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Oriental Fruit Moth Investigations In Ohio. I

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OHIO
AGRICULTURAL EXPERIMENT STATION
Wooster, Ohio

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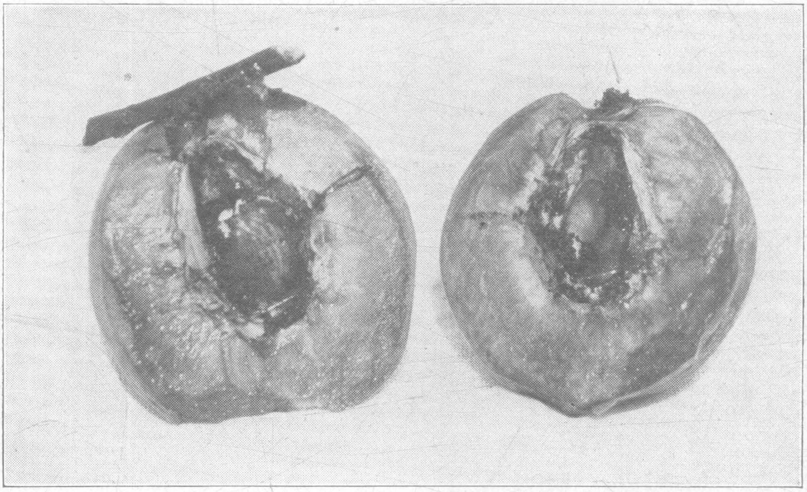

Peach split to show larva of Oriental Fruit Moth feeding within

ORIENTAL FRUIT MOTH INVESTIGATIONS IN OHIO[1]. I

L. A. STEARNS[2] AND R. B. NEISWANDER

INTRODUCTION

This publication is presented at this time as a report of progress of an investigation in Ohio pertaining to the oriental fruit moth, *Laspeyresia molesta* Busck, during the years 1927, 1928, and 1929.

In May, 1927, a laboratory was established at Ironton, Lawrence County, and research activities were centered there until March 1, 1929, at which time the work was transferred to the Experiment Station at Wooster.

A brief account of the investigation in 1927, relating essential facts concerning the activities and status of this new orchard pest in Ohio and offering certain suggestions for reducing infestation, has already been published (6).

The present progress report is made to acquaint the fruit-growing interests of the State, at whose instance the investigation was undertaken, with the latest knowledge concerning the insect, and to record findings up to the present time relative to its control.

I. BIOLOGICAL STUDIES

INFESTATION

1927.—A county by county survey, made during the summer of 1927, indicated that the oriental fruit moth had probably been present in Ohio for a somewhat longer period than was at first believed, in certain sections for at least two or three years; furthermore, that it was already widely distributed thruout the State in most areas where peaches were grown in abundance.

The infestation was found to be most severe along the Ohio River, especially in the extreme southwest in the vicinity of Cincinnati (Hamilton County) and farther east in Lawrence, Gallia, and Meigs Counties; in the center of the State south of Columbus

[1]Special funds, appropriated by the Ohio Legislature in 1927 and reappropriated in 1929, have been used in this study.

[2]Data prepared for publication by the senior author, formerly Assistant Entomologist at the Ohio Agricultural Experiment Station Acknowledgment is made herewith of the many suggestions offered by J. S. Houser, Chief of the Department of Entomology, under whose direction work was conducted, and of the assistance rendered in various phases of the investigation by F. C Daigh and H R Watts, temporarily employed during the summer of 1927, P. H. Johnson during 1928, and K A Haines during 1929.

(Franklin County); and in northern Ohio in the vicinity of Sandusky (Erie County) and Lorain and Elyria (Lorain County). It seems probable that the sale and inadequate disposal of infested peaches in the cities mentioned resulted in the establishment of the moth in commercial orchards of the surrounding country. In these several centers of infestation, injury was already fully as severe as in certain sections of the eastern United States where the insect had been introduced several years earlier. Practically no infestation existed in the important peach-producing area of Ottawa County on Lake Erie.

1928.—Conditions continued severe during 1928 in the districts just noted. Although the infestation showed an increase in Ottawa County and in the younger peach section of eastern Ohio, it still remained relatively light.

The infestation of the Elberta crop was approximately double that of 1927. In certain well-cared-for orchards in the neighborhoods of both Cincinnati and Columbus, from 80 to 90 per cent of the fruit was rendered unsuitable for shipping. Non-visible infestation was high. It averaged 22 per cent, with a range of from 1 to 58 per cent.

In apple orchards interplanted with early and mid-season varieties of peaches or where such varieties in solid blocks adjoined an apple orchard, infestation of apples was common.

1929.—Twig injury by both first and second broods was generally more severe in 1929 than in either 1927 or 1928. Excess precipitation thruout the season produced a continued, succulent growth on peach trees and delayed the normal movement of larvae from twigs to fruit. This fact, and the larger crop of fruit in southern and central Ohio in 1929, account for the apparent decline in infestation reported by some growers. Records indicate, however, a larger oriental fruit moth population for the State as a whole at the close of the 1929 season than at any time since the introduction of this pest into Ohio.

Serious fruit injury was again experienced in the older infestations in the State. In Ottawa County the infestation increased tremendously. The Elberta infestation in this district has shown a progressive increase from 0.5 per cent in 1927 to 13 per cent in 1928 and 51 per cent in 1929. It seems probable that the next few years will witness a still further extension of the insect's activities in this section of the State.

In the most severe infestations, three fourths of the Elberta peach crop and from one fifth to one third of the crop of certain apple and pear varieties were injured. Quinces, in small plantings, were a total loss.

SEASONAL LIFE HISTORY

In the study of the seasonal life history of the oriental fruit moth in the insectary at Ironton, (Fig. 1), during 1927 and 1928, a procedure developed previously (3 and 7) was followed, with slight modification. The work was begun too late to secure records for the spring and first broods of 1927. Observations in the orchard, however, indicated that moths of the spring brood had been active during April. On May 1, the first, first-brood larvae had already hatched and a scattering twig injury was evident. By May 15 and thruout the remainder of the month, such injury was conspicuous. First brood eggs must have been deposited and must have hatched in maximum numbers during that period. First brood larvae were collected from infested peach twigs in preparation for the detailed insectary studies summarized hereafter.

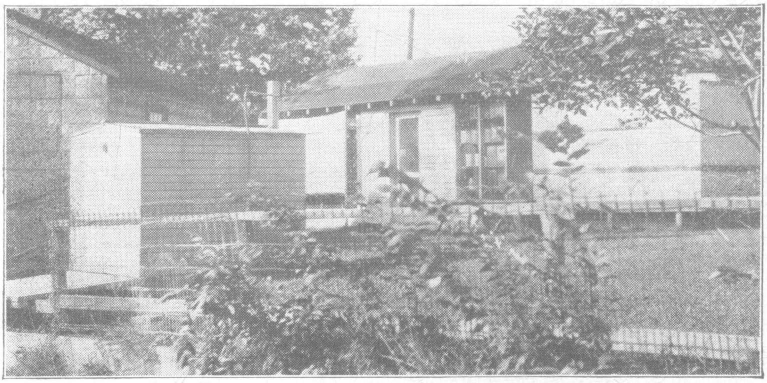

Fig. 1.—Insectary at Ironton

Number of broods.—Five broods of eggs and larvae developed in 1927. A slight break possibly occurred between the first and second broods during the first week in June. The second and third broods, on the contrary, overlapped for a period of 16 days, from July 18 to August 2, and the third and fourth broods for a period of 37 days, from August 28 to October 3. The deposition period of the small, fifth brood coincided with that for the last eggs of the fourth brood for a period of three days from October 23 to 25.

The periods of egg deposition for the second, third, fourth, and fifth broods were of 51, 78, 59, and 3 days' duration, respectively. The third and fourth broods of eggs and larvae were by far the largest, and of approximately equal dimensions. Maximum numbers of third brood larvae and the first, fourth brood larvae were hatching during late August, the ripening period of Elberta in southern and central Ohio.

Moth emergence.—The first and last moths of the first brood emerged on June 1 and July 17, respectively; of the second brood, on July 14 and September 19, respectively; of the third brood, on August 19 and October 15, respectively; and of the fourth brood, on October 3 and 29, respectively.

Fecundity.—Moths showed a varying fecundity increasing from 20.9 eggs per female for the first brood to 47.6 and 57.7 eggs for the second and third broods, respectively. The fourth brood showed a marked decrease to but 4.2 eggs per female.

Preoviposition period.—The maximum, minimum, and average preoviposition period of the first brood moths was 11, 1, and 4.2 days, respectively; of the second brood moths, 5, 1, and 2.9 days, respectively; of the third brood moths, 12, 1, and 2.9 days, respectively; of the fourth brood moths, 13, 13, and 13.0 days, respectively; and of the moths of all broods combined, 13, 1, and 3.4 days, respectively.

Period from emergence to last oviposition.—The maximum, minimum, and average period from emergence to last oviposition of the first brood moths was 22, 5, and 12.8 days, respectively; of the second brood moths, 23, 10, and 15.5 days, respectively; of the third brood moths, 26, 14, and 18.8 days, respectively; of the fourth brood moths, 15, 15, and 15.0 days, respectively; and of the moths of all broods combined, 26, 5, and 15.5 days, respectively.

Duration of oviposition.—The maximum, minimum, and average duration of oviposition of the first brood moths was 18, 1, and 9.6 days, respectively; of the second brood moths, 22, 9, and 13.6 days, respectively; of the third brood moths, 25, 3, and 16.9 days, respectively; of the fourth brood moths, 3, 3, and 3.0 days, respectively; and of the moths of all broods combined, 25, 1, and 12.1 days, respectively.

Longevity.—The maximum, minimum, and average longevity of the male moths of all broods combined was 32, 2, and 14.6 days, respectively; of the female moths of all broods combined, 36, 3, and 15.9 days, respectively; of both sexes of all broods combined, 36, 2, and 15.3 days, respectively. The records show an average longevity for female moths approximately one day in excess of that recorded for male moths and a uniform increase in longevity for both sexes thruout the succession of summer broods. This fact, and the corresponding increase in fecundity previously mentioned, account in part at least for the comparative immensity of the third and fourth broods.

Egg deposition.—The first and last eggs of the second brood were deposited on June 13 and August 2, respectively; of the third brood, on July 18 and October 3, respectively; of the fourth brood, on August 28 and October 25, respectively; of the fifth brood, on October 23 and 25, respectively.

Incubation.—The average length of the incubation period of eggs (both transforming and wintering material) increased from 4.4 days (second brood), 4.9 days (third brood), and 6.05 days (fourth brood) to 9.4 days (fifth brood). The maximum and minimum lengths of the incubation period for the eggs of all broods combined were 17 and 3 days, respectively.

Hatchability.—Ninety-seven and five-tenths per cent of the second brood, 98.2 per cent of the third brood, 96.6 per cent of the fourth brood, and 91.3 per cent of the fifth brood eggs hatched.

Larval hatching.—The first and last larvae of the second brood hatched on June 17 and August 6, respectively; of the third brood, on July 23 and October 3, respectively; of the fourth brood, on September 1 and October 6, respectively; of the fifth brood, on November 1 and 4, respectively.

Larval feeding.—The average length of the larval feeding period (both transforming and wintering material) increased from 19.5 days (second brood) and 27.2 days (third brood) to 35.8 days (fourth brood). The maximum and minimum lengths of the larval feeding period for all broods combined were 74 and 9 days, respectively. Wintering larvae of the second brood were feeding for 33.45 days or 13.95 days in excess of the average for the total brood. Transforming larvae of the fourth brood were feeding for 11.5 days or 24.3 days less than the average for the total brood. No larvae hatching *after* October 6 were full grown by November 20, the date of the last cocooning observation. It is apparent, therefore, that some third brood, many fourth brood, and all fifth brood larvae were feeding for a much longer period than the maximum indicated above. In fact, larvae were feeding thruout the greater part of the winter in apples stored in glass rearing jars in the insectary, full-grown individuals leaving the fruit and cocooning daily, a condition not unlike that of "common storage."

Larval cocooning.—The first and last second brooa larvae, transforming in 1927, cocooned on July 4 and September 10, respectively; third brood larvae, on August 6 and September 20, respectively; and fourth brood larvae, on September 17 and 19, respectively.

Combined cocooning period of transforming larvae and pupal stage.—The records of the length of the combined cocooning period and pupal stage for all individuals transforming in 1927, show but slight variation for the three summer broods, averages of 15.2, 16.7, and 16.5 days being recorded for the second, third, and fourth broods, respectively. The maximum and minimum lengths of this combined interval from the date of the leaving of twig or fruit by the larva to the date of emergence of the adult moth were 32 and 7 days, respectively.

Length of life cycle for transforming material.—The data for the length of the life cycle for all individuals transforming in 1927 show that the first record from egg to adult for the second brood was June 12 (deposition) to July 20 (emergence), and the last, August 2 (deposition) to September 10 (emergence); for the third brood, July 18 (deposition) to August 19 (emergence), and August 24 (deposition) to October 7 (emergence); for the fourth brood, August 31 (deposition) to October 6 (emergence), and September 3 (deposition) to October 3 (emergence). There was but slight variance in the averages for the sexes combined and for all broods (39.5 days, second brood; 42.75 days, third brood; 33.0 days, fourth brood). Females apparently required longer for completion of development than did males, but never was that average in excess of 1.5 days. The maximum and minimum lengths of the life cycle were 74 and 23 days, respectively.

Proportion of broods transforming and wintering.—One hundred per cent of the first brood, and approximately 97 per cent of the second brood, transformed; approximately 75 per cent of the third brood, approximately 100 per cent of the fourth brood, and 100 per cent of the fifth brood, wintered.

Combined cocooning period of wintering larvae and pupal stage.—The records of the length of the combined cocooning period and pupal stage of the wintering second, third, and fourth broods (1927-1928) show that a minimum of 235 days, a maximum of 293 days, and an average of 247.1 days were required for 28 individuals of the second brood; a minimum of 175 days, a maximum of 289 days, and an average of 236.3 days for 1,429 individuals of the third brood; and a minimum of 154 days, a maximum of 228 days, and an average of 192.4 days for 272 individuals of the fourth brood.

Cocooning period of wintering fourth brood larvae.—The records of the length of the cocooning period of wintering fourth brood larvae (1927-1928) show that a minimum of 125 days, a maximum of 207 days, and an average of 162.4 days were required for 248 individuals.

Pupal stage of the spring brood of 1928.—The records of the length of the pupal stage of the spring brood of 1928 (transformed larvae of the wintering fourth brood of 1927) show that a minimum of 19 days, a maximum of 43 days, and an average of 36.3 days were required for 203 individuals.

Length of life cycle for wintering material.—The records of the length of the life cycle of the wintering second, third, and fourth broods, completed by the pupation of larvae overwintered and their emergence as spring brood moths in 1928, show that a minimum of 275 days, a maximum of 329 days, and an average of 283.9 days were required for 28 individuals of the second brood; a minimum of 212 days, a maximum of 327 days, and an average of 270.2 days for 1,429 individuals of the third brood; and a minimum of 211 days, a maximum of 268 days, and an average of 236.5 days for 270 individuals of the fourth brood.

EARLY SEASONAL DEVELOPMENT

Earlier studies, (3) (7), of the seasonal life history of the oriental fruit moth have shown that local differences in brood conditions may exist; that they originate in the spring; and that they are due to certain environmental factors. In order to establish the applicability thruout the entire State of the detailed biological studies conducted at Ironton during 1927 and 1928 by adequate adjustments based on a knowledge of the accelerating or retarding effect of such influencing factors, effort was made to determine the progression in spring emergence from southern thru central to northern Ohio.

Eight localities—Ironton, Cincinnati, Marietta, Chillicothe, Columbus, Wooster, New Waterford, and Danbury—were selected as a succession of observation points extending from Lawrence County in the extreme south on the Ohio River to Ottawa County in the extreme north on Lake Erie, a distance of 208 miles, with elevations varying from 565 to 1053 feet, and with a range in average precipitation and mean temperature which amounted to 3.76 inches and 7.9 degrees, respectively, during the emergence period of the spring brood in 1928 and 1929.

During November, 1927, and December, 1928, and before local differences in mid-winter temperatures became effective, 300 wintering larvae of the fruit moth were placed in each locality. The standardized hibernation cage adopted in 1928-1929 is shown in Figure 2. The detailed data secured have been greatly condensed for presentation in Figure 3. The progression in spring emergence for the several localities is expressed in terms of days of delayed emergence in comparison with Ironton, in Lawrence County, the most advanced point in the initiation of development each year.

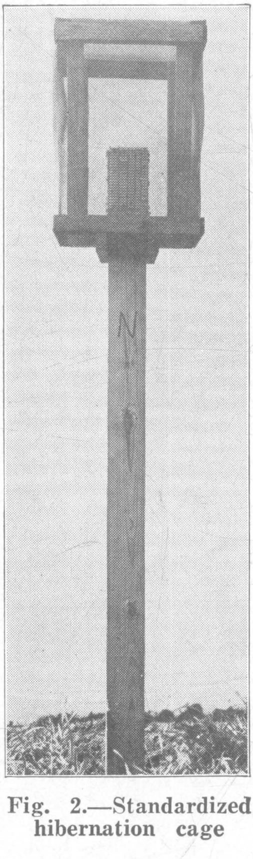

Fig. 2.—Standardized hibernation cage

The three years, 1927, 1928, and 1929, show a marked contrast, with 1927 and 1929 representing relatively advanced seasons with accelerated development and 1928 a relatively delayed season with retarded development.

1927.—A persistent and at times quite pronounced warm spell, commencing about the middle of January, in 1929, and continuing for some 60 days, resulted in one of the warmest Februaries on record. The accumulated excess temperature for February and March amounted to 11.0 degrees. Precipitation was above normal. Such conditions were conducive to early development of both the insect and its preferred host. A marked cold wave, however, with killing frosts on April 24 and 25 destroyed practically the entire peach crop in southern Ohio. In this section of the State, overwintered larvae had commenced to transform during March. The spring brood of moths emerged in April. The first, first-brood eggs were deposited and larvae hatched during the latter part of April and early May. On May 1, a scattering twig injury was already evident. By May 15 and thruout the remainder of the month such injury was conspicuous.

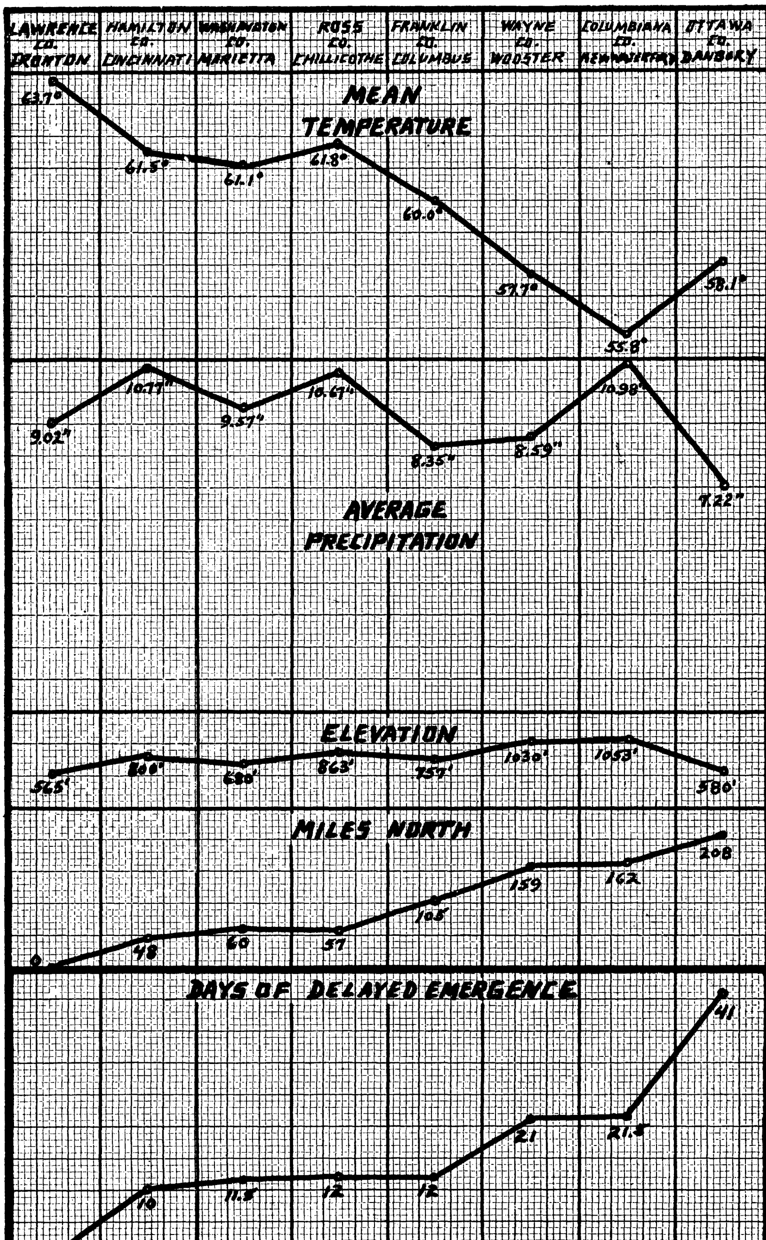

Fig. 3.—Progression in spring emergence, 1928 and 1929

1928.—Prevailing temperatures for January and February, 1928, were but slightly above normal, while March, April, May, and June showed an accumulated temperature deficiency of 10.8 degrees. Precipitation was below normal. Peach buds remained dormant and therefore escaped any serious injury. Only four Aprils in 46 years show a mean temperature for the State lower than that of 1928. The month was characterized by a succession of very pronounced and persistently cool waves, with frost temperatures prevailing on almost every night after the sixth. In May, the first warm spell from the first to the fifth produced the peak of emergence at Ironton; a second, lasting for but a day (the tenth) brought out the majority of moths at Cincinnati, Marietta, Chillicothe, and Columbus; and a third, from the fifteenth to nineteenth, produced maximum emergence of those at Wooster and New Waterford. At Danbury this peak was coincident with the only warm spell, commencing on the thirteenth, of the second wettest and fourth coolest June on record for Ohio. The earliest and latest dates of first emergence were April 30 (Lawrence County and May 23 (Ottawa County), respectively, and the earliest and latest dates of last emergence, June 4 (Lawrence County) and July 22 (Ottawa County), respectively.

1929.—An interval of temperature deficiency occurred in January and February, 1929. It included a cold wave, culminating on February 25 in minima ranging from about zero to 25 degrees below, which resulted in the destruction of peach buds in northern Ohio. Then followed a period of excess temperature in March and April amounting to 10.2 degrees. March was characterized by a persistent and, at times, summer-like warmth, favoring rapid transformation of overwintered larvae. There were two warm spells in April; one of almost unprecedented intensity from the third to the eighth, and the other of less intensity, from the twenty-fourth to the twenty-eighth. It was during the first of these warm spells that the maximum temperature of 90 degrees for the month was recorded and both the first and the maximum emergence of the spring brood occurred in southern Ohio. The second warm spell brought out the last moths of this brood in southern Ohio and the first moths in northern Ohio. The earliest and latest dates of first emergence were April 7 (Lawrence County) and May 9 (Ottawa County), respectively, and the earliest and latest dates of last emergence, April 21 (Lawrence County) and June 11 (Ottawa County), respectively.

Each year, 50 per cent of the spring brood emerged within a period of one week. Median emergence occurred three weeks earlier in 1928 than in 1929, but in each instance coincided with petal-fall of the peach thruout the State. Both pupation and emergence of this brood occurred from one to two weeks later in central Ohio and from two to three weeks later in northern Ohio than in southern Ohio. The median emergence date for Ottawa County on Lake Erie was 45 days later than that for Lawrence County on the Ohio River, in 1928, and 46 days later, in 1929, a variation sufficient to account for one brood less of this insect annually in the extreme northern section of the State.

ADULT BEHAVIOR

Observations on adult behavior during the midsummer of 1929 indicated that moths are normally most active during the evening. In hourly collections from pans filled with a 10 per cent syrup bait and placed in young peach trees immediately adjacent to the insectary (Fig. 4), 93 per cent of the moths captured came to the pans between the hours of six and nine P. M.

Fig. 4.—Insectary at Wooster

Oviposition.—Insectary records show that heaviest oviposition commonly occurs during the evening. Very few eggs are deposited during the day, oviposition usually commencing between four and five o'clock. It continues until about midnight, with maximum deposition occurring at approximately eight o'clock. Of the total eggs under observation on July 16 and 17, 1929, 55 per cent were deposited between seven and eight o'clock and 90 per cent between six and nine o'clock. On July 24, the afternoon was cloudy and rain began to fall at 5:15 P. M. The peak of oviposition was reached between five and six o'clock, when 52 per cent of the eggs for the day were deposited.

The close correlation of moth activity and oviposition with recorded temperatures for July 16, 17, and 24 is shown graphically in Fig. 5.

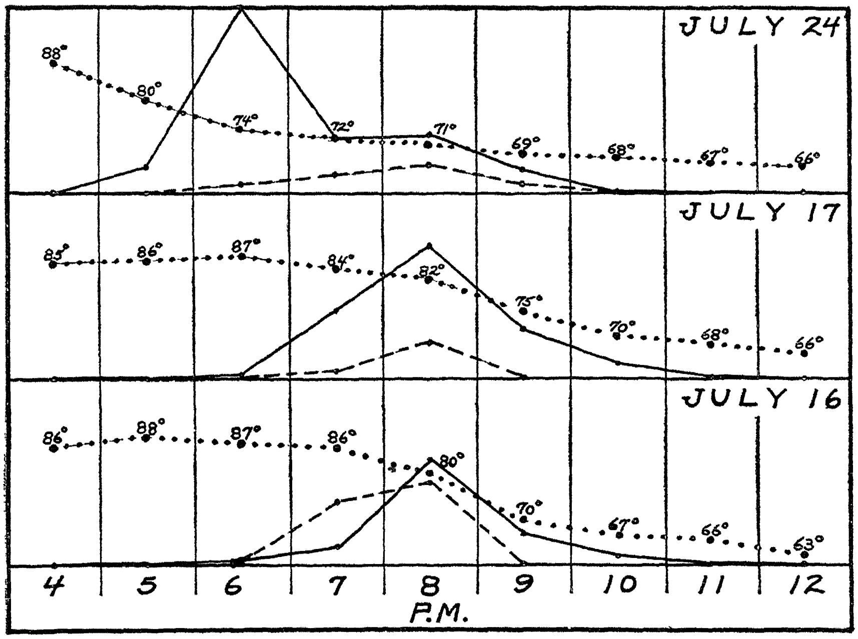

Fig. 5.—Correlation of moth activity and oviposition with temperature

Dotted line—Temperature; Dash line—Moths captured;
Full line—Eggs deposited

In the case of young peach trees, it was found that 94 per cent of the eggs were deposited on the under surface of the terminal leaves, five per cent on the upper surface, and but one per cent on the terminal twigs.

LARVAL BEHAVIOR

Observations on larval behavior on ripe Jonathan apples during the midsummer of 1929 indicated that the larvae spent an average of 1¼ hours crawling about before they commenced to effect entry. An additional 1¼ hours were consumed before a tunnel of sufficient length to conceal the insect was constructed. Thus, the average total time which elapsed between hatching and entry was 2½ hours. There is reason to believe, however, that the time ordinarily required for entry is considerably shorter than these figures indicate.

Any irregularity on the surface of an apple might be accepted as a favorable point of attack, but a large percentage of entrances were effected in either the calyx or stem end cavities.

Fig. 6.—Larva attacking surface of Jonathan apple

Under normal conditions with the surface uninjured, larvae attached the head and sometimes the entire body to an apple with a supporting web of fine, silken threads, which functions as an obstruction against which they can push in forcing the mandibles thru the surface tissue. Tiny particles were cut loose and cast aside. Very little, if any, of the surface was ingested.

Variation in feeding.—For some time it has been known that larvae of the oriental fruit moth feed longer in some fruits than in others, and that the length of the feeding period varies with the temperature. In a study, conducted during the summer of 1928, to determine the limits of such variation in feeding and the adaptability of various fruits for rearing purposes, peaches, plums, apples, pears, quinces, and certain dried fruits were employed. Each day, ten just-hatched larvae were placed with each of these fruits (Fig. 7) and the period of larval feeding determined.

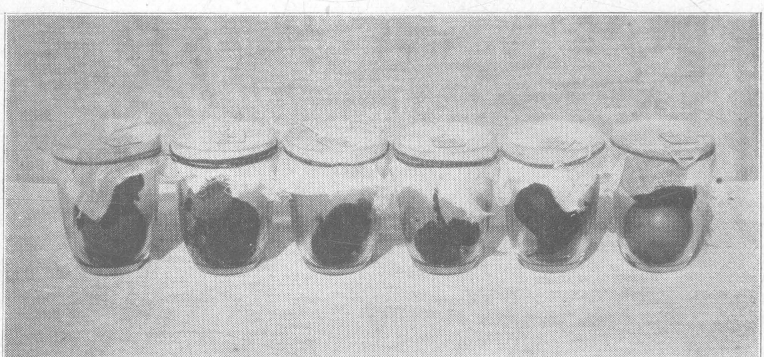

Fig. 7.—Rearing method

The detailed data obtained have been greatly condensed and are presented in Table 1. No larvae were reared from, nor would any feed in, dried fruits. Of the fresh fruits, apples were superior in every respect as a rearing medium. Larvae matured most rapidly in peaches, plums, apples, pears, and quinces in the succession named, with a range of almost a week (6.2 days) between the extremes. The length of the feeding period varied directly with the temperature, a high temperature speeding up development and a low temperature retarding it.

TABLE 1.—Variation in Length of Larval Feeding Period

Fruit	Length of feeding period in days			Per cent of larvae maturing
	Maximum	Minimum	Average	
Peach	26	8	13.8	44.0
Plum	27	9	14.5	33.0
Apple	34	8	16.7	56.9
Pear	26	10	16.9	12.0
Quince	32	12	20.0	13.3

PARASITISM

When the oriental fruit moth investigation in Ohio was entered upon in May, 1927, it was assumed, because of the recent establishment of the pest in this State, that its parasites were as yet absent. Accordingly, arrangements were made immediately with Dr. Alvah Peterson, at that time Entomologist in charge of the peach insect investigational work of the Federal Bureau, at Riverton, New Jersey, to forward parasitized material. It was hoped to introduce into Ohio *Macrocentrus ancylivora* Rohwer, the most important parasite of this insect in the East. Four shipments were made on May 20 and 31 and on June 7 and 18, 1927. The larvae were reared to maturity in the Ironton insectary and the adult *Macrocentrus,* after mating, were liberated in a Lawrence County orchard.

As a result of the county to county survey of infestation then in progress, it was soon discovered, however, that not only had the oriental fruit moth been present for a somewhat longer period than at first believed with the infestation fully as severe as in some sections of the East, but also that both *Macrocentrus ancylivora* Rohwer and *delicatus* Cress. and certain other parasites as well were already present. This line of endeavor was, therefore, discontinued at once.

The combined records for 1927, 1928, and 1929, which include rearings from twenty counties, indicate that the following 17 larval and pupal parasites of the moth are now active in Ohio:

Macrocentrus delicatus Cress., *Macrocentrus ancylivora* Roh., *Glypta rufiscutellaris* Cress., *Ascogaster carpocapsae* (Vier.), *Pristomerus ocellatus* Cush., *Cremastus minor* Cush., *Cremastus forbesii* Weed., *Eubadizon* sp?, *Apanteles epinotiae* Vier., *Apanteles aristoteliae* Vier., *Microgaster* sp?, *Meteorus trachynotus* Vier., *Centeterus ineptifrons* Gahan. (pupal parasite), *Dioctes obliteratus* (Cress.), *Eupelmus amicus* Gir., *Lixophaga mediocris* Ald., and *Lixophaga variabilis* (Coq.).

As a result of periodical collections and rearings of twig-feeding larvae in certain orchards in Lawrence, Hamilton, Ross, Fairfield, Franklin, Belmont, Knox, Cuyahoga, Lorain, and Ottawa Counties, an average parasitism of 15 per cent for the State was recorded during the summer months of 1929.

Observations suggest that the apparently low survival of parasitized material during the dormant season, which results in reduced activity in the case of the first brood each year, is possibly due to the facts that a high percentage of twig-feeding and a low percentage of fruit-feeding larvae are parasitized while a low percentage of twig-feeding and a high percentage of fruit-feeding larvae hibernate. The records of emergence from transformed larvae, which overwintered during 1927-1928, cocooned on and in peach mummies, show that no parasitized material hibernated in this manner.

Macrocentrus ancylivora Rohwer is now known to be present in Lawrence and Hamilton Counties and *Macrocentrus delicatus* Cress. in the following thirteen counties: Lawrence, Jackson, Meigs, Hamilton, Butler, Ross, Fairfield, Franklin, Knox, Belmont, Wayne, Sandusky, and Ottawa. The latter has continued to be the predominating species in southern Ohio during the period under consideration, and constituted in 1927, 1928, and 1929, 47, 55, and 78 per cent, respectively, of all parasites reared within the State. *Glypta rufiscutellaris* Cresson, the species of larval parasite second in importance elsewhere, is present in eleven counties—Lawrence, Meigs, Washington, Ross, Hocking, Fairfield, Wayne, Lorain, Erie, Sandusky, and Ottawa. It is by far the most abundant species in northern Ohio at the present time. *Macrocentrus* is apparently equi-brooded with its host. Parasitism by this species is commonly uniform with an upward seasonal trend. *Glypta*, on the other hand, is believed to be two-brooded. Its activity is more variable and its seasonal trend is decidedly erratic.

The records in general suggest an increasing activity and effectiveness on the part of these natural enemies of the moth in the Ohio area. Such conditions augur well a decline in infestation in certain sections of the State in the not far distant future comparable with that already experienced in the older infestations in the East.

Notwithstanding this probability, parasitism does not provide an adequate control for this insect. The cycle of infestation by the oriental fruit moth is characterized by a wave-like periodicity. It includes three or four years of increasing injury, followed by a like period of receding injury due to the introduction and combined efforts of its parasitic enemies. Determination of the presence, relative importance, and conditions favoring the maximum activity of these parasites is especially desirable, since they are an important factor influencing the efficiency of adequate artificial control measures which will eventually be developed and on which the fruit grower must rely during years of severe infestation.

II. CONTROL STUDIES

DORMANT SEASON SPRAYS

Previous studies, (1) (4), in New Jersey have shown that under average conditions the overwintering population of the oriental fruit moth is distributed somewhat as follows: 14 per cent in the upper portions of the tree, 11 per cent on the tree trunk, and 75 per cent away from the tree. These percentages are correlated with the number of peach mummies and amount of trash present on the ground and are also affected by the age of the trees, character of bark, and type of branching. Of the larvae overwintering on the tree trunk, about 88 per cent construct hibernacula within six inches from the ground.

The fall application of paradichlorobenzene, and spring cultivation, have proved effective in the control of those larvae hibernating at the base of the tree trunk and on the ground. During the winters of 1927-1928 and 1928-1929, tests were made with the following sixteen insecticides in order to determine whether any were sufficiently penetrating and toxic to destroy the remaining larvae overwintering in the upper portions of the tree: Dry lime-sulfur, 15-50; Carboleine, 1-10; Scalecide, 1-15; Sunoco, 1-15; Dormant oil (Schaeffer Bros.), 10%; L-43 (Standard Oil Product), 1-50; Medina oil emulsion, 1-15; Shale oil kerosene emulsion, 1-20; Carbolineum, 50%; Pure pine oil, 50%; Tar acid oil, 12½%; Red Arrow, 1-50; Volck (medium), 4%; Hydrated lime, 25-50. Nicotine sulphate 40%, 1-250; Hydrated lime, 40-50, Nicotine sulphate 40%, 1-250, Kayso, 1-50; and Hydrated lime, 40-50, Fish oil, 12 oz.-50. In each of these tests, 100 larvae which had cocooned normally on peach wood were employed.

The 12½ per cent Tar Acid Oil, resulting in a 90 per cent control, was the only one of this series worthy of further consideration.

Provided observations on parasitism, indicating that the majority of parasitized twig-feeding larvae hibernate on the tree, are correct, any effective control directed at this portion of the overwintering population of this insect would be disastrous in reducing still further the percentage of natural enemies surviving from year to year.

HYDRATED LIME IN SUMMER SPRAYS

The larval is the only injurious stage in the life cycle of the oriental fruit moth. The frequent repetition of the life cycle each season and the ability of larvae to feed during spring and early summer within the twigs and during midsummer and late summer within the fruits of most orchard trees account in a large measure for the tremendous yearly increase in the population of this insect and for its unparalleled destructiveness as a fruit pest. The prevention or reduction of larval entry into twigs or fruit seems, therefore, the logical control objective.

Nicotine sprays, applied with the hope of killing either the egg or the young larva and thus preventing twig and fruit infestation, have proved partially effective but prohibitive in cost. Because of the specialized feeding habits of the larva, the arsenical sprays usually applied for the control of other chewing insects of the peach and apple have proved ineffective.

The eggs of the oriental fruit moth are commonly deposited on the under surface of the terminal growth of the peach. Just-hatched larvae are forced to crawl for a considerable distance over the plant surface before reaching the favored points of entry, the tip of the twig or the stem end of the fruit. The senior author (5), commenting on tests conducted during 1926, recognized for the first time that the results with hydrated lime applied heavily either as a dust or spray on the foliage were significant as indicative of the possibilities of this and other similar materials as physical and mechanical hindrances to entry.

1927.—Further observations on the effectiveness of this material in 1927 substantiated this belief. Four treatments of hydrated lime (40 lb. to 50 gal.) applied at weekly intervals from

July 7 to August 4 in a Lawrence County, four-year-old, peach orchard without fruit, which had averaged 206 injured twigs per tree by the larvae of the first and second broods, reduced twig injury by the third brood 81 per cent.

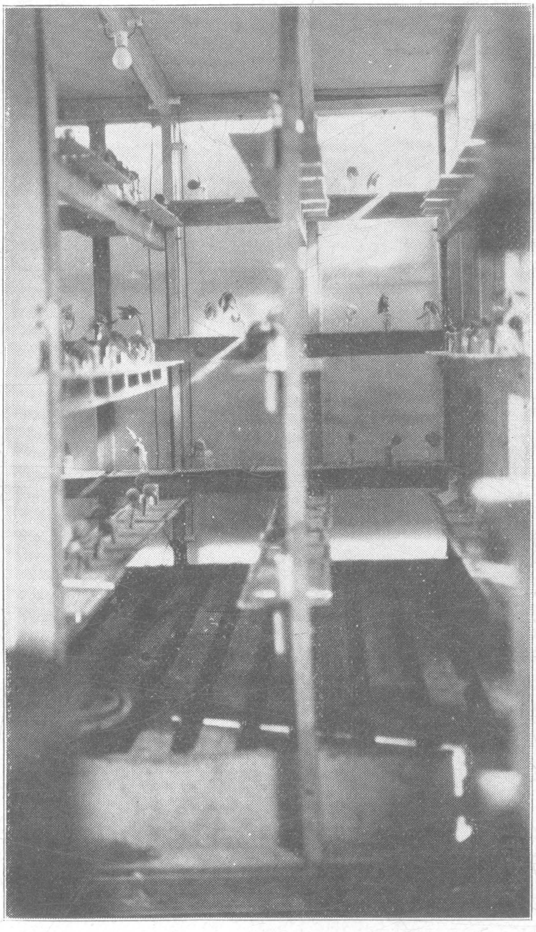

Fig. 8.—Control chamber for insecticide tests

1928.—During 1928, hydrated lime, alone and in combination with other insecticides, was included in practically all laboratory tests and orchard spraying experiments for the control of this insect in Ohio.

All sprays in the laboratory were applied with a standard, commercial sprayer, at 300 pounds pressure, from a distance of six feet and for a period of eight seconds. Approximately 17,000 eggs and larvae were employed in these tests, the material being retained for observation under controlled conditions of humidity and temperature for a period of about ten days following treatment.

It was discovered that moths display a pronounced indisposition to oviposit on foliage sprayed heavily with hydrated lime. In a varied series of repellency tests, an average of 48 per cent and a maximum of 84 per cent less eggs were deposited on foliage sprayed with hydrated lime (25 lb. to 50 gal.) than on unsprayed foliage.

In the case of eggs deposited on foliage subsequently sprayed with hydrated lime (15 lb. to 50 gal.), failure to hatch was due in part to the desiccating quality of the material and in part to the fact that the thickness of the spray covering prevented just-hatching larvae from breaking away from the egg shell. In addition, hydrated lime (25 lb. to 50 gal.) because of the continual cracking and scaling-off of the spray covering, was found to remove as high as 28 per cent of the eggs as compared with but 2.5 per cent that became detached before hatching under normal conditions.

In tests in which hydrated lime (15 lb. to 50 gal.) was combined with other insecticides, an average of 71 per cent more eggs became detached before hatching than in other tests in which these same insecticides were employed alone. When added to summer oils (2% strength), the increases in ovicidal efficiency recorded were partly due to this action. With such a combination, as high as 94 per cent of eggs failed to hatch, with a succeeding kill of 18.5 per cent of the larvae that did hatch. In the case of 40% nicotine sulphate (1-800 dilution) and hydrated lime, on the contrary, the rapid freeing of the nicotine resulting from such a combination more than counteracted this action.

The effectiveness of hydrated lime as a larvicide can be attributed partly to its desiccating quality and partly to the impeding of larval movement over the plant surface. Just-hatched larvae in particular become entangled immediately in the fine lime particles, and, in struggling to free themselves, soon succumb.

Approximately 90 per cent of the midsummer and late summer larvae enter peaches thru the stem-end. This type of injury, commonly referred to as "non-visible", since there is no external evidence that the fruit is infested, is highly variable. With Elberta, it averaged 22 per cent in Ohio during 1928. The larvicidal efficiency of hydrated lime was further emphasized by the fact that 69.5 per cent less peaches were injured thru the stem end when the cavity was filled by such a spray (20 lb. to 50 gal.).

In a peach orchard without fruit, composed of trees three years old and younger and divided into square blocks of approximately 48 trees each, an attempt was made to reduce twig infestation. The applications were given with the same sprayer and at the same pressure as in the laboratory tests. Treatments of hydrated lime (25 lb. to 50 gal.) alone, applied weekly on diagonally duplicate blocks reduced twig injury for the entire season exactly 53 per cent in each instance. Treatments of hydrated lime (15 lb. to 50 gal.)

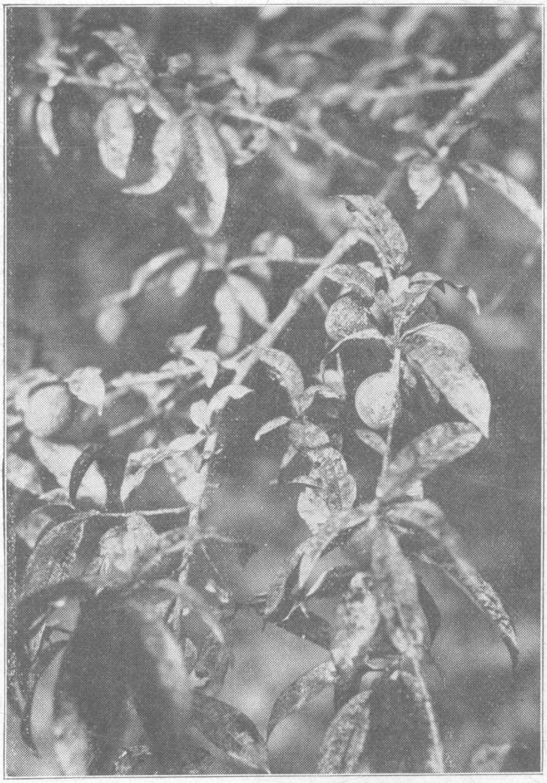

Fig. 9.—Appearance of Alton foliage and fruit, June 15, 1928

in combination with other materials and applied every two weeks thruout the season showed an approximately equal, and in some instances greater, efficiency. When added to hydrated lime and applied as indicated, tobacco fish oil soap (10 lb. to 50 gal.) reduced twig injury 58 per cent; rosin fish oil soap (3 lb. to 50 gal.), 65.5 per cent; Volck (2% strength), 63 per cent; and Volck (2% strength) and 40% nicotine sulphate (1-800 dilution), 77 per cent.

In a five-year-old peach orchard with a crop and under normal conditions of rainfall (the excess for the months of July, August, and September being but 1.13 inches), six applications were given at approximately ten-day intervals from May 1 to June 27 (40% nicotine sulphate at the 1-800 dilution in all but the fifth application and hydrated lime at varying rates as necessitated but averaging 80 pounds to 200 gallons in all but the sixth application).

The results of the laboratory tests suggest that nicotine was possibly a negligible factor in this experiment.

First and second brood larval injury averaged but 0.9 and 12.6 twigs per tree, respectively, a reduction of 75 per cent as compared with the remainder of the orchard which has been sprayed in accordance with the Ohio schedule. Many of the injured twigs had been tunneled to a depth of but one-fourth of an inch; no larvae could possibly have matured in them.

Fig. 10.—Appearance of Alton foliage and fruit at harvest, August 7, 1928

Sprayed Elberta were harvested with 91 per cent marketable clean fruit, while from an unsprayed area only 49 per cent of the fruit was clean. The contrasting percentages of absolutely clean fruit in the case of this variety were 85 and 38, respectively, a reduction of 47 per cent in injured fruit and a decrease of 76 per cent in infestation in favor of the experimental treatment.

Alton were harvested earlier with 100 per cent marketable and 98 per cent absolutely clean fruit, and the late season variety, Krummel's October (with two additional hydrated lime applications on July 7 and 14) with 79 and 46 per cent, respectively.

The records of fruit infestation indicate that as long as the foliage and fruit were heavily coated with hydrated lime spray the infestation was abnormally light. When treatments were of necessity discontinued and the spray covering commenced to wear away, the infestation increased proportionately.

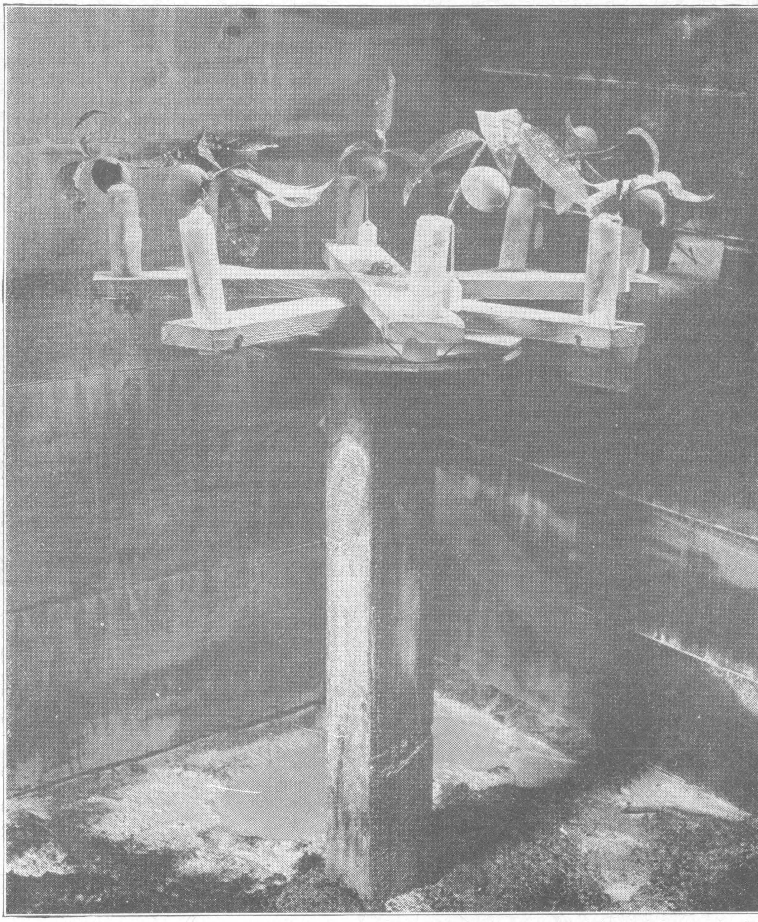

Fig. 11.—Spraying device

1929.—Summer laboratory studies were continued and expanded in 1929, 21,000 moths and 47,000 eggs and larvae being employed in repellency, ovicidal, and larvicidal tests conducted under both normal and controlled conditions of temperature and humidity.

The results in general substantiated those secured in 1928. A heavy, hydrated lime spray (15-40 lb. to 50 gal.) was effective as a repellent to oviposition (56-82 per cent), as an ovicide (10-28 per cent), and as a larvicide (15-87 per cent). Summer oils (2% strength) showed corresponding efficiencies of 84, 99, and 76 per cent, respectively. The hydrated lime-summer oil combination, as compared with hydrated lime alone, proved much less effective as a repellent to oviposition (28 per cent), more highly effective as an ovicide (97 per cent), and about equally effective as a larvicide (71 per cent).

Eleven tons of hydrated lime[1], of high calcium content (total CaO, 73%; total MgO, 0.7%) and with 96 per cent passing thru a 300 mesh screen, and two tons of talc[2] (300 mesh) were employed in cooperative and experimental spraying and dusting during 1929.

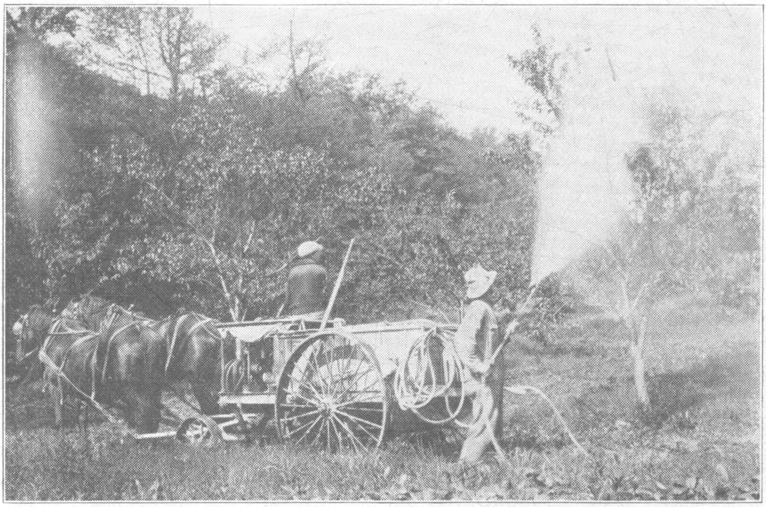

Fig. 12.—Spraying with hydrated lime

Continued observations on early seasonal development have shown that maximum spring emergence normally coincides with petal-fall of the peach. This fact, and the standard spray and dust treatments for peach in Ohio, were considered in formulating the tentative control schedule for 1929 presented in Table 2.

Eight representative peach growers in southern, central, and northern Ohio (Fig. 13), whose combined interests comprise some 200 acres of fruit, with varying severity of infestation, were secured as cooperators. By agreement, these cooperators recorded daily emergence of the spring brood of moths in standardized hibernation cages (Fig. 2, page 10) in their respective orchards,

[1]Bald Eagle Hydrate brand of the American Lime and Stone Company, Bellefonte, Pa.
[2]Secured from the W. H. Loomis Talc Corporation, Gouverneur, N. Y.

sprayed or dusted under supervision and in accordance with the schedule and with the materials furnished by the Ohio Experiment Station. At the conclusion of the season their frequently recorded observations were summarized. Data relating to fruit infestation were secured by the writers at harvest.

TABLE 2.—Tentative Spraying and Dusting Schedule, 1929

Brood	Application	Time	Materials	
			Spray schedule (Seven cooperators)	Dust schedule (Two cooperators)
1	1	Bloom off	Hydrated lime 15–50	Talc
	2 (Standard)* (Treatment)	Shuck-split	Hydrated lime 25–50 Fish oil 6 oz –50 (Sulfur-lime 12½–50) (Lead arsenate 1½–50)	Talc (80–10–10)
	3	1 week later	Hydrated lime 15–50	Talc
	4 (Standard)[1] (Treatment)	2 weeks later	Hydrated lime 15–50 (Sulfur-lime 12½–50) (Lead arsenate 1½–50)	Talc (80–10–10)
2	5	3 weeks later	Hydrated lime 15–50	Talc
	6	5½ weeks later	Hydrated lime 15–50 Volck 1 gal. –50	Talc
	7	6½ weeks later	Hydrated lime 15–50 Volck 1 gal. –50	Talc

*Standard Treatment Materials in Parenthesis [1]Preharvest spray or dust optional

Notwithstanding that exceptional and pronouncedly unfavorable weather conditions (excess precipitation range, 0.08 to 5.84 inches; average, 1.41 inches; temperature deficiency range, 3.4 to 13.0 degrees, average, 5.8 degrees) prevailed during both the spraying and preharvest periods, from 25 to 56 per cent reduction in visible infestation was secured thru spraying. The complete records are summarized in Table 3.

The seven-application talc dust schedule, comparable with the seven-application hydrated lime spray schedule, gave no better control than the usual two applications of dust, which in turn proved inferior to the similar two applications of spray.

In general, infestation was less severe in the cooperative than in neighboring orchards, and the larger the area treated the higher the degree of control. No difficulty was experienced due to the quantity and character of the materials employed. No spray residue of an undesirable nature was encountered on the fruit at harvest. The growth of the limed trees exceeded that of the

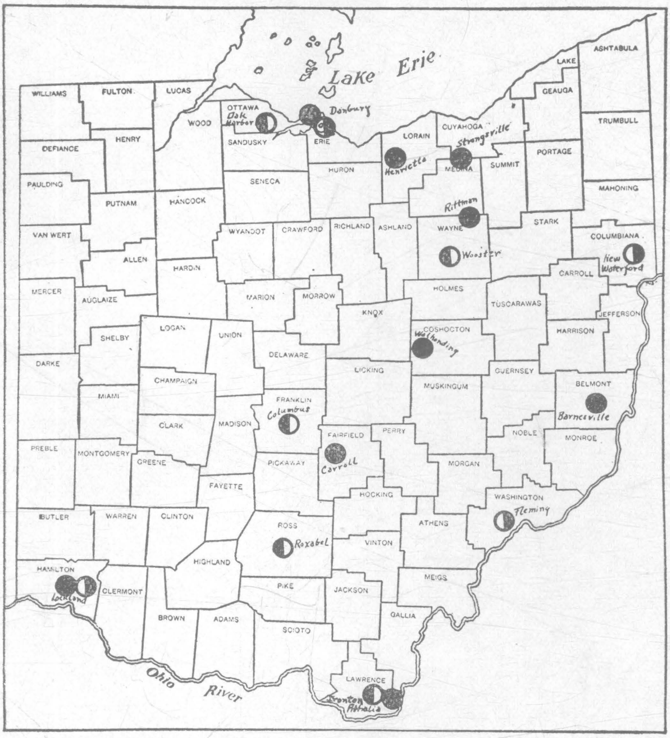

Fig. 13.—Location of investigational work

Black-white circles—Biological studies
Black circles—Biological and control studies

Fig. 14.—Orchard sprayed with hydrated lime

SUMMARY - COOPERATIVE SPRAYING AND DUSTING - ORIENTAL FRUIT MOTH CONTROL - OHIO - 1929

LOCALITY	VARIETY	TREATMENT: NUMBER OF APPLICATIONS	TREATMENT: MATERIAL	1929 INFESTATION: VISIBLE	1929 INFESTATION: TOTAL	1929 CONTROL: PERCENT REDUCTION IN INJURED FRUIT	1929 CONTROL: PERCENT REDUCTION IN INFESTATION	1928 INFESTATION: VISIBLE	1928 INFESTATION: TOTAL	1928 CONTROL: PERCENT REDUCTION IN INJURED FRUIT	1928 CONTROL: PERCENT REDUCTION IN INFESTATION
ATHALIA	CARMAN	7	LIME	10	11						
	ALTON	..	..	6	10			0	2		
	ELBERTA	5	..	26	37.5	15-12.5	37-25				
	..	7	..	18	31	23-19	56-38	9	15	42-47	82-76
	..	2	NO LIME (S.O.S.)	41	50			51	62		
ROME	CARMAN	..	80-10-10 (S.O.D.)	38	39						
	ELBERTA	..	..	59	67			19	28		
SOUTH POINT	..	3	LIME and [illegible] Dust	18	32			49	62		
CINCINNATI-1	MAYFLOWER	5	LIME	0.5							
	CARMAN	..	..	9							
	ELBERTA	..	..	13	20			85	90		
	..	..	TALC DUST	+50							
CINCINNATI-2	..	7	LIME	15	29	8-5	35-15				
	..	2	NO LIME (S.O.S.)	23	34						
	..	7	TALC DUST	33	46	NO					
	..	2	80-10-10 (S.O.D.)	30	46						
CARROLL-1	..	7	LIME	7	11	3-8	30-42				
	..	2	NO LIME (S.O.S.)	10	19						
CARROLL-2	..	7	LIME	9	18	3-5	25-22				
	..	2	NO LIME (S.O.S.)	12	23						
COLUMBUS	SHIPPERS LATE RED		LIME	15	19			75	79		
BARNESVILLE	CARMAN	7	..	20		27-	57-				
	..	2	NO LIME (S.O.S.)	47							
	ELBERTA	7	LIME	56	70	7-8	11-10				
	..	2	NO LIME (S.O.S.)	63	78						
WALHONDING	..	7	LIME DUST	9	18	6-3	20-6				
	..		TALC ..	30	45	NO					
	..	2	80-10-10 (S.O.D.)	15	21						
STRONGSVILLE	..	5	LIME	33	67	17-12	34-15				
	..	2	NO LIME (S.O.S.)	50	79						
HENRIETTA	..	5	LIME	25	54	12-7	32-11 5				
	..	2	NO LIME (S.O.S.)	37	61						
DANBURY	..	7	LIME	24	35	19-16	44-31				
	..	2	NO LIME (S.O.S.)	43	51						
MAXIMUM						23-19	56-38				
MINIMUM						3-5	25-22				
AVERAGES	7 APPLICATIONS WITH VOLCK 2% IN 6 AND 7					16-12	46-27				
	.. ..					10-10	28-24				
	5 ..					15-11	34-17				

TABLE 3.—Summary of Cooperative Spraying and Dusting, 1929

unlimed trees and the foliage appeared more healthy, larger, and deeper green in color. Other insect and disease troubles were noticeably less. The apparent control of *Bacterium pruni* was remarkable. There was apparently a better set of fruit on the limed trees and the increase in crop due to the larger size of the fruit was evident without actually measuring the yield. In one orchard in which accurate measurements were taken, the limed block showed an increase of 16.1 per cent in twig growth for the year and a crop of fruit greater by 1.4 bushels per tree than that of the adjoining unlimed block. Post-harvest observations indicated increased fruit bud formation.

Fig. 15.—Appearance of Mayflower foliage and fruit at harvest, June 26, 1929

In experimental spraying, 16 variations of the tentative schedule furnished cooperators were followed out by the writers' employing half-acre plots in an eight-year-old, cultivated, Elberta orchard in a vigorous condition of growth.

In planning the experiment, the uniformity of the experimental area was studied with respect to topography, direction of prevailing winds, planting irregularities, difference in growth conditions, variation in crop, et cetera, and the effect of these possible influencing factors guarded against by replication of certain treatments and by adequate checks. A standard, commercial sprayer, of the same kind as that employed in experimental orchard spraying in 1928 and in the laboratory tests of both 1928 and 1929 but with a tank of larger capacity, was used. Records of both twig and fruit infestation were secured for each tree.

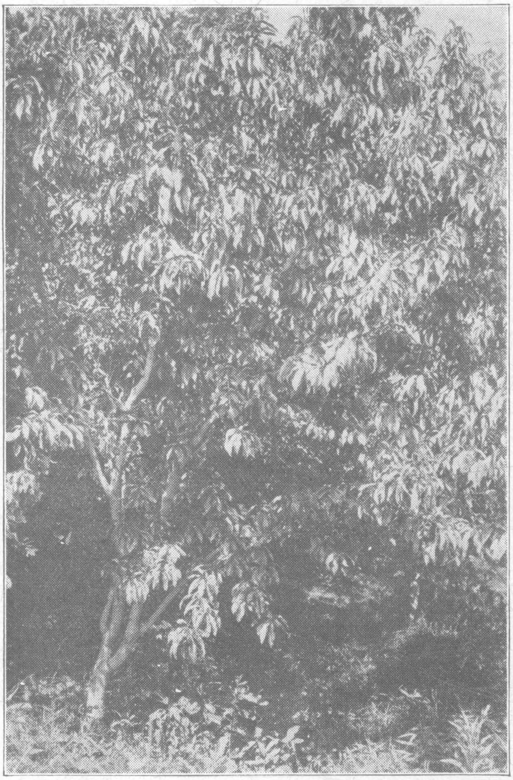

Fig. 16.—Foliage of typical tree in a limed block, July 23, 1929

Untreated areas showed a visible infestation of 42 per cent, an additional infestation of supposedly clean fruit amounting to 26 per cent, and a total infestation of 58 per cent.

Although still maintained, the sequence in reduced twig injury for plots treated with increasing amounts of hydrated lime was less pronounced in decreased fruit infestation at harvest. In Figure 19, the percentages of variation for the several treatments are expressed graphically in relation to the least effective of the hydrated lime (alone) series, to which has been assigned the arbitrary value of zero.

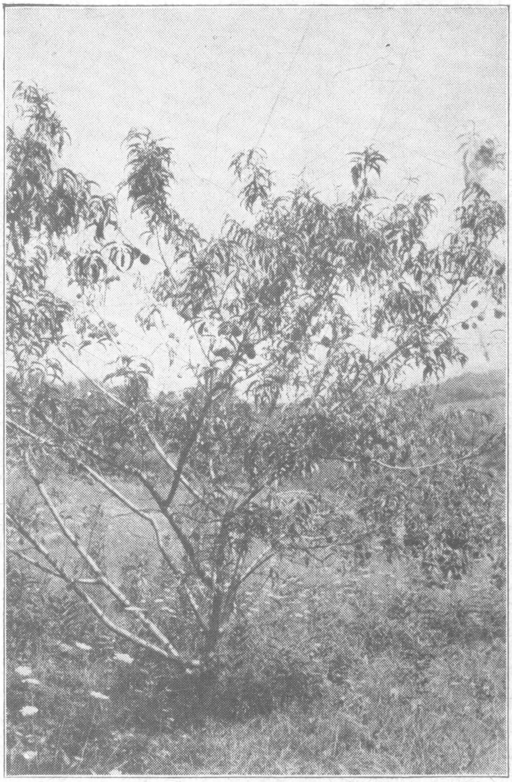

Fig. 17.—Defoliation of typical tree in an unlimed block, July 23, 1929

The results indicate a possibly greater effectiveness with a seven-application schedule of hydrated lime increased thruout from 15 to 25 pounds to 50 gallons of water or a five-application schedule (at increased rate, applications one and five omitted) with an adequate spreader and sticker included in applications two, three, and four.

A statistical interpretation of the data accumulated in this experiment emphasizes that peach tree vigor as evidenced by twig length and weight is positively and decisively correlated with both the number and per cent of injured twigs; that a similar correlation exists between total fruit and the number of injured fruit; and finally, that an inverse correlation exists between total fruit and the percentage of injured fruit (2).

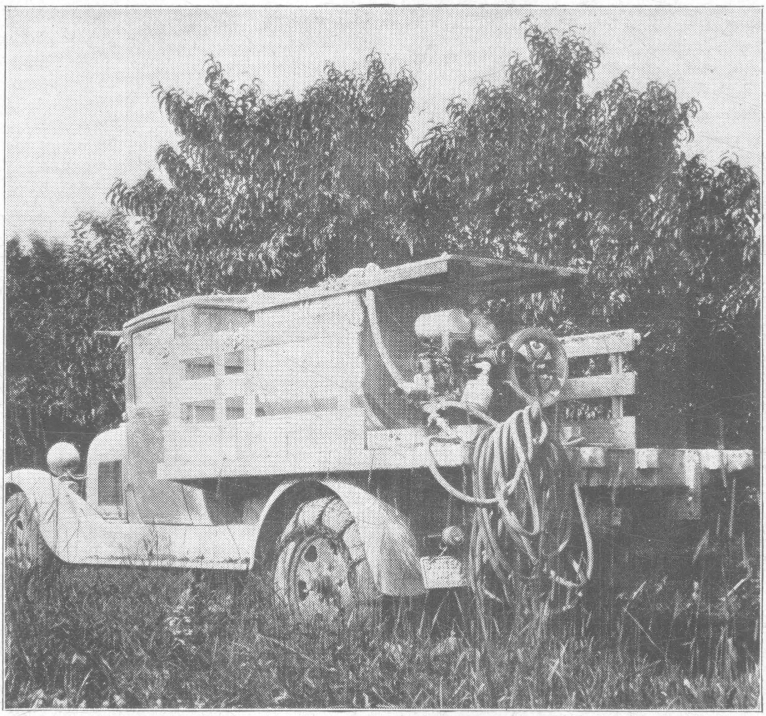

Fig. 18.—Sprayer employed in experimental orchard spraying, 1929

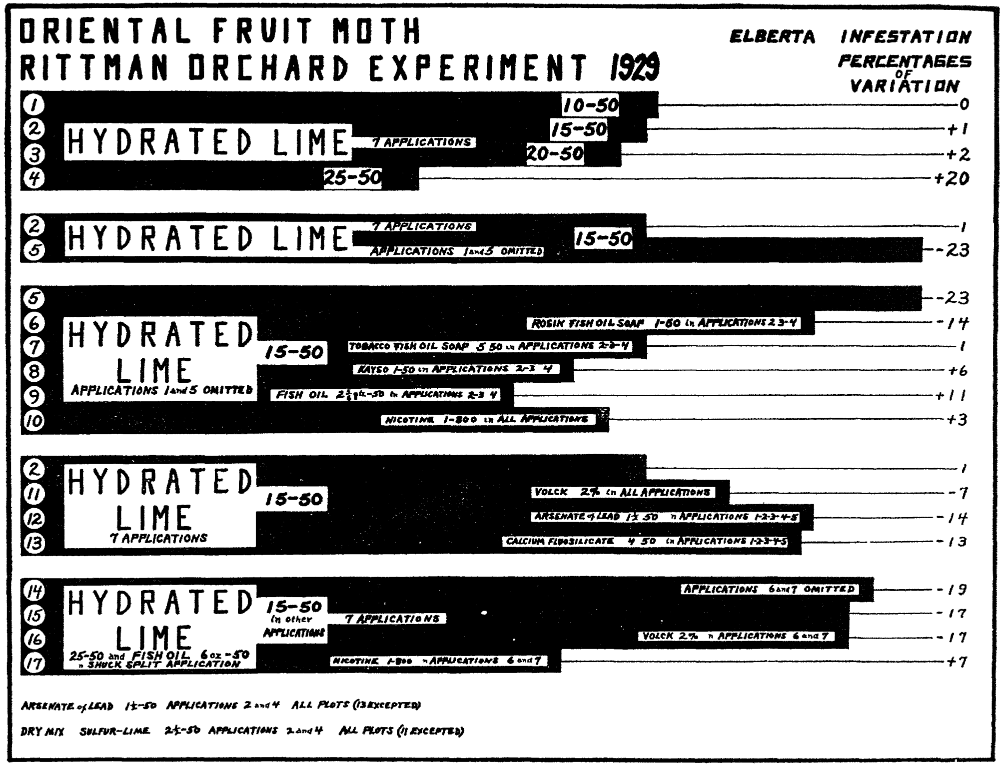

Fig. 19.—Summary of experimental spraying, 1929

SUMMARY

The results to date of an investigation of the oriental fruit moth in Ohio in progress since May, 1927, which have been singled out and discussed herein and which are indicative of the needs and trend of investigation in the future, may be summarized as follows:

A survey of infestation suggests that this insect made its initial appearance in Ohio in either 1924 or 1925. By 1927, it was already widely distributed thruout the State, wherever peaches are grown in abundance. In several localities the infestation was then fully as severe as in certain sections of the East where the insect had been introduced several years earlier. There has been a progressive increase in infestation in the important peach-producing area of Ottawa County on Lake Erie during 1927, 1928, and 1929. It seems probable that the next few years will witness a further extension of the insect's activities in this section of the State.

Five broods of eggs and larvae were developed in southern Ohio in 1927, and four in 1928 and 1929. Studies of early seasonal development indicate that both pupation and emergence of the spring brood occur from one to two weeks later in central Ohio and from two to three weeks later in northern Ohio than in southern Ohio. The median emergence date for Ottawa County on Lake Erie averages 45.5 days later than that for Lawrence County on the Ohio River, a variation sufficient to account for one brood less of this insect annually in the extreme northern section of the State.

Behavior studies show that moths are normally most active during the evening, the heaviest oviposition occurring between the hours of six and nine. Approximately 95 per cent of the eggs deposited on peach foliage are located on the under surface of the leaves. The length of time required by just-hatched larvae for effecting entry into ripe Jonathan apples averaged 1¼ hours. Very little, if any, of the surface tissue was ingested. Larvae matured most rapidly in peaches, plums, apples, pears, and quinces in the succession named. Apples were superior in every respect as a rearing medium, although the average length of the feeding period in this fruit was 16.7 days as compared with but 13.8 days in the peach, its preferred host.

Records indicate a larger oriental fruit moth population for the State as a whole at the close of the 1929 season than at any time since the introduction of this pest into Ohio. The general conditions of parasitism are, however, encouraging. The combined

records for 1927, 1928, and 1929, which include rearings from twenty counties, indicate that 16 larval and pupal parasites of this insect are now active in Ohio. Parasitism, in the more important fruit growing counties in 1929, averaged 15 per cent, with *Macrocentrus* and *Glypta*, the most effective larval parasites of the fruit moth thruout the area of its distribution in this country, the predominating species in this State as well. These suggestions of increasing activity and effectiveness on the part of the natural enemies of the moth in the Ohio area augur well for a decline in infestation in certain sections of the State in the not far distant future comparable with that already experienced in the older infestations in the East, where the initial cycle of infestation is now complete.

No spray has been discovered as yet sufficiently penetrating and toxic to prove effective during the dormant season. In fact, any effective control directed at that portion of the hibernating population present in the upper portions of the tree might prove disastrous in reducing still further the percentage of the natural enemies surviving from year to year, since observations indicate that here the majority of parasitized twig-feeding larvae overwinter.

The results of extensive laboratory tests and of both cooperative and experimental orchard spraying, emphasize the belief that a probable summer control for this insect will result thru a succession of early season sprays which will include hydrated lime or some like material acting as a physical or mechanical hindrance to oviposition, hatching, and larval entry. A spray program of this character is still very decidedly in the experimental stage and no recommendation is advisable at this time. Until the details of such a schedule are determined and its efficiency established, fruitgrowers must accept responsibility for success or failure when spraying in accordance with present information on this matter.

For the present, the supplementary control measures generally recommended—fall application of paradichlorobenzene, spring cultivation, packing house sanitation, adequate disposal of cull fruit, the separation of early and late varieties of peaches and apples in making new plantings, and moderation in pruning and fertilization—should be adhered to in an endeavor to reduce infestation in so far as may be possible.

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