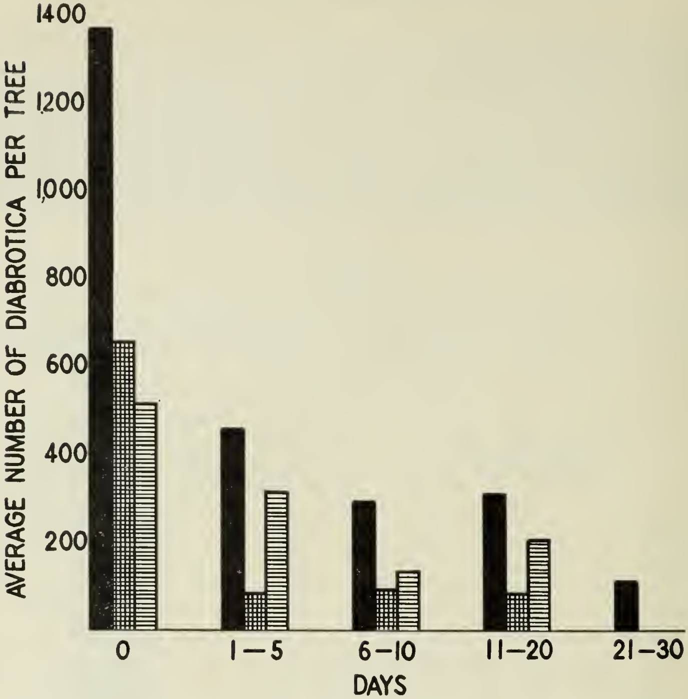

Fig. 18.—Reduction in diabrotica population in three orchards following dusting with Pyrocide (pyrethrins, 0.1 per cent) in talc. The three tall bars at the left indicate the populations at the time of dusting; the shorter bars indicate later counts in the respective orchards.

The orchards represented by the black and the cross-hatched bars received applications of 50 pounds per acre; that of the horizontally hatched bar, 46 pounds per acre.

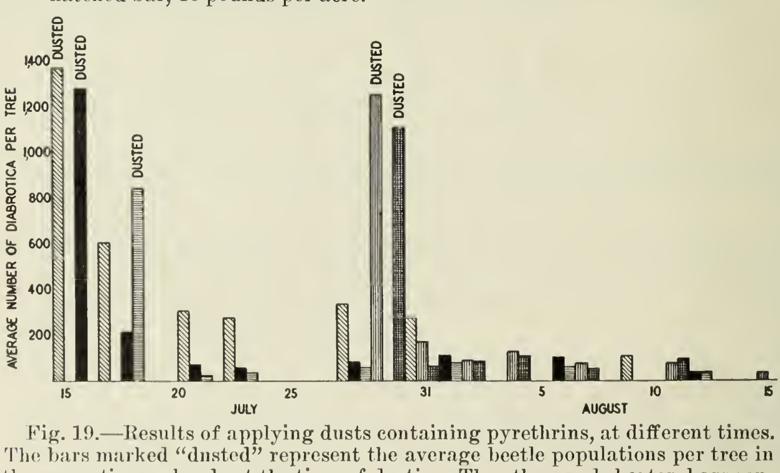

Fig. 19.—Results of applying dusts containing pyrethrins, at different times. The bars marked "dusted" represent the average beetle populations per tree in the respective orchards at the time of dusting. The other, and shorter, bars represent subsequent counts. Since the orchards were all in the same general area, and the dates of application covered a 2-week interval, it can be assumed that the sharp reduction in population after dusting was due to the effects of the insecticide rather than natural factors.

otherwise expected; however, even where the dust was applied under more favorable conditions the mortality from the Pyrocide dust was hardly equal to that obtained with the pyrethrum-Lethane 384 dust. The control nevertheless was satisfactory, and from visual observations equalled that obtained with the latter mixture. Although relatively large populations were left in two of the treated orchards, feeding by the beetles ceased almost entirely. The dust must have been responsible for this, for in each case the fruit was being seriously attacked up to the time it was applied. The protection afforded lasted until the entire crop was harvested. This was obtained with a single dusting, and the period of control lasted at least 2 weeks or longer.

There was a marked reduction in populations in all orchards where experimental commercial dusting was carried out. In order to show that these

TABLE 8

COMPARISON OF ACTUAL NUMBER OF BEETLES FOUND PER TREE WITH THE EXPECTED NUMBER AS CALCULATED FROM MORTALITY AT THE END OF 48 HOURS, FOLLOWING THE APPLICATION OF A 5 PER CENT PYROCIDE DUST

Initial population per tree at time of dusting (from table 7)	Per cent mortality at end of 48 hours (from table 7)	Beetles per tree calculated from 48-hour mortality count	Actual number found per tree 72 hours after dusting
514	99.0*	5	318
1,369	78.5	295	457
658	95.5	30	84
300	43.0	171	214

* Sacks containing beetles were placed in a car exposed to the direct rays of the sun. The car became hot and the high mortality indicated is believed to be due to excessive temperature.

reductions were due to dusting and not some other factor, figure 19 has been prepared. Here results for five orchards are graphically shown; the period covered is from July 15 to August 15. The beetle population at the time each of the orchards was dusted, and the populations as determined by later counts are shown. None of the orchards were more than 2½ miles apart, and in all cases they consisted of peach or nectarine trees. The area was a rather homogeneous one and for that reason if the reduction in population was due to some natural factor, it would be expected to occur in all the orchards at about the same time. However, an examination of the graph shows that dusting was done over a period of about 2 weeks and that in every case the reductions in populations did not occur until the dust was applied.

It is possible that other factors may influence the population of beetles in the orchard during harvest. Picking of the fruit certainly causes some movement of the beetles and may at times drive large numbers from an orchard. While this may be possible it is probably not the usual condition. Large migrations from an orchard do not occur until harvest is complete or nearly so.

It is the belief of some growers that sulfur dust will drive the beetles from an orchard. During the 1941 season much sulfur was applied shortly before the fruit had begun to ripen in an effort to check brown rot which was rather prevalent. In most of these orchards there was no evidence of the beetles being killed or driven from them. In the region of heavily infested orchards at Brentwood it was necessary to use an insecticidal dust to protect the ripening crop from serious damage. At the time these dusts were applied the number of beetles per tree in some of the orchards exceeded 1,000. Under certain conditions a sulfur dust may cause the beetles to leave an orchard but the treatment at best is of doubtful value and should not be relied upon to save a crop from serious damage.

Under favorable conditions a single application of an effective dust is all that is needed to protect a ripening fruit crop. The conditions under which it should be applied have already been discussed. However, if the beetle

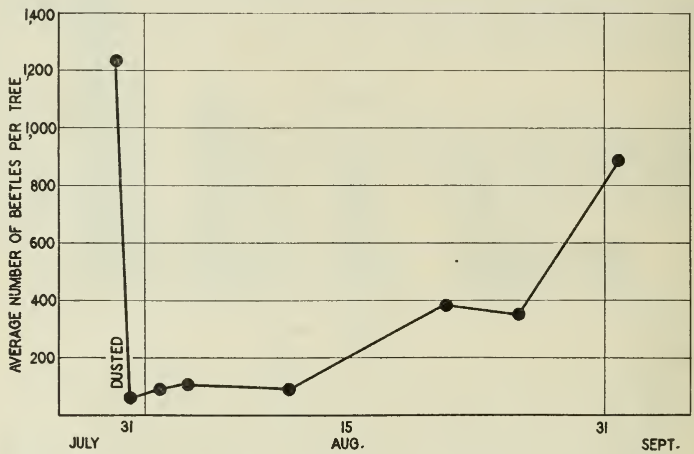

Fig. 20.—Reinfestation of an orchard by diabrotica in late summer following the reduction of the population by dusting in midsummer.

population has not become stabilized, and there are large numbers still migrating into an orchard, a second application might be necessary. This condition is very likely to occur early in the season in apricot orchards where many beetles may be still moving in from the uncultivated areas after the apricots have begun to ripen. Because of the danger of beetles migrating into orchards late, control measures should be delayed as long as possible so that a maximum number of beetles can be killed. In certain localities, large numbers of beetles may migrate into orchards as late as September. Because of this it is not uncommon to find large populations building up in orchards following the application of effective insecticides. This is graphically shown in figure 20. The orchard was dusted on July 30, and the population was much reduced, but later increased numbers of beetles were found owing to migration into the planting.

The present authors have not had opportunity to conduct any extensive control experiments where the insect has caused economic damage to recently planted trees. However, in one case when there was a serious infestation in small almond trees the farmer used a lead arsenate spray to good advantage. In still another case which involved almond trees a cryolite dust was used effectively.

NATURAL ENEMIES

Probably the most important parasite of *Diabrotica 11-punctata* is a tachinid fly, *Celatoria diabroticae* (Shimer). Shimer (1871) reared this parasite from *D. vittata* and described it in the genus *Melanosphora.* Koebele (1890) reported a dipterous larva parasitizing *Diabrotica* in California and stated that Alexander Craw had noted the parasite as early as 1886. Coquillett (1889) reared a tachinid fly from *D. 11-punctata* and later (1890) he obtained a number of specimens for which he erected a new genus and species—*Celatoria crawii.* In his revision of the Tachinidae, Coquillett (1897) placed *C. crawii* as a synonym of *C. diabroticae.*

Celatoria diabroticae probably lays its eggs in the abdomen of its host while in flight; the larva develops there and in issuing it breaks away the larger portion of the beetle's abdomen, falls to the ground, and probably pupates in the surface soil. The brown puparia are frequently seen on the bottom of cages which have contained beetles collected in the field. Only one larva to a host has been observed.

Although Coquillett (1890) and Shimer (1871) thought the parasite very effective, the present authors have never observed heavy parasitism. Sell (1915) recorded it as rare and it is the opinion of the present authors that this parasite is of little importance in holding *Diabrotica 11-punctata* in check.

Chaetophleps setosa Coq. is another very similar parasite of *Diabrotica.* However, it is most effective in the East. Bussart (1937) gives an excellent account of the bionomics of this parasite.

There are many other natural enemies of *Diabrotica* beetles. Some of these have been considered by Chittenden (1919) and Houser and Balduf (1925). These include rodents, birds, predaceous beetles, mites, spiders, and nematodes. The present writers have observed evidences of rodents, probably field mice, feeding on diabrotica, and have on numerous occasions seen them spun up in webbing of spiders. Although the number of beetles destroyed by any one of these natural agencies may not be great, it is probable that in the aggregate the natural enemies play at least a minor roll in limiting the beetle.

SUMMARY

Diabrotica, or western spotted cucumber beetle, *Diabrotica 11-punctata* Mann., is mainly western in distribution and is most destructive in California and Oregon. The eggs are laid about the bases of host plants, the larvae feed on the roots, and on reaching maturity construct a cell in which they pupate. All stages other than the adult are spent in the soil. Both the larvae and adults feed on many kinds of plants. In most of central California there are probably three generations a year. The insect passes the winter in the adult stage. The first spring generation occurs largely in the uncultivated regions. Because of this the size of the first brood is largely dependent upon rainfall. Unless there is a good growth of vegetation in the winter and early spring, the first brood of beetles is likely to be small. This first brood appears during the latter part of April through May and most of June. In the uncultivated areas the beetles may concentrate in large numbers on the floral parts of such plants as timothy and mayweed (*Anthemis Cotula*). As these plants dry up the beetles

move into the cultivated areas, and large numbers find their way into deciduous fruit orchards. Serious infestations in the fruit orchards are likely to occur only in those years when large beetle populations develop in the uncultivated regions. Even in these years it is only the orchards adjacent to the uncultivated regions that are likely to suffer damage.

The insect attacks both the fruit and foliage of deciduous fruit trees. Serious injury to foliage has never been observed in well-established orchards, although newly planted trees may sometimes be heavily attacked. The beetles are principally a pest of the ripening fruit, and if not controlled may injure the fruit by eating holes in it. Besides feeding on the fruit, they are important in spreading the brown-rot organism.

Control is possible because the beetles do not attack the fruit until it is nearly ripe. As a result protection is necessary for a period of only about 2 weeks. A dust containing 0.15 or 0.2 per cent of pyrethrins and 2.0 per cent of Lethane 384 in talc, applied at 50 pounds to the acre, was found to be very effective. Mortalities of nearly 100 per cent were obtained. A 5.0 per cent Pyrocide dust (0.1 per cent pyrethrins) was also used to good advantage. The mortality was not so high as that obtained with the former dust, but the fruit protection appeared to be about equal.

For satisfactory control it is necessary that the dusts be applied at a temperature of less than 65° F, and that the velocity and volume from the duster be adequate to push the cloud of dust through the tree. The full dosage, to be effective, must be applied from one side of the tree; very small amounts of dust dislodge the beetles from the trees with a sublethal dose, and it is for this reason that the rows of trees cannot be treated from both sides. It is very important also that the drift be into the dusted area; for if into the nondusted portion of the orchards the beetles will be knocked out of the trees with a sublethal dose, and as the day warms up they will recover and fly back into the trees. Dusting operations should be stopped as soon as the drift changes into the undusted part of the orchard. This precaution cannot be overemphasized.

Life history studies were conducted in the laboratory. The beetles were reared in constant temperature cabinets, that did not vary more than ± 1½° F. At 60° the beetles completed their development from egg to adult in 101 days, while only 27 days were necessary at 85°. It was found that soaked wheat kernels and lettuce leaves served as excellent food for the larvae. Before the larvae would pupate it was necessary to construct cells for them. If this was not done they would die.

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