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An investigation of onion pests in the Connecticut Valley with special reference to the onion maggot and onion thrips.

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AN INVESTIGATION OF ONION PESTS IN THE CONNECTICUT VALLEY WITH SPECIAL REFERENCE TO THE ONION MAGGOT AND ONION THRIPS

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INTRODUCTION

The primary purpose of this investigation was to develop practical methods of control for the onion maggot, *Hylemya antiqua* Meigen and the onion thrips *Thrips tabaci*, Lindeman, two very serious pests of onions in the Connecticut Valley. The lack of such control methods has been of concern to farmers for many years and recently has become a very pressing problem.

Since the knowledge of the life history and habits of insects is intimately related to control problems, it was necessary to investigate the biology of both insects. Adequate studies of this type have been lacking for the northeastern United States. Timing of treatments with certain phases in the development of any insect is an important factor with regard to the achievement of successful control.

In addition to biological studies, it was necessary to evaluate the numerous new insecticides available for agricultural use. Manufacturers of agricultural chemicals with their flood of new insecticides and convincing advertisements, make it necessary to evaluate their products in order that the consumer may obtain the most economical protection from insect pests.

The use of chemicals immediately confronts the consumer with the problem of proper dispensing equipment. It also was necessary therefore, to determine the most economical and efficient methods of dispensing insecticides with equipment that was available and applicable to the cultural methods used in the onion industry.

The methods of control in these investigations deal with the protection of four general types of onions which are grown in the Connecticut Valley. "Seed Sets," "Seed Onions," Onions grown from "Sets," and "Spanish Onions" are the four forms with which control of pests was concerned. "Seed Sets" are those onions which are grown from seed for the production of small bulbs which in turn are planted the succeeding year for the production of marketable Onions. Onions grown from "Sets" have been referred to locally as "Set Onions." "Seed Onions" are those onions grown from seed to marketable onions in one season. "Spanish Onions" are produced from transplants and grown to marketable onions in one season. Each of these types of onions requires its own peculiar methods of culture and some, therefore, required particular methods of pest control.

HISTORY OF THE ONION INDUSTRY IN THE CONNECTICUT VALLEY OF MASSACHUSETTS

Onions were first grown as an agricultural crop in Massachusetts, in Essex County. Until 1885, when less than 100 acres were grown in that county, it was the leading center of production for the state. In the year 1885, 111 acres of onions were raised in the Connecticut Valley. From then on, expansion of acreage increased steadily, and from 1895 the Valley has been the leading center of onion production in the state. Thus, within half a century a new and important agricultural industry developed in the Connecticut Valley.

According to Beaumont, Snell, Doran and Bourne (1935), onion culture in the Valley first developed on an extensive scale in the town of Sunderland, and later spread and was almost entirely confined to the towns of Sunderland, South Deerfield, Whately, Hatfield and Hadley. They indicated that the Polish and Lithuanian immigrant influx was an important factor in the development of the industry. The habits, temperament and experience of these peoples were well suited to the great amount of hand labor, laborious weeding and small capital investment necessary for onion culture.

The peak of the onion acreage in the Connecticut Valley was reached in 1920 when 4850 acres were grown. Since that time the acreage has fluctuated widely according to the natural or economic factors such as poor yields and high or low prices. Onion acreage was lowered to

2520 in 1931 and a steady decline was taking place. In 1951 only 803 acres were produced. In 1952 Massachusetts marketing reports indicated that somewhat over 1000 acres had been grown. Recent trends of production indicate that the onion acreage will continue to average about 1000 acres.

Prior to 1920, about 90 per cent of all onions grown in the Connecticut Valley were grown from seed. Since that time the acreage of onions grown from sets has rapidly increased while seed onions decreased. This process has continued until at the present time about 95 per cent of onions are sets while the remaining 5 per cent is divided between seed onions and sweet Spanish onions. The reasons for the shift from seed onions to sets were earliness for market, less chance of complete failure of the crop because of onion maggot, greater opportunity of securing a better crop by avoiding attacks of thrips and the disastrous effects of blast and mildew.

During the peak years of onion production, ready markets for the harvest were at hand. As the years progressed, competition in the onion industry from other parts of the country made markets and prices unpredictable. These unreliable conditions led the farmers to rely on more than one crop for their own protection. This same situation exists at the present in the Connecticut Valley and most farmers divide their production among many crops, the most prominent of which consist of onions, potatoes, tobacco and cucumbers.

SECTION I. THE ONION MAGGOT

TAXONOMY

Some difficulty has been encountered in assigning the correct generic name to this insect. Most of the difficulty has been traced to an attempted change of spelling of the original name by Macquart in 1835.

The original spelling of the name was proposed by Robineau-Desvoidy in 1830 as *Hylemya*. In 1835 Macquart proposed the name *Hylemyia* to take the place of *Hylemya* because the ending *-yia* refers to the diptera while *-ya* has the conotation of snails.

According to the laws of priority, we should accept the name *Hylemya* as correct and discard the spelling *Hylemyia*. Economic entomologists of America have chosen to comply with the original spelling and it will therefore be used as such in this report.

Hylemya antiqua Meigen was first described by Meigen in 1826, as *Anthomyia antiqua*, but as seen earlier was evidently described to the wrong genus and later given the name *Hylemya antiqua* Meigen.

The following is the synonymy as recorded by Huckett (1924).

Anthomyia antiqua Meig., 1826. Syst. Beschr., vol. 5, p. 166, no. 145.

Anthomyia ceparum Meig., 1830. Syst. Beschr., vol. 6, p. 376, no. 217.

Musca liturariae Ratzeb. 1844. Forstins., vol. 3, p. 170, no. 1.

? *Anthomyia caepicola* Rob.-Desv. 1851. Guer.-Men., Rev. et Mag. Zool., ser. 2, vol. 3, p. 234, no. 1.

<u>Chortophila cinerea</u> Meade nec Fall. 1882-83. Ent. Mo. Mag., vol. 19, p. 147.

<u>Phorbia cepetorum</u> Meade. 1882-83. Ent. Mo. Mag., vol. 19, p. 218.

<u>Anthomyia angustifrons</u> Strobl nec Meig. 1893. Verh. Zool.-Bot. Ges. Wien., vol. 43, p. 259.

BIOLOGY OF THE ONION MAGGOT

REVIEW OF LITERATURE

The economic importance of the onion maggot, *Hylemya antiqua* Meig., in the United States, was first brought to attention by Harris (1841). Fitch (1867) indicated that this insect had been a serious pest in Europe from time immemorial, and that its introduction from Europe had taken place many years past. The destructiveness of the insect reached extremely serious proportions during the years 1854 and 1863, in parts of New England and New York. Cowper (1875) was the first individual in Canada to indicate the economic importance of this pest and outstanding early investigators in the United States were Lintner (1882), Fernald (1891), and Slingerland (1894).

The onion maggot was listed by Osten-Sacken (1878) in his Catalogue of the Diptera of North America, but the exact date of its introduction was unknown. It was certain, however, that the onion maggot was well established along the eastern seaboard during the middle of the 19th century and Paillot (1914) indicated that the "onion fly" was probably introduced into the United States previous to the year 1840.

Biological observations of the onion maggot were reported as soon as its economic importance became known. Fitch (1867) reporting on insects of New York, gave brief descriptions of the natural history of this pest. At that time it was known that the eggs were laid on or around the plants, soon after the seedlings emerged. Fitch also observed that the larvae, after feeding was completed, pupated in the soil and successive generations occurred throughout the season.

The most complete early report on the natural history of the onion maggot appeared in 1882 by Lintner, the State Entomologist of New York. In this report appeared a detailed description and habits of each of the four stages of the insect. A brief summary follows:

"There are successive broods throughout the season. The first attack is made as soon as the young seedlings are an inch or two above the ground. Eggs are deposited upon the lower part of the leaves, either among them or at their base. Seldom more than a half dozen eggs are deposited on a single plant."

Eggs - Readily seen by the eye, hatch usually within a week, varying with the temperature of the season.

Larvae - Following hatching, the larvae bore into the sheaths down to the bulb, and consume the interior of the bulb. Full growth is attained in about 2 weeks, and departure from the onion takes place.

Pupae - The larva pupates generally outside the onion in the soil, the last larval skin forming the puparium within which is the pupa. This state ordinarily requires about two weeks in the summer time. It is also stated that the last brood of larvae pass the winter in the pupal state and flies emerge in early June the following year.

A condensed report by Fernald (1891) was apparently a summary of Lintner's work of 1882, with no new additional information. Slingerland (1894) indicated that the onion maggot closely resembled the cabbage root worm, Hylemya brassicae Bouche (= Phorbia brassicae Bouche) in both appearance and life history, except for its choice of food. He refers to the insect as par excellence the Onion Maggot, for he has not recorded it feeding on any other plant.

Further knowledge of the biology of the onion maggot was not recorded until Paillot (1914) summarized the life history, and noted that overwintering took place as both adults and pupae. Adults were said to hibernate in disused sheds, barns, bark of trees, and any other place where they could obtain protection from the elements. In the same year, Levtejev (1914) in Russia, made observations on the destructiveness and biology of this pest in and around Moscow. He reported that maggots could be found in numbers of 3 to 12 per bulb, with as many as 20 at times. His records showed that the adults were on the wing during the second half of May, and that both larvae and pupae were apparently nearly mature during the first week in August.

Several new observations on the life history of the onion maggot were made by Severin and Severin (1915) in Wisconsin. Their observations indicated that eggs were more regularly placed on or in crevices of the soil than they were on the onion plants. The egg stage was found to have a duration of three to four days, the larval stage two to three weeks and the pupal stage nine to sixteen days. The total duration of the first generation was reported to extend over 29-35 days. Emergence of the second generation adults took place from June 28 to

July 25 with the peak of emergence between the 1st and 12th of July. Apparently only two generations were observed in Wisconsin. In contrast, Gibson and Treherne (1916) observed that there were probably three generations of the onion maggot in Ottawa, Canada. Their observations also indicated that there was a rather prolonged preoviposition period. This period was observed to have a duration of 10-14 days. Further work by Gibson (1917) showed that the insect hibernates in the pupal stage in Canada.

Ruhmann (1921) reported on this insect in British Columbia, Canada, and indicated that the first eggs were found on May 17th. The first larvae were found on the 22nd of May with the first pupae on the 6th of June. Second generation adults were taken on June 29. During the following year, Treherne and Ruhmann found that many larvae pupated in the fleshy onion bulbs beneath the loose epidermis. This observation indicates at least one method by which distribution could occur.

In Alberta, Canada, Gray (1924) indicated that the onion maggot was one of the major garden insect pests and was under study during the 1923 season. Flies and eggs were observed in the field on May 15th. The larval period of 54 individuals of the first generation averaged 16.4 days with a range of from 12 to 22 days. First eggs of the second generation were secured on July 13th, and it was found that only 35 per cent of second generation eggs were fertile, as compared to 80 per cent of the first generation. Second generation larvae, taken on the 26th of July, had a developmental period averaging 18.2 days. Gray observed evidence of a third generation but was unable to prove this point definitely. He also observed that the majority of the larvae entered the bulb about 6 mm. above the root attachment and only one case was detected where the maggots entered through the leaves.

A study of the life history of the "onion fly" was made in Great Britain by Smith (1922), who reported that this pest had become so abundant that the culture of onions in certain sections of the country was impossible. The statement was made that onion was the preferred food of the onion maggot but leeks, shallots, tulip bulbs, and even lettuce, had been attacked. This statement conflicts with that made by Slingerland (1894) in which he considered onion to be the only food of Hylemya antiqua Meig. Smith (1922) states that adult flies in the laboratory lived from three weeks to two months when fed on casein, but that the length of life under natural conditions was undetermined. The preoviposition period was determined as lasting from seven to ten days and its importance in the use of baits was emphasized, this period being necessary to bait the flies before they oviposit.

The most complete and detailed presentation on the bionomics of the onion maggot was prepared by Eyer (1922). This treatise was prepared under Pennsylvania conditions which, however extensive, would not necessarily fit the biology of the pest in other sections of the world. Eyer's data on the biology and description of this pest are reproduced in summarized form.

Description of the Adult

Male - Somewhat smaller than the housefly with a light greenish, gray body, darker on the sides and venter. The legs, bristles, genitalia and mouthparts are black, and the wings are unmarked.

Female - The general color is similar to that of the male, although somewhat paler. Adults average about 6 mm. in length.

Period of Emergence

First Brood - Adults emerged from overwintering puparia from April 29 to June 30 depending entirely upon the temperature of the season.

Second Brood - Data for three seasons indicated that emergence of the second brood occurred between July 1 and July 20, with the maximum emergence about July 15.

Third Brood - Adults of this brood emerged from September 4 to October 28. Puparia formed after October 30 produced adults the following spring.

Mating and Reproduction Habits

Proportion of Sexes - The ratio of female to male flies in the laboratory was about equal. However, individuals captured in the field indicated a ratio of about three to one in favor of the females. This discrepancy may be explained by the longer life of the females, thus presenting an accumulated number of females.

Duration of Life - The males lived approximately 10 days, while the females varied from 15 to 25 days.

Mating Habits - Caged experiments revealed the fact that copulation would not take place in the absence of food and sunlight, and that if these essentials were provided copulation was of short duration.

Preoviposition Period - This is the period of time during which the female feeds and the eggs ripen in the ovary. The average number of days is ten, with a variation of 7 to 21 days. Overwintering adults may have a period of six months or more.

Oviposition Period - The time consumed by the female to deposit her full complement of eggs may be 4 to 5 days, or as long as 15 to 20 days, depending largely on weather conditions; bright sunny weather being more conducive to rapid oviposition.

The Egg

Description - The egg of *Hylemya antiqua* was reported as 1.2 mm. long, 0.5 mm. broad, sausage shaped, conical, slightly flattened at one end and bluntly rounded at the other. The chorion is white, glistening, opaque and marked with 12 longitudinal ridges.

Placement - Observations showed that eggs were laid on the onion plant, basally in the leaf axil, or in crevices and on top of the soil near the stem of the growing plant. The latter position was most prevalent. During harvest eggs were deposited directly on exposed onion bulbs.

Egg Complement - The average number of eggs per female consisted of 30 to 40 with a maximum of 60. Six or seven eggs were deposited daily.

Duration of the Egg Stage - After extensive studies it was determined that the average incubation period of the first brood was 5.5 days, that of the second brood 5 days and of the third 5.3 days.

The Larva

Description - The mature larva was 10 mm. in length, and dirty white in color, with the black pharyngeal skeleton, which showed through the anterior portion. The posterior spiracles were described as round, slightly knob-shaped, yellow in color and perforated by three narrow apertures.

Hatching - First generation larvae appeared between June 8th and June 15th. Second generation, July 20 to August 15, and the third generation between September 10 and October 1.

Duration of Larval Period - Under moist soil conditions the larval cycle was completed in 18 to 19 days, while in dry soil the period was lengthened to 25 days.

The Puparium

Description - The puparium consisted of the third larval skin formed by contraction and hardening of the chitin. This puparium varied from a light yellowish color to a deep reddish brown. Generally the length of this stage varied considerably but averaged 4 to 5 mm.

Duration of Puparium Stage - This period varied from 15 to 19 days in the first brood, 8 to 14 in second, and 5½ to 6 months in third, regulated entirely by the seasonal conditions.

Location of the Puparium - First brood puparia were formed 4 to 5 inches below the surface of the ground, an inch or two away from the bulb. The second brood puparia were found usually among the roots, not as deep as the first brood. The third brood puparia usually formed within the onion in which they were feeding at harvest.

Seasonal Habits

Number of Generations - Three distinct generations were reared in Erie County, Pennsylvania, each season. A partial fourth brood sometimes occurred in stored onions.

Hibernation - The majority of individuals of the species *H. antiqua* passed the winter in the pupal stage. Some adults of the third generation emerged late in autumn and passed the winter in the adult stage.

Food Plants - Three years observation in Erie County indicated that the onion maggot restricted its feeding to the cultivated onion plant. No records were obtained of its occurrence on wild species of the genus *Allium*.

By 1923 investigations on this insect were taking place as far west as Oregon. Lovett (1923) observed that two generations were completed in that area, the larvae of the second pupated in the soil and remained there through the winter.

The Island of Montreal also was plagued by this onion pest. Baker and Stewart (1929) found the onion maggot to be the most destructive garden insect of the area. Their observations indicated that there were two full generations and a partial third per season. The eggs for the two generations were deposited in June and August. They also observed that a newly hatched larva could travel no more than about one inch to find an onion plant. Adults emerging from pupae of these two generations possessed an oviposition period of eleven to twelve days.

In 1928, Baker studied the habits of the onion maggot and determined that rainwater was not harmful to the adults and in rainy weather they did not seek shelter. He could not find any one single factor which could be responsible for either high or low infestations during particular seasons, or on particular fields. Even the type of soil apparently could not be correlated with infestation frequencies.

Wilson and Whitcomb (1929) working in Wisconsin have observed adult onion maggot flies as early as April 11, and in great numbers on April 25. These observations and reports tend to indicate that adults must overwinter in significant numbers in Wisconsin. Their studies on the habits of the onion maggot indicated that there is a tendency for adults to congregate in protected areas and to oviposit during the early spring. They also determined that during windy weather more adults could be observed in the protected fields of potatoes than in onion fields. No indication, however, was given on whether or not any oviposition took place on the potatoes.

The onion maggot was causing much the same concern in Europe as it was in America during the early part of the 20th century. In Germany, Kästner (1929b) carried on extensive investigations on the biology and control of the onion maggot. His investigations indicated that there were apparently three generations per season in the Calbe, Saxony area. The three generations were observed to coincide with two month periods; generation number one, May to June, number two, July to August, number three, September to October. The preoviposition period of the adults averaged twelve days, and females were found that deposited 78 eggs. The egg stage required 3 to 4 days, the larval stage 14 to 21 days, and the pupa 14 to 19 days.

In following investigations Kästner (1929c, 1930d) observed that larvae which attacked seedlings were able to go from plant to plant in order to fulfill their nutrient requirements. This type of attack was found to be very disastrous, causing extensive damage by single individuals. His investigations on the influence of weather showed that a continued week of rain in the spring, especially during oviposition, delayed the ensuing generation a whole week.

Kendall (1932) in Ontario observed preoviposition periods as short as four days and averaged 7 to 11 days. He also was able to determine some of the movement phenomena concerned with maggot migration from one plant to another. He observed that while seedlings were young and easily killed, the tendency was greater for larvae to migrate to healthy plants even before the infested plants were entirely consumed. It was also determined that maggots more than seven days old could reach onions ten inches away within twenty-four hours.

Under field conditions, Sleesman (1937) confirmed the results of laboratory studies showing a high correlation between soil moisture and the survival of the larvae of *Hylemya antiqua* Meig. on onion. Significant increases in larval populations may be expected in wet seasons.

According to Mann (1945), the onion maggot has two full generations and a partial third in Holland. The adults emerge during May and the life cycle is completed in three weeks, at which time the second generation adults of the season emerge. In Austria, Schreier (1953) indicated that there are three to four generations per year and declared that the first was the most destructive. This observation was explained by the fact that each larva may destroy several young seedlings while later in the season a more developed onion may support as many as 10 to 12 larvae.

INVESTIGATIONS ON THE BIOLOGY OF THE ONION MAGGOT

The biology of the onion maggot was studied primarily to obtain information relating to developmental habits as they occur in the Connecticut Valley in Massachusetts. Emphasis was placed upon method and location of overwintering forms, as well as the number of generations and periods of oviposition. This information is necessary in the control of maggot with respect to the timing of a spray program.

Most investigations concerning the life history of this pest of onions were carried out in the field where infestations were known to occur previously. The only equipment used in the field were cages to retain an infestation that was artificially started. Other investigations consisted of caging specific plants after the first eggs were deposited by naturally occurring adults. These caged plants were then observed daily to determine the emergence of adults of succeeding broods and the date of oviposition.

The cage method of observation was entirely satisfactory and data obtained using set onions will be presented. Both sets and Spanish onions were used in determining third generations of the onion maggot. The cages used in these observations were made of wooden frames, covered on three sides with cheesecloth. The fourth side and top were made of glass. The cages were 2 feet in height and 1 square foot in cross-section. The top was hinged. Plate I shows the cages in use.

With this type of cage it was possible to observe the habits of these insects. The conditions within the cage for the most part closely approximated the conditions in the field. With three sides open to air exchange the temperature and humidity conditions very seldom deviated from those of the field.

The first step in the study of the maggot was to determine where and how the insect passed the winter. Reports by other workers indicated that they overwintered as pupae in the soil. Therefore, following this supposition, the author, early in the spring of 1953, after the frost had left the ground, attempted to locate the wintering forms. The first attempts consisted of taking soil samples from a field that had been heavily infested with maggot during the summer of 1952. These samples were carefully examined in the laboratory for pupae of the onion maggot, but none were found.

The next step was to investigate any refuse that had been left on the field or near onion fields. One farmer had started a compost pile near his fields the year before. Into this pile had been placed loam soil, tobacco stalks, vegetables of all sorts, along with onions that had been discarded during the process of screening. Upon investigation, this refuse pile proved to be a very productive source of onion maggot pupae. The pupae were found primarily in and near rotten onion bulbs.

Upon further investigation it was found that many of the farmers whose land bordered on the Connecticut River discarded their crop refuse over the banks of the river. Here also was a supply of pupae. Continued investigation showed that the overwintering pupae were concentrated in onion refuse wherever it was discarded. It was evident that as the adults emerged from overwintering pupae, they made their way to the new onions in the spring and there initiated the infestation that would be present throughout the growing season.

In order to follow the life cycle throughout the growing season, 8 pupae were placed 2 inches under the soil in each of 4 cages. Six onion set bulbs were also planted in each of the 4 cages so that when the adults emerged they were able to oviposit in the presence of sprouting onion plants. With this method, using the cages described earlier and pictured in Plate I, observations of the habits were made with relative ease.

In conjunction with these prepared, caged, infestations, observations were made constantly in commercial plantings. During the early spring, sweeping with an insect net was carried on every 2 to 4 days. This sweeping was maintained from the time onions emerged from the ground until a drop in the population of adult flies took place. With this method of population survey it was possible to determine when the first adults were moving into fields after emerging from the pupae and also to determine the peak emergence period of adults.

A third method of population survey that was used in commercial plantings was the inspection of emerging leaves and soil around the stem for the presence of eggs. In the use of this method it was necessary to check great numbers of plants. Inspection was made on set onions that were in close proximity to a source of emerging adults, that is, on a planting close to a refuse pile containing discarded onions. Set onions were chosen because they are planted early and develop earlier in the season than other types of onions. Two rows of onions were used, each onion inspected carefully for the eggs.

The information obtained with this method was useful in two ways. First, it provided the period when the first eggs of the first generation were being deposited. This information correlated with the appearance of the first adults obtained by the sweeping method, gave the approximate interval of time that the adults were in the field before oviposition.

Secondly, the peak of the oviposition period could be determined by the numbers of eggs found during each inspection.

By using the data obtained from the above information, one can determine the time that applications of insecticides should be made in order to provide the best control. Since this investigation was one in which the final objective was to obtain control, the data taken on the biology were so compiled as to be most useful in the control of this insect.

Observations on Prepared Infestations

On the basis of the information gathered from the cages that had "prepared infestations," a life history cycle was obtained. Early in April the cages were prepared as discussed earlier. Into each cage was placed 6 set bulbs and 8 pupae, which were obtained from onion refuse piles. These cultures were allowed to progress throughout the season.

First Generation

Adults. The first adults which emerged from overwintering pupae, were observed on May 6 and others continued to emerge until the 20th of May. Since all the overwintering puparia were placed 2 inches beneath the surface of the soil, it was presumed that a shorter period of emergence would take place than the longer period in naturally occurring puparia. Naturally occurring puparia may be situated anywhere from the surface of the soil to a depth of 6 to 8 inches. Under these natural conditions it is obvious that all the pupae would not be exposed to identical physical factors and therefore would not emerge within a short period of time. However, those pupae placed in the cages were all placed at the same depth in the soil and in turn would all be exposed to similar physical conditions. It therefore would be expected that adults would emerge within a relatively short period of time. As indicated above, all adults emerged within a two-week's period.

The first signs of copulation never took place sooner than 4 days after emergence from puparia. Perhaps the confinement to these cages had some effect upon the natural mating conditions, but fertile females did occur, indicated by the deposition of viable eggs.

Eggs. The first eggs of the first generation were deposited on the 15th of May, and continued to be deposited until the 7th of June, the day before all adults were dead. Whether the confined condition of the adults had anything to do with their longevity was not determined. However, each female apparently deposited a full complement of eggs, which averaged about 25. This number is somewhat smaller than the 30 to 40 that had been reported by Eyer (1922), who worked in Pennsylvania.

The eggs of the first generation were all deposited in a particular manner and place. The adults without failure deposited the eggs around the base of the stem of the onion plants at the point where the soil and stem adjoin. Although specific to the area that the eggs were deposited, the adults were rather haphazard in the act of oviposition. Some of the eggs were deposited on the stem close to the soil, some were placed on the soil close to the stem, and still others were deposited in the crevice between the onion stem and the soil. Although the area within which the eggs were deposited was very limited, seldom did the adults that were observed consistently assume a particular position for oviposition. For this reason the eggs became scattered over the limited area that has been described.

Generally, each female would deposit an average of 8 to 10 eggs at a particular site. The next oviposition might take place within a few hours, but generally, females oviposit once a day. These facts were observed in small screen cages with one plant and one female.

The duration of the egg stage varied considerably. The extremes of the duration were 2 to 8 days. Eyer (1922) found that the average incubation period for the first brood to be 5.5 days. In the present investigations the average incubation period was 6.8 days.

The differences of duration obtained between individuals are natural, however, and averages are dependent upon the temperature conditions. During a cold season the duration of the incubation period may be extended greatly, and lowered during warmer seasons. The spring season of 1953 was a cold wet period accounting for the extended duration of the egg stage.

Second Generation

Adults. The first adults of the second generation emerged July 6, and continued to emerge until the 8th of August, with the maximum emergence about the 25th of July. The procedures and actions of the adults during oviposition were similar to those of the first generation, except that the adults were somewhat more particular in placing the eggs into crevices between the soil and the stem of the onion. Very few eggs of the second generation were evident by casual examination. More careful examination was necessary to observe the eggs. The explanation of this deviation in oviposition lies undoubtedly in the physical presence of larger and deeper crevices around the neck of the growing and expanding onion.

Eggs. The oviposition of the second generation adults commenced on the 16th of July and continued late into August. The time of oviposition was dependent largely upon the emergence date of the adult from the puparium.

Third Generation

Adults. Very few adults emerged from the second generation larvae. About 8 per cent of the pupae transformed to third generation adults. The onions growing within the cages had become mature at this time and the bulbs were well exposed on top of the soil. Eggs laid by the third generation adults were placed on these mature onions rather randomly - on top, near the roots, etc.

The majority of the second generation puparia were formed in the soil around the onions. Most of the puparia recovered from the cages were found to be in the overwintering condition and adults did not emerge from them while they were kept in the cages, in the field during the fall season.

It is obvious that under Massachusetts conditions which, during the summer of 1953, were very dry, two generations of the onion maggot occur. The third generation was incomplete and was developed perhaps from individuals that emerged early in the season.

Field Observations

Perhaps the most significant facts observed in the field were the occurrence of the first and maximum periods of emergence and oviposition of adults. These observations when correlated with the information obtained from caged infestations, are useful for more accurate timing of insecticide applications for the control of the onion maggot.

These observations as indicated earlier were taken in commercial plantings where maggot has been a major pest. The presence of the adult population, signified the rate of emergence and was sampled by sweeping with an insect net. Three collections were taken every other day until first adults were taken. Each collection represented fifty strokes through the onions at a walking pace. Subsequent examinations were made at weekly intervals.

The first adults were taken on the 8th of May and a steadily increasing number was taken until June 2nd, which was the day of the peak adult population. A steady decline was experienced thereafter until July 12th, when the numbers started to increase, due largely to the appearance of second generation adults in the field. Apparently the adults that were present throughout the period between first and second generations were those emerging late in the season from over-wintering pupae or offspring of early emerging individuals in the spring.

The second peak of adults observed by this sampling method was present during the period from July 26 to August 4. The number of adults taken in each sample (50 sweeps) during this latter peak was somewhat higher than that of the first peak, as indicated in Chart 1. Although one would expect to obtain a very high increase in numbers because of the increase through reproduction, these large numbers were not taken. There is no doubt that adults were present in much greater numbers because of the increased numbers of eggs that could be found, as is shown subsequently.

The logical explanation for the apparently slight increase in adult population in the second generation over the first is the denseness of the onion foliage. During the peak of the first generation adult population, the onion tops were only a few inches in height while during the second generation, onion tops averaged close to two feet in height. It is obvious that with onions so fully grown, the sweeping technique for adult counts could not be as effective. The denseness of the tops provided an excellent means of escape for the adults and as a result, the majority of the insects were not taken. This does not mean, however, that the data that were taken are not accurate.

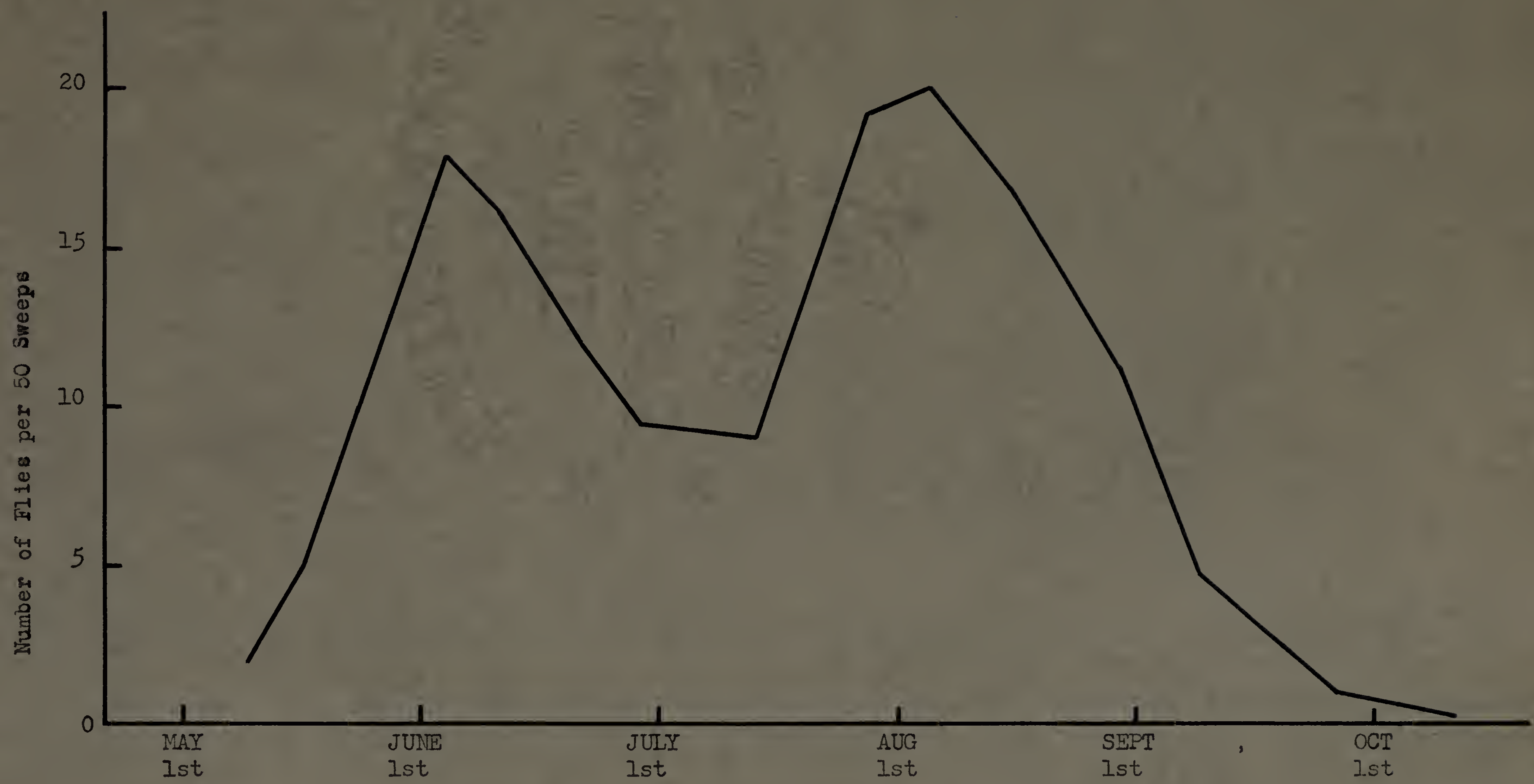

Chart 1. Seasonal adult onion maggot populations showing the two major generations , 1953.

Sweeping was, at most, only of relative value and the adults that were taken represented a valid sample of the total population. Thus, it was possible to determine the period of greatest abundance of adults, and the time of greatest emergence from puparia.

Adults of the third generation were also taken by the sweeping method. They were very difficult to find, primarily because most onions had been harvested by the end of August and those that were taken were collected from piles of debris left in the fields as the result of screening and grading the harvested crops. The piles of debris consisted primarily of onion skins, pickle or undersized onions, and rotten onions discarded in the process of screening. There was no obvious peak of populations of third generation adults. For the most part the third generation adult population was scarce and were taken only occasionally under conditions described. These adults were found late in September and early October. Oviposition by third generation adults was observed in only one instance. These eggs were deposited on the root end of a slightly rotted onion.

Observations on Egg Deposition

The height of the egg laying period of each generation was determined by the observation of plants. It was found that the number of eggs had a definite relation to the number of adults that were taken in the population survey. However, the egg counts tended to lag behind the adult counts by approximately 8 days for the first generation and about 5 days for the second generation. That is to say, the peak of egg deposition was approximately 8 days behind the peak of the adult fly population.

This result can readily be explained by the fact that the preoviposition period extends over a period of 5 to 8 days, depending upon the particular factors involved. Early in the season when temperatures are cooler the time required for the eggs to develop may be as much as 8 to 10 days. During the second generation when the temperature is much higher, the period required for the eggs to develop may be as low as 5 to 6 days.

Table 1. Peaks and Range of Adult and Egg Populations of Onion Maggot in Caged and Field Populations.

	1st Generation		2nd Generation	
	Adult	Egg	Adult	Egg
Prepaged Cages	May 12 6-20	May 25 5/15 - 6/7	July 25 7/6 - 8/8	July 30 7/16 - 8/20
Field Observations	June 2 5/8 - 6/15	June 10 5/26 - 6/20	July 28 7/14 - 8/5	August 3 7/26 - 8/21

CONTROL OF THE ONION MAGGOT

REVIEW OF LITERATURE

The first indications of the economic importance of the onion maggot were also accompanied by remedial measures. It was stated by Harris (1841) that the onion crop could be preserved from the attack of this fly by sowing seed in ground upon which a quantity of straw had previously been burnt. The object was to destroy the pupae in the ground. However, only those on top or nearly so would be affected.

A most humorous method of damage suppression to onions was related by Fitch (1867). A "Mr. Somebody" wrote to Dr. Fitch and indicated that since the eggs of the onion maggot were contained within the seed, control was being obtained by dipping the seeds in boiling water for just a moment before planting. The true remedy, however, recommended by Fitch was to observe carefully the onion plants for signs of wilt. Every wilted plant should be uprooted and the worms within the bulb destroyed. This practice eliminated further migration of the maggots from one plant to another and prevented further damage.

The early preventive measures were many and varied, some sound and others without basis. A variety of these preventives and remedies are described by Lintner (1882) as follows:

(1) Strew the onion bed with powdered charcoal, leaving small portions without application where the flies may oviposit. The infested onions should subsequently be taken up and destroyed by deep burying or burning.

(2) Onions should be grown in hills so that if the seedlings of one hill were destroyed, the maggots would not be able to travel to the next hill, for the distance would be too great.

(3) Scatter dry unleached ashes over the beds as soon as plants are up, while they are wet with dew or rain. This procedure should be followed weekly through the month of June.

(4) Pulverized gas-lime scattered among the onions kept the insect off the onions.

(5) Onions watered with the liquid from pig-styes gave good control of the maggot.

(6) Deep cultivation in autumn with good manuring and a well packed soil in spring afforded good control.

(7) Hen manure or horse manure well turned into the soil during the winter to preserve the ammonia, produced excellent results.

(8) Dry soot dusted lightly over the soil, once in two weeks during egg laying, appeared satisfactory.

It must be remembered that these recommendations were generally prescribed for the home gardener and would neither be feasible nor of much value for a commercial grower to follow. Apparently few or no commercial growers were producing onions in those times.

Fernald (1891) had little to add to the above list to prevent onion maggot attack. The only new though expressed by Fernald was to use crop rotation, each year onions planted in areas as remote as possible from where they were grown the previous year.

An extensive study of the cabbage root maggot was made by Slingerland (1894), in which he stated that many of the preventive measures recommended for the cabbage maggot could be used for the onion maggot. Many of the methods that he recommended were tested eventually on onions by subsequent workers and the detailed descriptions given by Slingerland will not be presented. Some of his recommendations were the use of gas-lime, kerosene, hellebore, crop rotation, pyrethrum, carbolic acid emulsion, corrosive sublimate, and a host of other cultural and chemical means, some of which were of value in the control of root maggots.

Onion maggot attacks were also being dealt with in Russia. Valch (1913) recommended the late sowing of seed or late replanting, in case of biannual cultivation such as that necessary with set onions. His recommendations also included spraying the earth between plants with lime water to which some carbolic acid had been added. This latter method leaves a coating on the soil, and with the smell of carbolic acid prevents the insects from ovipositing. The third remedial measure consisted of removing all attacked plants and destruction of the maggots thereof. Levtejev (1914) working in the Moscow area also recommended the removal of infected plants in June in order to prevent the appearance and damage of the second generation.

Kassatkin (1914), in the area of Vladimir, recorded a 20 to 25 per cent reduction in yield because of the maggots. Rotation of crops, poisoning with formalin and applying a carbolic acid and lime solution were his recommendations against the pest.

In France, Paillot (1914), recommended some of the usual remedies such as delay of planting, crop rotation and milk of lime. He also introduced an emulsion of crude phenic acid which apparently showed promise. The emulsion concentrate consisted of 2 pounds of black soap, 7 pints of boiling water, and 1 pound of crude phenic acid. This concentrate was used at the rate of one part to 30 parts of water and applied when the plants emerged and again 4 to 5 days later.

The number of various types of treatments and recommendations for the control of onion maggot had been growing steadily for 60 to 70 years. In 1914 Fernald and Bourne attempted to evaluate some of the more promising methods which had reportedly given control of the insect. The following results were obtained with various methods presented:

(1) It was found that carbon disulfide, if applied close enough to the plants to kill the maggots, also killed the plants.

(2) Powdered hellebore dusted along the rows was far too costly and results were far from satisfactory.

(3) Soap wash, poured along the rows, three times at ten-day intervals gave only moderately good results. Cost being more than $50.00 per acre made it an undesirable treatment at any rate.

(4) Carbolic acid and lime also failed to give good control. Coating around the plants appeared heavy enough but infestations were as heavy as in untreated plots.

(5) Kerosene emulsions at dilutions of 1-9, 1-14, 1-19, gave no difference in results and no injury to the plants nor protection from the maggots was observed.

(6) Carbolic acid emulsion gave the best results as far as protection from maggots was concerned, but was not entirely satisfactory.

Fernald and Bourne concluded that none of the treatments were entirely satisfactory, and that most of them were prohibitive because of their expense. In 1915 Bourne found that naphthalene alone prevented germination and injured seedlings. Addition of inert substances appeared to safen the material and warranted its use in further experiments.

The first experiments in the use of poisoned baits were used in the year 1913 by Severin and Severin (1915). The results obtained in preliminary experiments indicated that sweetened baits gave encouraging results. The baits consisted of 1/4 pt. of molasses, 1/4 oz. of sodium arsenite and one gallon of water. This mixture was applied to the onions in the form of a spray. Bait was renewed once during each week, through the period of fly emergence.

Other workers quickly attempted to try the sweetened bait method of maggot control. Russell (1915), Gibson (1915, 1917), and Sayre (1916) all found that the poisoned bait method had its merits, killed many flies and apparently was quite effective. In contrast, Howard (1918), Ruhmann (1920) and Treherne and Ruhmann (1922) were of the opinion that poisoned baits were ineffective in controlling the onion maggot in their experiments.

Headlee (1920) in reports on the progress of onion maggot control, indicated that excellent control was obtained with the use of poisoned baits. A mixture of one ounce of sodium arsenite, two quarts of molasses, and one gallon of water placed in clam shells which were located at the corners of either twenty-five or fifty foot squares in onion fields, gave good control in contrast to check plots. Other workers who found poison baits effective in the control of this pest were Eyer (1922) and Lochhead and Tawse (1922).

A new method of baiting flies was devised by Kästner (1929a) in Germany. He halved large onions and dipped them in a saturated solution of a poison to which 3 per cent sugar was added. Thirty-seven to fifty-two pounds of these onions were then placed in onion fields and were reportedly more attractive to the flies than many types of jars and pie-tin bait stations. Sodium fluoride, sodium arsenate, and sodium arsenite all gave good results but sodium arsenite was superior to the others. Using the described method, Kästner (1930) reported damage in test plots using sodium fluoride poison, as negligible.

The lack of sufficient control of the onion maggot in the United States by bait methods prompted Ruhmann (1921) to investigate the values of trap crops. His preliminary findings indicated that trap crops, that is a few rows of early onions in the fields, were highly successful in protecting the seedlings from maggot damage. One year later, Treherne and Ruhmann (1922), found that a row of trap onions planted every 100 feet in onion fields, gave excellent results. The procedure consisted of planting the cull onions at the prescribed intervals, and removing and burning these trap plants about June 15, before pupation of the first brood larvae took place.

Continued investigation by a host of research men indicated that trap plants were most promising for the control of onion maggot. Jardine (1922) and Lovett (1923) both working in Oregon, came to the conclusion that cull onions used as traps were very promising methods of maggot control. Tawse (1923), Hammond (1924), and Dudley (1925), also came to the same conclusions, but all used trap crops in combination with other measures.

An important advance in the control of onion maggot was the introduction of mercury salts. The first account of their effectiveness came in 1923 when Brittain found that corrosive sublimate solution would kill the larvae of both the cabbage and onion maggots. Smith (1923) using corrosive sublimate solution in field tests, was unable to draw any conclusions. However, Flint and Compton (1925) reported that one ounce of mercuric chloride dissolved in 10 gallons of water gave most promising results when applied to the soil. Three applications at 10-day intervals of the same material was reported by Ruhmann (1925) to give 95 per cent control.

The use of Bordeaux oil emulsions for the control of maggot appeared at about the same time that the mercury compounds were recommended. Flint and Compton (1925) found that an emulsion of 3 per cent oil in a Bordeaux mixture gave better control than oil at one or two per cent. Glasgow and Cook (1929) discovered that a two per cent red engine oil emulsion in a Bordeaux mixture (4-4-50), freed fields of infestation when sprayed at 20 to 30 pounds pressure and applied at 150 gallons per acre. Bordeaux oil emulsions were highly regarded by many workers and recommended for many years. Dustan (1930, 1933), Jones (1930), and Sleesman (1931), obtained increased yields and less injury with the use of Bordeaux oil emulsions containing one to three per cent oil. Increased yields of as much as 45 per cent were obtained by Jones.

In 1935, Sleesman completed tests on the toxicity of certain materials to onion maggot eggs. The results which he obtained indicated that petroleum lubricating oil emulsions alone or with Bordeaux, were not toxic to eggs even if used at a concentration of 2 to 6 per cent. Eggs immersed in undiluted lubricating oil were not affected, thus indicating that these oils possessed no ovicidal value.

The fact that oil emulsions were proven worthless against maggot eggs led the group working on this pest back toward mercury compounds, especially dust formulations. Kendall (1932), Hahne (1933), and Dustan (1937) were the last to recommend the use of mercury bichloride solution. As early as 1929, Glasgow found that mercurous chloride (calomel) was less toxic to plants than mercuric chloride and that mercurous chloride showed promising results as an insecticide. Sixty to 70 per cent control was obtained by Sleesman (1932) by the use of 6 per cent mercurous chloride with a gypsum carrier drilled in on top of the seed. In 1934, Glasgow obtained 82 per cent control using 2 pounds of calomel per pound of seed, while 95 per cent damage occurred where no treatment was applied.

Initial investigations indicated that calomel gave excellent results for control of onion maggot. Dustan (1938) found that 1 to 1½ pounds of calomel per pound of seed gave better control than the Bordeaux oil emulsion treatments. His results showed that 5.7 per cent of plants treated with calomel were injured, while untreated plants showed 22 per cent to be injured. In England, Wright (1939) treated onion seeds with calomel at the rate of one pound per pound of seed. His results indicated an increase in yield of 728 per cent over the check plots. He also obtained good results by applying a 4 per cent dust along rows at the rate of one pound per 50 yards when plants were $\frac{1}{4}$-inch tall. An increase of 636 per cent over the check was obtained in these tests.

Tests carried on in Canada by Matthewman, Dustan and Davis (1941) indicated that neither mercuric chloride solution, calomel dust, oil emulsion nor calomel seed treatment were satisfactory treatments alone. However, calomel seed treatment was quite satisfactory for light infestations, and was therefore tested in combination with other treatments. The seed treatment, in combination with mercuric chloride solution, or dust treatment consistently gave good control under any circumstances.

Investigations in Europe also indicated that calomel was a chemical that reduced onion maggot damage significantly. In Holland, van der Helm (1942), showed that calomel used in equal weight with seed reduced infestation to 4.2 per cent as compared to 27.7 per cent in untreated plots. Ahlberg (1942), obtained approximately the same results using the same procedure. His results showed that 4.4 per cent of the calomel-treated onions were infested while 27.5 per cent of the untreated ones were infested. Ahlberg also indicated that both arsenicals and emulsions of tar distillates at low concentrations gave no control. Wilson (1943) in England indicated that calomel treatment could be supplemented by early planting and other cultural methods such as deep plowing.

Experiments carried on in Russia by Gerasimov (1944) disclosed that creolin emulsions and dust gave unsatisfactory control. His experiments in the laboratory with emulsions showed that 92 to 100 per cent of the eggs of Hylemya antiqua Meig. were killed. When used under field conditions, however, the creolin emulsion gave 24.3 per cent damage, creolin dust, 28.7 per cent and 52.3 per cent was observed in the untreated plots.

The first extensive work with the use of a synthetic chlorinated hydrocarbon insecticide for onion maggot control took place in Holland. Here, Heringa (1946) carried on experiments to find materials that were more readily available than calomel for seed treatment against the onion fly. Preliminary work showed that DDT was equally or more effective than calomel and naphthalene apparently was of little value.

Preliminary investigation of hexachlorocyclohexane (BHC) by McLeod (1946a) for the control of onion maggot, indicated that this material showed promise in control of this pest. A DDT treatment was highly successful but impractical in the form in which it was used. He indicated that hexachlorocyclohexane had phtotoxic effects when used at increased concentrations. During the same year (1946b) McLeod found, when working in the laboratory, that all seedlings grown in soil containing from 0.25 gram to 256 grams of hexachlorocyclohexane per pound of soil, showed a marked effect which appeared as a thickening of the shoots and browning of the root tips.

The use of DDT as a seed treatment against the onion maggot was investigated more fully by Maan (1947). He compared the recommended calomel seed treatment and 50 per cent DDT applied at the rate of 40 per cent of the seed weight, with untreated seed. The results showed that 7 per cent of DDT treated seeds, 8 per cent of calomel treated seeds, and 14 per cent of untreated seeds were infested. In other tests, using the same weights of chemicals, he found 2 to 6 per cent infestation when using a 25 per cent DDT dust, 5 per cent infestation for calomel and 15 per cent for the controls.

In the same year Munro (1947) used DDT as a spray against the onion maggot. His results disclosed that one ounce of 25 per cent DDT per gallon of water gave 90 per cent control of adults. The liquid in these tests was applied as a course spray at the base of the plants after the flies appeared.

Another method of insecticide application and the effectiveness of three insecticides was reported by Rawlins and Newhall (1950). Insecticides were blown into the seeding furrow by a rotary duster at the time of planting, the duster having been operated by the tractor used to draw the planters. Insecticides were applied at the rate of 20 pounds of a 20 per cent mixture to the acre. Under these conditions it was found that maggots injured 3 per cent of plants treated with heptachlor, 4 per cent with dieldrin, 29 per cent with aldrin and 90 per cent where no treatment was applied.

Further experiments with new insecticides were made in Germany by Schreier (1953). His results indicated that when BHC was applied to seedlings before planting they were free from infestation but tainting and injury to plants was observed. Both parathion and lindane gave good control when applied to seedlings even after larvae had entered the plants. DDT, however, was ineffective in this respect. A few investigations indicated that spraying or watering with the synthetic insecticide, Systox, was ineffective against the onion maggot.

Phenology

The occurrence of the adult population was well as the periods of oviposition are important factors concerning the control of the onion maggot. In order to control this pest effectively with spray programs, it is necessary to know when adults are present and when eggs are deposited in the field. This knowledge is necessary for the correct and most effective timing of sprays. To apply a spray too late or too soon might well mean the useless expenditure of time and materials. Certain phases of the life cycle of the onion maggot, therefore, were correlated with other natural biological phenomena so that interested persons might easily know when certain phases of maggot life history are taking place by merely observing something more prominent than adult maggots.

<u>Occurrence of Adults</u>:

The appearance of the first adult flies taken in the field by sweeping, was correlated with the following:

1. Peach blossoms in full bloom.
2. Apple blossoms barely showing pink.
3. Dandelions at the height of bloom.

<u>Oviposition</u>:

Observation of plants in the field indicated that a substantial amount of eggs of the first generation were deposited when:

1. Fifty per cent of petals had fallen from pear trees.
2. McIntosh apples were in full bloom.
3. Dandelions were in full bloom.
4. Spiraea in bloom.

These phenomena were based on observations taken for two years. In both years these related phenomena occurred and could be used as a basis for timing control programs.

In both the occurrence of adults and oviposition it must be remembered that the correlations are comprised not of the appearance of a single adult or a single egg, but of the first regular occurrence which takes place. It must be remembered also, that the adults and eggs continue to occur for many weeks thereafter.

The Occurrence of Adults is by far the most important of the two periods in the control of the onion maggot. It is at this time that first sprays should be applied for the control of onion maggot.

INVESTIGATIONS ON CONTROL OF THE ONION MAGGOT

The control of the onion maggot is of primary importance in the culture of onions. In the Connecticut Valley the two types of onions that suffer the most damage by onion maggot are "seed sets," and seed onions. Of less importance but of economic concern is the loss that is produced in set onions.

The manner of damage to see sets is very characteristic. As the eggs that are deposited around the stems hatch, the larvae follow the stems underground to the roots. Here they may destroy some of the roots, or enter the bulb. Because these onions are very small during the time of the first generation, one larva may destroy several young seedlings successively. Adult flies lay their eggs in groups, thus making possible the destruction of large sections of a row. Thirty to fifty per cent loss has not been uncommon. A thinning effect may also be produced by the onion maggot. Such thinned onion sets are of poor quality because they tend to grow too rapidly and produce large sets. If these are planted the following year, they tend to produce flower stalks or "spikes," and are virtually worthless as marketable onions.

Like seed sets, seed onions are also very susceptible to the ravages of the onion maggot. Since they too are planted as seed, the young tender seedlings are very attractive to the ovipositing adults, and disastrous results may occur. The young larvae that feed on the roots and young onions very seldom are able to receive enough nourishment from one plant to complete their cycle. The result is that larvae may go from plant to plant damaging or killing many onions. If infestations are heavy enough, an apparently profitable crop might readily result in a sizeable monetary loss. The attack of the onion maggot is one important reason which caused the seed onion industry to be replaced by the culture of set onions in the Connecticut Valley. The depredations of the onion maggot cannot be minimized when destruction of 50 to 60 per cent or more of a stand of seed onions can take place. Under these circumstances it is understandable why the Connecticut Valley growers have turned to the production of the more hardy and profitable set onions.

Typical onion maggot damage is shown in Plates II-V. Plate II indicates the type of damage produced shortly after maggots have entered a vigorously growing seed onion. Fleshy portions of the developing bulb are eaten away predisposing the onion to infection by secondary organisms.

Plate III indicates the second stage of maggot damage. Here much of the onion bulb has been destroyed, causing malformation and destruction by secondary organisms. At this stage, the onion succumbs to the attack. Plate IV indicates the final stage of an onion destroyed by a combination of maggot attack followed by other secondary organisms. The bulb is completely destroyed.

Plate V shows a series of onions suffering from onion maggot.

As shown from left to right, the series indicates the progress of the damage inflicted. On the left are shown onions shortly after infection and on the right onions completely destroyed.

Set onions, although apparently more "resistant" to the attack of maggot, are by no means free of this pest. Their so-called "resistance" may be explained by the method of culture. Sets are grown for two years. The first year entails the production of seed sets, and the second year, the production of mature onions from the seed sets. In the spring of the second year the seed sets are planted as little bulbs. With a ready supply of food these onions grow rapidly, and in comparison to seed onions, the leaves are 3 to 4 inches in height before the leaves of seed onions begin to emerge. This all means that during the critical period in the spring when the maggots are active, the set onions are bigger and stronger than seed onions. As a result, any maggots that are found on sets have a plentiful supply of food within one plant. It is possible that a number of maggots could mature within one onion bulb.

From this information it is evident that while one maggot may damage several seed onions, one set onion may suffice for food of many maggots. As a result, fewer set onions are damaged than are seed onions in a comparable infestation. This is the manner in which the term "resistance" may be applied to set onions in relation to onion maggot damage.

Although "resistant," set onions may still be heavily damaged by maggot in years of heavy infestations. The damage to set onions usually is not as obvious and may be quite insidious in nature. The effects are not as noticeable and the damage may not be apparent until harvest, at which time many rotten onions are discovered. Many of these rotten onions are the direct result of maggot infestation. Although the maggots may not kill the plants, they weaken and leave the plant open to other pathogenic organisms, which destroy the onion bulb completely.

In order to control the onion maggot in the three types of onion production that have been discussed, it is necessary to consider the cultural methods employed for each. For instance, the type of insecticidal application for one type of crop may not be feasible or effective for another kind. Therefore, the controls of the onion maggot for all three types of onions were treated separately, and will be presented as separate entities. In all cases where spray was applied with a potato sprayer, the fungicide dithane, D-14, was included for protection from mildew and blast. In all sprays applied for maggot control, the spreader Triton B-1956 was included as a wetting agent. The spreader was used at the rate of 8 ounces per 100 gallons of spray.

Control of Onion Maggot in Seed Sets

In these investigations three types of treatment were applied for the control of onion maggot in seed sets. The first was spraying. In this method the residual insecticide is deposited against adults as they come into the field for oviposition and larvae as they emerge from any eggs that have been deposited. The second method is called the dry seed treatment. This merely indicates that the seed and dry insecticide are mixed together in the absence of a sticker. The third method has been called pelleting of seed. This process involves the wetting of the seed with the sticker, methyl cellulose, in order that the insecticide adhere to the seed and form pellets.

The areas used for experimentally testing these methods were made available by commercial farmers in the town of Sunderland, Massachusetts during the summers of 1952 and 1953.

The soils of the onion growing areas of the Connecticut Valley are typically a fine mineral loam. They are well drained and fairly retentive of moisture. These fields were arranged into plots during planting, and all tests were replicated at least three times.

The method for evaluating the amount of damage produced by the maggots in seed sets was an indirect one. Since seed sets are sown thickly, it was decided to simplify the counting by using the number of inches of onions destroyed per 50 feet of row.

These evaluations were made about one week prior to harvest of the crop. The damage recorded was that produced by the larvae throughout the growing season.

Spraying. The possibility of control using a spray treatment was based on the hypothesis that the residue left on the plants and soil would kill the adults as they arrived in the fields to oviposit, and the larvae as they emerged from the eggs. The habits of this insect are such that control in this manner appeared possible.

As the adults arrive in the field to oviposit they are quite active among the plants and readily come in contact with residual insecticides. Adults lay their eggs on the stems of onions or in cracks of the soil in close proximity to plants. When the eggs hatch the larvae emerge and seek an onion stem and crawl down toward the roots. Once there, they may feed on roots or they may enter the onion bulb through the root crown.

At the time of planting the rows of seed sets were spaced to allow a power sprayer drawn and powered by a tractor to pass through the field. The sprayer used in these tests was a conventional "Field Force" 6-row potato sprayer. It was equipped with an eighteen nozzle boom which was slightly modified to produce an even spray covering twelve rows. Each twelve rows was considered a plot.

Four applications of the insecticides were made during the season. The timing was based on the seasonal development of the onion maggot. The first treatment was made when the first adults were found. This coincided with the development of the onions which were just passing the "knee stage." Thus the first application occurred on May 12 and others followed at approximately 10-day intervals to cover the emerging period of the adults.

Emulsions were used exclusively in these tests. Dieldrin, DDT, chlordane, heptachlor, aldrin and parathion were applied in amounts shown in Table 2.

Table 2. Results of Four Spray Treatments to Control Onion Maggot Damage to Seed Sets.

Treatment	Lbs. of Actual Toxicant/Acre	Inches Destroyed/ 50 Feet of Row	Per Cent Reduction
Dieldrin	0.50	10.3	65
DDT	0.60	12.4	58
Chlordane	1.0	13.4	55
Heptachlor	0.75	15.5	47
Aldrin	0.75	18.8	36
Parathion	0.25	20.3	31
Check	---	29.4	--
LSD - 5 per cent level		6.3	

Pelleting Seed

This method of insecticide application refers to the procedure of mixing seed and insecticide in the presence of a sticker.

To each pound of seed was added 100 cc. of the sticker Methocel, to which was then added the insecticide and in most cases a powdered fungicide, Arasan. The mixture was then agitated in a covered can by shaking. When thoroughly mixed, the individual seeds resemble little pellets about 1/8-inch in diameter. When dry, they are ready for planting.

Control of the onion maggot with this method is dependent upon the residual action of the insecticide on the larvae as they make their way through the soil to the roots and bulb. The insecticide is deposited in the soil at the point where seeds were dropped in planting and in soil through which the seeds were carried during germination.

The plots in these tests were arranged at the time of planting. Each plot consisted of six rows and each insecticidal application was replicated 3 or 4 times. The insecticides DDT, heptachlor and dieldrin were used in combination with Arasan, which was added for smut control.

In order to obtain the proper amount of coated seed, the openings of the planter were adjusted. All seed was planted with the type of planter shown in Plate VI. This is the "Planet Jr.," one-row seed drill used almost exclusively for seeding in the Connecticut Valley. Results in the use of pelleted seed for the control of maggot are shown in Table 3.

Table 3. Results of the Use of Pelleted Seed for the Control of Onion Maggot.

Treatment	Lbs. of Dust/ Pound of Seed	Inches Destroyed/ 50 Feet of Row	Per Cent Reduction
1% heptachlor	0.5	31.8	15.9
5% DDT	0.5	15.9	58.0
10% DDT	0.5	1.2	96.8
1% dieldrin	0.5	1.2	96.8
Check	---	37.8	----
LSD - 5 per cent level		14.6	

Dry Seed Treatment

This is also a one-treatment method for maggot control. It simply requires the mixing of dry seed and powdered insecticide at the time of planting. One pound or more of seed was placed in a 2-gallon can and then the proper amount of insecticide was added. The cover was replaced and the seed and insecticide shaken vigorously to produce an equally dispersed mixture. This mixture was then placed in the hopper of the seed drill and planted.

An even distribution of insecticide is deposited in the furrow with the seed and remains there as a barrier against the larvae. In order to insure the proper amount of seed to be discharged by the planter, adjustments had to be made.

Control of onion maggot by this method is based on the same principles as those discussed under the pelleting method.

As in the pelleting method, the plots were arranged at the time of planting and were likewise carried out on commercial farms, using 4 to 6 rows per plot and 3 to 4 replications per treatment.

Tests during the summer of 1952 produced information of the more promising insecticides. In 1953 tests were conducted to confirm results obtained in 1952 and also to determine the proper amounts of insecticides to be used in these methods. The results of these tests are presented in Table 4.

Table 4. Results of Dry seed and Insecticide Mixtures on the Damage Produced to Seet Sets.

Treatment	Lbs. of Dust/ Pound of Seed	Inches Destroyed	Per Cent Reduction
1% aldrin	0.25	23.2	32.1
1% heptachlor	0.25	22.7	33.5
calomel	0.25	21.9	35.6
5% chlordane	0.125	19.8	42.0
1% heptachlor	0.50	14.4	57.8
5% DDT	0.25	8.0	73.6
5% DDT	0.50	3.2	90.8
10% DDT	0.25	1.7	95.1
1% dieldrin	0.25	1.5	95.5
1% dieldrin	0.50	0.8	97.5
10% DDT	0.50	0.5	98.6
Check	---	33.6	----
LSD - 5 per cent level		2.4	

Discussion and Results

The methods of insecticide application here considered present feasible control for the onion maggot. Expensive application equipment can be eliminated and control carried on with very little labor or expense to the farmer.

Spraying seed sets with power sprayers is a comparatively expensive procedure and it apparently does not give the desired amount of control. With four spray applications it can be observed in Table 2 that by using dieldrin at the rate of 0.5 pound of actual toxicant per acre, a 65 per cent reduction in damage was obtained. DDT and chlordane gave approximately the same control as did dieldrin. Heptachlor, aldrin, and parathion gave rather poor results, parathion being least effective, resulting in only a 31 per cent reduction.

Spraying seed sets appears to be at this time a rather poor method of control, both as regards effectiveness and cost. The loss in yields caused by spacing to allow spraying equipment to enter the fields is a prohibiting factor in itself. Expensive labor and equipment to do this job also adds to the disadvantages. It appears that four or more applications are necessary to obtain a desirable amount of control.

The data in Table 3 show that the pelleted seed method gave very good control. Ten per cent DDT used at the rate of $\frac{1}{2}$-pound per pound of seed and 1 per cent dieldrin used at the rate of $\frac{1}{2}$-pound per pound of seed were exceptional in control, both reducing the damage by 96 per cent. Heptachlor and 5 per cent DDT gave considerably less control. It is quite apparent that this method is adaptable to a farm of any size. Treatment of the seeds was made in advance of planting and since no other applications are necessary throughout the season, this becomes a very valuable method of control to the busy farmer. Perhaps the only disadvantage of this method lies in the preparation of the pelleted seed. Mixing wetted seed and insecticide is a laborious task unless some sort of mechanical agitator is available. After the seed is pelleted it must be spread out in thin layers for drying. If large amounts of seed are involved a large floor space is necessary.

In contrast to the pelleting of seed, the dry treatment is most promising with reference to the ease of preparation and its effectiveness. The only equipment necessary in this method is a covered can for mixing the seed and insecticide. The treatment itself is simple and trouble-free as described in the procedure.

Table 4 shows that excellent results were obtained with this method. Ten per cent DDT used at the rate of $\frac{1}{2}$-pound per pound of seed and one per cent dieldrin used at $\frac{1}{2}$-pound per pound of seed, both were highly effective, showing 97 per cent reduction in damage for dieldrin and 98 per cent reduction for DDT.

Ten per cent DDT and one per cent dieldrin at $\frac{1}{4}$-pound, per pound of seed, also was effective, resulting in a 95 per cent reduction in damage. Five per cent DDT used at ½-pound per pound of seed gave 90 per cent reduction, but heptachlor, chlordane, calomel, and aldrin proved quite unsatisfactory for good control.

The middle row of Plate VII shows typical effects of maggot infestation in seed sets. As the onions die from maggot damage the tops fall over, dry up and leave spaces in the rows.

The Control of Onion Maggot on Seed Onions

Three methods of insecticide application were used in tests for the control of the onion maggot on seed onions. These methods were designated as seed treatment, high pressure and high volume spray, and low pressure and low volume spray.

The experiments were carried out on a two acre planting of seed onions located on very light sandy loam. The cooperator was exceptionally helpful in laying out the plots and as a result, each type of treatment was replicated 3 or 4 times. The number of insecticides used was somewhat limited because of the number of plots that could be arranged. It was necessary, therefore, to choose those insecticides that were apparently of high effectiveness as shown by previous experimental work.

Dry Seed Treatment

The method of insecticide application for the dry seed treatment was exactly the same as that method used for dry seed treatment explained previously for the planting of seed sets. In short, the seeds, insecticide and fungicide for smut control, were placed into a 2-gallon friction top can and shaken vigorously in order to obtain an evenly dispersed mixture of seed and powder chemicals. This mixture was then ready to be placed into the seed hopper of the planter for planting.

The insecticides used in these tests were DDT, dieldrin and heptachlor. Ten per cent DDT dust was used at the rate of $\frac{1}{2}$-pound per pound of seed. One per cent dieldrin was used at two concentrations, $\frac{1}{4}$-pound of dust per pound of seed and $\frac{1}{2}$-pound of dust per pound of seed. Heptachlor was used at the rate of $\frac{1}{2}$-pound of $2\frac{1}{2}\%$ dust per pound of seed. Four rows of onions were treated with each of these formulations and replicated four times. These plots were arranged in a randomized block. Planting took place on April 9.

Sampling the plots for maggot damage was undertaken in the latter part of June so that damage by the first generation larvae could be determined. Damage by the first generation larvae is readily visible because one maggot can completely destroy one or more plants. By sampling during the latter part of June, any plants that were affected could readily be distinguished. A sample from each plot consisted of the number of infested onions from 50 feet of row. The 50 feet of row was randomly taken between the four treated rows of each plot, and the data recorded. The results of this test are presented in Table 5.

Table 5. Results of Dry Seed Treatment of Seed Onions for the Control of Onion Maggot.

Insecticide	Lbs./Lb. of Seed	Ave. No. of Infested Onions/50 Feet of Row
1% dieldrin	0.50	1.5
10% DDT	0.50	3.0
1% dieldrin	0.25	3.5
$2\frac{1}{2}$% heptachlor	0.50	7.01
Check	----	16.0
LSD - 5 per cent level		1.66

It is evident from the analysis in Table 5A of the Appendix that there is no significant difference in the effectiveness of 1 per cent dieldrin and 10 per cent DDT applied at the rate of $\frac{1}{2}$-pound per pound of seed. There is a difference, however, between dieldrin applied at $\frac{1}{2}$ and $\frac{1}{4}$ pounds per pound of seed. Two per cent heptachlor at $\frac{1}{2}$-pound per pound of seed is obviously significantly less effective than any of the other materials.

Low Gallonage, Low Pressure Spray for Onion Maggot on Seed Onions. The insecticides used in these tests were applied with a sprayer mounted on a Bollens Garden tractor. The pump was of the rotary gear type, delivering 80 pounds of pressure to 6 nozzles. Cone nozzles of the type used for weed control were attached to drop pipes which were mounted on a horizontal pipe adjustable in height. With this arrangement three rows of onions were sprayed with two nozzles per row. Delivery was at the rate of about 25 gallons per acre, dependent largely upon the speed of the tractor.

The plots in this set of experiments were arranged so that every three rows represented a plot. Four insecticides were used in these tests, and each plot with its particular insecticide was replicated three times. Dieldrin, chlordane, DDT and malathion were the insecticides used in these tests.

Spraying was carried on from the time the plants attained a height of about 2 to 3 inches, until the time that the tractor could no longer enter the field because of damage to the onions. The first spray was applied on May 10th and the last on June 26. A total of 5 sprays was applied at approximately 7-day intervals. The period over which the sprays were applied coincides closely with the time of emergence of the adults of the first generation.

The principle upon which the spray program was designed to protect the onions was based upon the effectiveness of the insecticide against the adult flies, egga and larvae. The adults were killed as they attempted to oviposit or rest upon onions that were sprayed. The eggs and larvae were killed as they were hit by the spray or as the larvae emerged from the egg on treated surfaces.

As in the dry seed treatment method, the results of these experiments were determined by the number of visibly damaged plants that occurred per 50 feet of row. Here again, the 50 feet of row was selected at random from the three treated rows of each plot. The results of these tests are recorded in Table 6.

Table 6. Low Gallonage Spray for Control of Onion Maggot on Seed Onions.

Treatment	Dosage/Acre Actual	Gal./Acre	Ave. No. Damaged Onions/ 50 Ft. of Row
Dieldrin	0.5	25	6.0
Chlordane	1.4	25	8.0
DDT	0.6	25	10.0
Malathion	1.0	25	13.0
Check	---	--	17.0
LSD - 5 per cent level			4.7

Inspection of Table 6 indicates quite strongly that low gallonage spraying of onions is not as effective as some of the other methods of control. Of the insecticides that were tested, dieldrin was the most effective, with chlordane, DDT, and malathion following in the order named. Analysis (Table 6A - Appendix) shows that only those insecticides with differences of 4.7 damaged onions are significantly different from one another.

During spraying operations it was evident that the spray was not covering as well as was necessary. With low gallonage equipment it is not possible to cover all the foliage and soil surface as thoroughly as with a high volume and high pressure sprayer.

Malathion showed very little effectiveness against the maggot. It is possible that malathion's property of short residual effectiveness is responsible for the poor control. In order for an insecticide to be effective against this onion pest it is necessary for it to have a considerable residual period because the adult flies emerge continuously over a 3 to 4 week period. The egg-laying period also persists over a period of 3 to 4 weeks, which closely coincides with the adult population levels. With a careful insecticide application the low gallonage method may be a practical means of control for the farmer who cultivates a small number of acres of seed onions.

High Gallonage Spray for Maggot Control on Seed Onions. The high volume and pressure application of insecticides on onions has the virtue of thorough coverage. The adults are active among the stems of the plants at the soil line, and the insecticide must be present in this area if good control is to be obtained. In comparison to the low gallonage method, the high volume, high pressure method produces a much better coverage around the bases of the plants, especially after the plants have begun to develop heavy foliage.

The insecticides used with this method were applied with a tractor-powered "Field Force" six row potato sprayer. The delivery rate of insecticide was regulated to one hundred gallons per acre at a pressure of 400 pounds. At this rate of application an even and thorough distribution of insecticide was deposited on the soil as well as on the plants.

The operation of this type of equipment in an onion field made it necessary to leave blank rows. That is, for each swath down a field it was necessary to omit two rows during plantings so that the tractor and sprayer were able to enter the field without causing damage to the crop as the foliage matured.

The plots for this experiment were arranged for 4 insecticides. Each swath included 12 rows, and was considered a block, treated with one insecticide. Because this large equipment is not conducive to arranging randomized blocks, each swath was considered to represent 4 plots of a particular insecticide and four sets of counts were taken from each swath in order to obtain replicate samples. In this manner the data were analyzed as though there were four insecticides, replicated four times. This arrangement of plots was necessary because stands of seed onions of more than two acres were not available for the use of heavy equipment in a randomized block pattern.

The spray program that was prepared was based on the seasonal development of the onion maggot. A total of five sprays had been applied to this block of seed onions, when the results of the maggot experiment had been recorded. The first spray was applied so that a residue would be present when adults emerged from the overwintering puparia. This spray was applied when the onions were 2 to 3 inches in height on May 12. The following four sprays were applied at approximately weekly intervals until June 20, when the counts of maggot damage were recorded.

Three samples, each of which consisted of 50 feet of row, were taken from each of the 12 rows that represented one swath during spraying.

The insecticides tested in this experiment were the same as those used at low gallonages, so that the two types of application methods could be compared. Dieldrin, chlordane, DDT and malathion were all used as emulsions, and applied at the rate of 100 gallons per acre. It was observed that the relative effectiveness of the four insecticides was the same as found in the low gallonage application. However, it was found that each insecticide was more effective in the control of maggot by the high volume method, that is less damage was observed in the high volume sprays than with the low volume sprays. These effects were no doubt, the result of better spray distribution and coverage attained in the high volume method.

In Table 7 it can be observed that dieldrin, chlordane, DDT and malathion were effective in the order named. As in the low gallonage method of application, malathion undoubtedly possesses a low rate of effectiveness, because of its short residual action. Significant differences in the effectiveness of the insecticides, as derived in Table 7A in the Appendix, are found between those insecticides which have a difference in the average number of damaged plants, greater than 3.57.

Table 7. The Effectiveness of Four Insecticides Applied with High Volume, High Pressure Machinery for the Control of Onion Maggot on Seed Onions.

Treatment	Lbs. of Actual Toxicant/Acre	Ave. No. of Damaged Onions/50 Ft. of Row
Dieldrin	0.5	3.0
Chlordane	1.5	5.0
DDT	0.6	7.0
Malathion	1.0	9.0
Check	---	16.0
LSD - 5 per cent level		3.57

The application of insecticides at high volumes with this method proved to be a very effective means of control for the onion maggot. Dieldrin used at the rate of 1½ quarts per 100 gallons (0.5 pound of actual toxicant) proved beyond doubt that the high pressure, high volume method was an effective means of controlling onion maggot in the culture of seed onions.

One factor involving this method must be taken into consideration before putting it into general use. The omission of two rows per swath must be weighed against the increase in yield from spraying. During a season when maggot infestation is light the gain from spraying would not be economical, but during a season when maggot infestation is heavy, the crop would be saved when it may have been totally destroyed if no spray program had been followed.

This method of application also has an advantage in that other chemicals can be included in each spray for the control of other pests. For example, the early applications of insecticide for maggot control also results in the control of thrips. Fungicides may also be incorporated for the protection of the plants from such diseases as mildew and blast.

Further consideration of the use of combined sprays will be made in the general discussion of advantages and disadvantages of insecticide application.

<u>The Control of Onion Maggot on Onions Grown From Sets</u>

The need of control measures for onion maggot on set onions in the Connecticut Valley, has generally been thought unnecessary. This conception has been brought about primarily by the fact that onion maggot damage to set onions is insidious and is not readily visible to the farmer. As a result, the amount of damage has never been thoroughly studied by a trained investigator. This deceptive type of infestation is perhaps due to the greater ability of set onions to withstand maggot attack. This ability is related to the greater vigor of onions grown from seed sets or bulbs which grow to maturity more rapidly with a greater supply of food for the maggot, than other types of onions possess. One onion plant may have food enough for as many as 10 larvae to complete the larval cycle. It is apparent, then, that an infestation disastrous to a field of seed onions may hardly be noticeable in a field of set onions.

The fact that an infestation may not be noticeable, does not mean that damage and destruction of onions is not taking place. One or two maggots present in a vigorously growing set onion does not necessarily mean that the death of that plant is inevitable. However, these onions at harvest time are the ones that are discarded as rotten onions. A great many of these onions could be saved if maggot control were practiced.

Damage to set onions may also be disastrous and destruction of a crop is possible. During the summer of 1953, a particular plot of onions was brought to the writer's attention because it lacked the typical green color that designates a healthy crop. The owner had decided that the soil nutrients were not sufficient for good growth and proceeded to add nitrates and top dressing fertilizers. No beneficial effects were noticed from the addition of nutrients, and at this point the field of onions was brought to my attention. Upon inspection it was obvious that the damage had been the result of an onion maggot infestation. Forty to fifty per cent of the crop had been destroyed by that time.

It is obvious then, that the control of maggot on set onions may become a necessity in the Connecticut Valley.

During the summers of 1952 and 1953, three methods of insecticide application were tested for the control of onion maggot on set onions. The first of these methods was directed toward a single insecticide application at the time of planting. This method consisted of blowing insecticide into the furrow at the time of planting just before the seed sets were covered with soil. The second and third methods of treatment used during the summer of 1953 were applied as sprays. The two types of sprays used in these tests were the high volume, high pressure spray and the low volume, low pressure spray.

Furrow Treatment

Set onion culture methods should be understood before discussing this method of insecticide application. As soon as the land is workable in the spring, it is fitted for planting by plowing or wheel harrowing. It is then smoothed over with a meeker harrow and is ready for planting. The small set bulbs are placed into a planting machine which, when in operation, makes a furrow into which the sets are distributed. The sets are planted at the rate of about 10 to 12 per foot. These sets may be covered in the operation of planting, but many farmers still prefer to space the sets by hand and then cover them with a hand cultivator.

These tests were made under the latter conditions, and the insecticide was distributed in the furrow just before the sets were covered. The insecticide was dispersed with a rotary hand duster which was equipped with a flexible nozzle. This nozzle was kept within six inches of the open row of sets while the insecticide was being distributed. The operator of the duster treated one row at a time by walking up and down the rows at a pace that would deliver approximately 20 pounds of dust per acre. In order to obtain this pace, preliminary trials were necessary and calculations were made so that approximately this amount of insecticide would be delivered.

At the rate of 20 pounds of dust per acre, a film of insecticide was deposited in the furrow which was readily visible on the soil and sets. When the onions were covered the insecticide on the soil surrounding the sets was turned over on top of the onions so that a complete barrier of insecticide encircled the bulbs.

Following this technique, a randomized block was arranged in which five insecticides were tested. Ten per cent DDT, 1 per cent dieldrin, $2\frac{1}{2}$ per cent heptachlor, 5 per cent chlordane, and 1 per cent lindane were distributed in the fashion described above. Two rows of onions were arranged for each plot which was replicated three times for each insecticide. A three-row check plot was maintained for each set of replicates.

The results of these tests for onion maggot damage were recorded late in Juhe, after the larvae of the first generation were well on their way to maturity. Infested plants are readily noticeable by their stunted growth and yellowed color. Any plants suspected of maggot damage were pulled in order to determine the presence of maggots. Samples from these plots consisted of 100 feet of row and damage was recorded as the number of infected onions from each sample of 100 feet. The 100 feet as in other tests, was selected at random from the two rows of each plot. The results of this test may be observed in Table 8.

Table 8. Results of Dust Furrow Treatment for the Control of Onion Maggot on Set Onions.

Treatment	Lbs./Acre	No. of Onions Infested/ 100 Feet of Row
10% DDT	20	7.0
1% dieldrin	20	9.0
1% lindane	20	10.0
5% chlordane	20	11.0
2½% heptachlor	20	13.0
Check	**	15.0
LSD - 5 per cent level		4.7

It is evident that all five insecticides exhibit some control of onion maggot in set onions. If the insecticides were applied at a higher rate perhaps there would be a greater amount of control. However, at 20 pounds per acre a significant amount of control was obtained and both 10 per cent DDT and 1 per cent dieldrin are insecticides which show the most promise for use against the onion maggot. Only DDT, dieldrin and lindane show significantly different effectiveness as compared with the check plots. Chlordane and heptachlor treatments are not statistically different from the checks.

<u>Low Gallonage Spray</u>

During the season of 1952 the author noted that many of the farmers were using the small narrow-tired Allis Chalmers "G" tractor for a number of operations in the culture of set onions. During the planting season this tractor was used to draw four set planters and cover the onions in one operation. Later in the season this same machine was used to cultivate the onions and to apply weed killers. The possibility of spraying for maggot control was obvious but it was too late in the season to attempt a maggot control program.

During the following winter and early spring, arrangements were made with one of the growers to carry out a maggot control program on set onions using the weed control spray equipment, mounted on an Allis Chalmers "G" tractor. This equipment consisted of two side tanks mounted on the rear axle of the tractor just inside the wheels. The liquid was drawn from the tanks by a "rotary gear" pump powered directly from the motor. The liquid was then carried to a horizontal pipe, mounted at the rear of the tractor, from which drop pipes and nozzles were suspended.

The pump was capable of delivering about 80 pounds of pressure, but during actual spray application the pressure averaged about 60 p.s.i. The spray material was discharged at the rate of about 35 gallons per acre. The two side tanks carried about 70 gallons of liquid so that one load would cover two acres of onions.

The boom carried eight nozzles, two for each row of onions. The nozzles were the fan type nozzle, Teejet #6. While the plants were small the spray boom was lowered so that not only the plants received a cover of insecticide but the soil around the plants received a fair amount of spray.

The plot arrangement in this set of experiments was carried out on a piece of onions containing about five acres. The rows were quite short and made an ideal location for the use of this type of equipment and arrangement of plots. Each plot consisted of four rows and every plot for each of six insecticides was replicated three times. The first spray was applied on May 13. Four additional sprays were made at approximately weekly intervals. More treatments would have been made but damage to the onions by the tractor was too great.

The insecticides dieldrin, heptachlor, chlordane, lindane, DDT and aldrin were used in these tests against onion maggot on set onions. In the accompanying table (9), it can be observed that the amounts of actual toxicant applied per acre were variable among the insecticides. These figures were based upon the use of these insecticides on other insects and recommendations supplied by the manufacturer.

For anyone who owns this type of sprayer and tractor, the method of insecticide application described may become a routine detail in the culture of set onions. Not only is this tractor versatile in spraying, but as explained earlier it is an ideal piece of equipment for many operations in an onion field. The narrow tires with which it is equipped do not interfere with the plants and it is not necessary to omit rows for the tractor to pass through the field. Table 9 shows that dieldrin, chlordane and DDT have exceptional control potentials against maggot, with this type of equipment.

Table 9. The Results of Insecticides Applied by Weed Killer Application Machinery for the Control of Onion Maggot on Set Onions.

Treatment	No. Lbs. of Actual Toxicant per Acre	No. of Damaged Onions per 100 Feet of Row
Dieldrin	0.5	4.3
Chlordane	1.5	5.7
DDT	0.6	6.0
Aldrin	0.75	8.0
Lindane	0.5	9.0
Heptachlor	1.0	10.3
Check	---	15.3
LSD at 5 per cent level		1.5

Statistically, as derived in Table 9A in the Appendix, dieldrin and chlordane are not significantly different in their effectiveness. Aldrin, lindane and heptachlor are all significantly less effective than dieldrin, chlordane and DDT.

High Gallonage Spray

The equipment used in this experiment was the same as that described under high gallonage sprays for control of maggot in seed onions. In order to use this tractor-powered sprayer in a field of sets, it was necessary to omit two rows for every swath so that the tractor would not crush any onions. Each swath consisted of 12 rows of onions and as in the seed onion experiments, each swath was broken up into three plots which were treated as three replicates of the same insecticide. DDT, dieldrin, chlordane and heptachlor were the insecticides used in these tests, the whole experiment consisted of 48 rows (four swaths of 12) plus the untreated checks which were intermingled with the treated material.

The first application of the insecticides was made on May 10th. Succeeding applications were made at approximately weekly intervals with a total of seven sprays, throughout the season. The last spray was applied on the 2nd of July about a week-and-a-half before the onions were harvested. The piece of onions used for this experiment had a relatively heavy infestation of maggot and the results that were obtained showed well marked differences between treatments and checks. The results of this set of treatments were recorded as the number of visibly infected onions per 100 feet of row. Here, as in other tests, this 100 feet of row was randomly sampled from the four rows of onions that made up the plot. Table 10 illustrates very adequately the fact that the high pressure, high volume type of spray equipment is a very excellent method as far as the control of maggot on set onions is concerned.

Table 10. Control of Onion Maggot in Set Onions Using High Volume, High Pressure Spray Equipment.

Treatment	Lbs. of Toxicant per Acre	No. of Damaged Onions per 100 Feet of Row
Dieldrin	0.5	1.3
Chlordane	1.5	3.0
DDT	0.6	3.7
Heptachlor	0.5	4.6
Check	---	18.3
LSD - 5 per cent level		1.9

It should be pointed out that it was necessary to make observations during the spring season so that the insecticides were applied before the height of the adult population was reached. If, for instance, the first treatment had been delayed for two weeks the control obtained would not have been as significant as that presented in Table 10. It is necessary to have the insecticide present when the adults are entering the onion fields for the purpose of oviposition.

Analysis of the data in Table 10 is presented in Table 10A of the Appendix. Differences in the averages of damaged onions per 50 feet of row must be 1.9 onions in order that a significant difference exist between treatments. All treatments were significantly different than untreated checks, but no difference was observed between dieldrin and chlordane. Differences did exist between dieldrin and DDT and heptachlor.

THE EFFECT OF INSECTICIDES ON GERMINATION AND EARLY GROWTH OF ONION SEEDS

Literature Review

One of the first observations concerning injury to onion by the newer organic insecticides was made by McLeod (1946). In tests which he made comparing calomel, DDT and hexachlorocyclohexane for their efficiency against onion maggot, it was determined that high concentrations of hexachlorocyclohexane were injurious to seedlings. In seed treating experiments it was found that all plants, the seeds of which were pelleted with equal weights of 20 per cent hexachlorocyclohexane (benzene hexachloride), were killed. Other plots which were treated with dusts containing less BHC were not as seriously affected.

In order to investigate further this effect of BHC on onion seedlings, McLeod (1946) attempted to determine the nature and obtain detailed information concerning this phenomenon. In the greenhouse therefore, he added to a series of pots containing 2 pounds of soil, amounts of 20 per cent hexachlorocyclohexane ranging from 0.01 gram to 32 grams. In each of these pots were planted 100 onion seeds. In every case the seeds germinated normally and it was not until seedlings in the check pots were about one inch high, that the effect of the insecticide began to manifest itself. All pots containing 0.5 gram or less of the 20 per cent dust showed healthy seedlings, while the ones which had received 1 gram or more were injured. The shoots of the latter seedlings were shorter and thicker than the former. Seedlings in pots to which 4 grams, 8 grams and 32 grams of dust had been added never emerged through the soil and the shoots of these plants were tremendously disfigured.

Cullinan (1949) experimenting with the effects of DDT, chlordane, toxaphene and BHC on plants and soils, came to the conclusion that all were capable of depressing growth on at least some plants. He found that these effects could be demonstrated when insecticides were applied in amounts of 25 pounds per acre. It also was indicated that root systems were more affected by BHC and chlordane than they were by DDT.

Cox and Lilly (1952) investigated the effects of aldrin and dieldrin on germination and early growth of many field crops. In general, they obtained information that indicated aldrin and dieldrin were relatively safe for most plants. Plants were somewhat more tolerant to dieldrin than to aldrin. All crops (barley, buckwheat, corn, flax, oats, rye, soybean and winter wheat) gave good emergence and seedling growth at all levels of dieldrin application, up to and including 128 pounds per acre. With aldrin only corn, flax and soybeans showed good emergence and growth at the 128 pounds per acre level, while other crops such as oats and rye gave good germination and growth only at the 2 and 4 pounds per acre level.

Investigations on the Effect of Insecticides on Germination and Growth

During the summer of 1952 seed treatments of chlordane and lindane applied to onion seed, as explained earlier for dry seed treatment, for the purpose of maggot control caused extensive damage to the seedlings. These effects were observed in plots which were treated with chlordane at the rate of 1 pound of 5 per cent dust per pound of seed. The seed in these plots was sown for the production of seed sets at the rate of approximately 40 pounds per acre.

Damage in both cases resulted in thinning the onions to such an extent that the remaining onions took the appearance of seed onions instead of seed sets, as may be observed in Plate XII. The appearance of normal seed sets, in comparison to the injured seed sets as shown in Plate XII, may be observed in Plate VII. It is noticeable that normal seed sets grow in very dense stands while those injured early in the season during germination have been greatly thinned out and sparse in appearance. Apparently all the seed germinated but those seedlings affected by the chemicals never regained their normal appearance and eventually died.

The circumstances given above led to investigations concerning the effect of lindane, chlordane and other insecticides on the germination and growth of onion seedlings in the greenhouse.

The prime purpose of these tests was to determine the amounts of insecticides used for seed treatment which began to show signs of injury to the plants.

The conditions for experiments in the greenhouse were manipulated so that they approximated those of the field as closely as possible. The soil used in these experiments was brought in from the Connecticut Valley onion growing area. This was necessary because the onion soils in the Valley are a very light mineral loam. The effect of soil type could possibly play a role in the amount of injury inflicted by the insecticides.

The experiments were carried out in greenhouse flats 1' x 2'. Seeds were mixed with the chemicals and sown in the flats, with each treatment replicated 4 times. DDT, dieldrin, lindane, heptachlor and chlordane were insecticides tested. Two hundred seeds per plot were sown in such a manner as to approximate the number of seeds per linear unit, as those sown for seed sets in the field. For mixing purposes, one ounce of seed was taken as the standard to which desired amounts of insecticide could be added. In all cases the dry insecticide and seed were thoroughly mixed in a friction top container and then sown in the flats. Each flat was used for one insecticide only, for if rows of different insecticides were planted in one flat, contamination during watering and root growth could take place. Plate XIII shows the arrangement of flats representing plots in the greenhouse. Each flat with its particular insecticide, is shown with rows of replicates.

Six different mixtures of insecticide and seed were used during these tests. The concentrations of the insecticides were as follows: lindane 1 per cent, chlordane 5 per cent, heptachlor $2\frac{1}{2}$ per cent, DDT 10 per cent, and dieldrin 1 per cent. Each of these materials was mixed with seed at different rates, as indicated in Table 11, ranging from 1/10 pound insecticide per pound of seed to 1 pound per pound of seed. In addition to the insecticide 1/8 pound of Arasan was added to each pound of every mixture of seed. The Arasan was added since it is used for smut control in all commercial plantings.

The insecticidal injury to onion seedlings caused by lindane, chlordane and heptachlor showed characteristic thickening of the shoot and the root tips showed browning. Those shoots, sectioned and studied microscopically, all indicated a polyploidal condition of the chromosomes. Most seedlings affected with this condition eventually died and only those that escaped injury continued growth.

The determination of the per cent of injured seedlings in each plot was taken by counts of those injured and those uninjured. Except in the most severe damage produced by lindane, the majority of injured plants managed to emerge through the soil and thus could be observed. However, in the case of lindane, many seedlings never emerged from the soil. When the seeds were uncovered they were observed to have germinated but then failed to grow.

Since one pound of insecticide is approximately the limit with which one pound of seed can be conveniently handled during the planting, it was necessary to increase the concentrations of the formulations of DDT, dieldrin, heptachlor and chlordane in order to obtain more of the toxicant per pound of seed. Results of the experiments are presented in Table 11.

Table 11. Per Cent of Seedlings Injured by Insecticides Applied as Seed Treatments at Varying Dosages.

Treatment	Per Cent of Seedlings Injured					
	Dosage - Lbs./Lb. of Seed					
	1/10	1/8	1/4	1/2	1	1*
Lindane 1%	0	12	85	100	100	100
Chlordane 5%	0	0	0	4	32	80*
Heptachlor 2½%	0	0	0	0	0	13*
DDT 10%	0	0	0	0	0	0*
Dieldrin 1%	0	0	0	0	0	0*
Check (Arasan) 1/8	0	0	0	0	0	0

*Concentrations increased - Chlordane 40%, DDT 50%, dieldrin 25%, heptachlor 25%.

It may be observed in Table 11 that lindane is by far the most toxic of the insecticides tested to onion seedlings. One-eighth of one pound of 1 per cent lindane dust was responsible for injury to

12 per cent of the emerging seedlings. At one-half pound of 1 per cent lindane, 100 per cent of the seedlings were injured to the extent that they never recovered. Plate XIV shows the effect of lindane on germination. The greenhouse flat on the left contains seedlings, the seeds of which were treated with the fungicide, Arasan, and was used as a check. The flat on the right contains seedlings, the seeds of which were treated with lindane at the rate of 1/4 pound of 1 per cent lindane per pound of seed.

Chlordane was less toxic than lindane to the seedlings, but it was obvious that an increased amount would be very injurious. One pound of 5 per cent chlordane caused 32 per cent injury while 1 pound of 40 per cent chlordane caused 80 per cent injury.

Heptachlor was less toxic than chlordane. Thirteen per cent injury appeared when 1 pound of 25 per cent heptachlor was mixed with 1 pound of seed.

Neither DDT nor dieldrin were observed to cause injury even when applied at increased dosages. Both 50 per cent DDT and 25 per cent dieldrin applied at 1 pound per pound of seed were safe and no injury could be recognized. The seedlings were normal in every respect.

The information presented in these experiments indicates that both lindane and chlordane should not be used as seed treatments on onions. Heptachlor, apparently is relatively safe and could be used at concentrations lower than those which showed injury to seedlings. Both DDT and dieldrin showed exceptional safety with respect to injury of onion seedlings.

Experiments carried out during the above investigations, consisted of determining the effect of insecticides on onion seed germination. In these tests treated seeds were placed between moistened paper towels and then into petri dishes where germination could take place.

With no exception, the seeds whether treated with dilute dusts or concentrated powders, always germinated in the presence of each of the insecticides. This series of experiments without doubt indicated that germination of onion seed was not influenced by the treatment received before planting, but that the influence became evident after germination. That is, the insecticide was toxic to the growing parts of the new seedling but not to the dormant seed.

SECTION II. THE ONION THRIPS

BIOLOGY OF THE ONION THRIPS

REVIEW OF LITERATURE

The ravages of the onion thrips, *Thrips tabaci* Lind. in the United States were first recorded by Packard in 1872, at which time he apparently and erroneously referred to the insect as *Limnothrips tritici* Fitch. The damage in 1872 was unusually severe in Essex County, Massachusetts, amounting that year to at least one-tenth of the crop which had a value in that county of at least $10,000. Destruction proved so severe in some localities that the crop was abandoned.

Research on this insect was lacking until 1888, at which time Lindeman in Russia undertook the study of its life history, habits and control on tobacco. Lindeman's conclusions, quoted by Lintner in 1896 were so different from those which have been reached by workers on the same species in this country that it led Hinds (1902) to believe that the early stages of several species were confused by Lindeman.

Little more than mention of the occurrence of the onion thrips was made in American literature until 1893 when Gillette discussed the insect in Colorado. He indicated that serious damage to onions had been observed and was characterized by silvering and premature death of the tops in late July and early August. In the following year, Osborn and Mally (1894) reported similar damage in Idaho. Much of the information presented by Lintner in 1896 was based on Lindeman's observations in 1888 which apparently were not made on Thrips tabaci Lind. and therefore will be omitted from the biological reports.

Research on the biology of the onion thrips in the United States had its origin in Iowa. Osborn and Mally (1895) found that the eggs of the onion thrips were deposited beneath the surface of the leaf and embedded in the cell structure of the tissue. As the eggs hatched, the larvae worked their way through the surface of the leaf and soon began to feed upon the plant tissue. They found that several generations were present during the season and that the winter was passed in either the larval or adult stages, since both were present in refuse during the winter. The adults were found to deposit eggs as early in the season as suitable vegetation was available.

In 1895, Pergande thoroughly examined the literature for all records of thrips infesting onions and indicated that all these thrips were a single species. He discovered, after careful comparison of the American insect with determined European specimens, that they were one and the same, Thrips tabaci Lind. Along with this information Pergande included a complete description of the male, the female and the nymph of the onion thrips.

The next important account of the biology of Thrips tabaci was published in 1898 by Quaintance who studied this insect in Florida on onions, cabbage and cauliflower. He reported that the behavior of this pest was practically the same on all three plants. The observations made by Quaintance, as those by other American workers, did not agree with those made by Lindeman (1888) in Russia. Quaintance observed that the eggs were deposited singly just beneath the epidermis of the plant. In the onion, this took place anywhere on the leaf but in the case of cabbage and cauliflower a preference was shown for the veinlets. The actual process of oviposition was observed but once, in which case a small patch of epidermis was torn off with the mouthparts before a slit was cut in the leaf with the ovipositor. The egg stage was observed to last three to four days, the nymphal stage seven to nine days, and the quiescent stage, four days. The total life cycle in Florida was approximately sixteen days, with an undetermined number of generations per year. A detailed description of each stage of development was also included.

A complete summary of the literature with a discussion of life history, economic considerations and descriptions was presented by Hinds (1902). The descriptions were original and noted for their excellence.

Further original research on the biology of onion thrips was lacking in the literature for several years. During these years many reports have been made upon the generally known aspects of thrips biology. Among these were the publications of Pettit (1905), Chittenden (1907), Slingerland, Herrick and Crosby (1910), Davis (1911), Sanborn (1912), Britton and Walden (1914), and many others during this period.

Fernald and Bourne worked on this pest for several years and in 1914 presented information additional to that already in the literature. They indicated that the thrips passed the winter as an adult in protected places such as refuse on the onion fields, rubbish heaps, in grass clumps, and along uncultivated portions of the fields where weeds were rampant. In the spring when the onions were two to three inches in height, the insects left their winter quarters, attacked the onions and began oviposition.

Shull (1914) worked on the sex ratios and life cycles of several common thrips which belonged to the genus (Thrips). Shull also indicated that this insect overwinters only as adults. He found that the male sex of Thrips tabaci Lind. was very rare. He was able to collect only two during his studies, and these were taken in September. The occurrence of males in the fall season might have represented a vestige of a former sexual phase, and he believed that the onion thrips was wholly parthenogenetic.

Kinsey (1917) and Watson (1917) discussed the onion thrips and reviewed briefly the aspects of the biology which were already known. Other workers especially those in experiment stations, made similar types of reports on the insect.

A complete report of the onion thrips was prepared by Chittenden in 1919. Observations gathered throughout the United States provided excellent data for this publication. It was indicated that the thrips occurs wherever onions are grown and thus has become almost cosmopolitan in its distribution.

Results of life history studies showed that females deposit eggs in slits made in the tissues by the ovipositor, where they are hidden from view by the epidermis. The life cycle from the time of egg laying until the mature adult appears, was found to require about three weeks under the most favorable conditions. Under semi-tropical conditions such as those found in Texas, it was possible for at least six generations to develop during a season.

Chittenden presented a list of food plants which the onion thrips had been found to injure. In addition to onions, garlic and related plants, it was found that cabbage, cauliflower, cucumber, melons, pumpkin, squash, kale, turnip, tomato, lettuce, beets, beans, peas, celery, blackberry, strawberry and practically all vegetables and truck crops were injured. Although tobacco had been reported damaged in Europe, no sign of this injury was recorded in America. Other crops upon which the onion thrips had been found include cotton, timothy, clover, rye, wheat, and many other grasses.

Chittenden indicated that growing onions from "sets" was an extremely common cause of early injury by onion thrips. Onions grown from sets emerged from the soil sooner than other onions with an especially succulent tissue to which thrips rapidly made their way. Development of thrips on onions was apparently more rapid than on other plants.

The above facts were well established by Horsfall (1921) in Iowa. His records showed that thrips established themselves and began to breed on set onions two to three weeks earlier than on seed onions. Life history studies in the same area indicated that fifteen days was an average life cycle for the onion thrips. Thus, the thrips had an opportunity to complete one generation before infestation of seed onions could take place. These facts, indicated that when set onions are grown next to seed onions, a much heavier initial infestation of thrips would invade the seed onions than if sets were not planted next to seed.

The same author also indicated that infestations of thrips were observed to originate from fields of alfalfa, greenhouses, early onions, and refuse piles or other shelters which adjoin fields of onions. In many instances infestations were traced from an initial focal point to a general infestation later in the season.

The most complete and precise work on the biology of the onion thrips since the work of Quaintance in Florida, was presented by Horsfall and Fenton in 1922. The life history studies were carefully carried out in vials containing onion leaves which were kept in an outdoor shelter. Their results indicated that the egg stage was passed in two to seven days, the nymphal period in three to eleven days, and the "pupal" period in two to eight days. A period of 7 to 16 days with an average of 11 was observed to be necessary from the time of egg hatching to the appearance of the adults.

Studies by the above authors of the climatic factors influencing epidemics of onion thrips showed that temperature and moisture were the two major factors involved. Above normal temperatures and sub-normal precipitation were found to be ideal conditions. Any variations of these two factors were found to have direct effects upon the degree of infestation of the onion thrips. It was also obvious that conditions favoring thrips were unfavorable for normal growth of the onions.

Interesting notes on the longevity of the adult onion thrips were presented by Shepard in 1925. He states that according to earlier workers, the length of the life of adults was recorded as lasting from 1 to 4 days. In his observations Shepard found that adult life averaged fifteen to sixteen days with some surviving for as many as fifty to sixty days.

In 1926, Bourne, investigating the life history of the onion thrips in Massachusetts, found a close correlation of the "set" onion industry to the problem of thrips injury on onions grown from seed. It was stated that set onions served as ideal nurseries for the colonization and multiplication of thrips which later migrated to nearby seed onions and there produced severe injury. Injury was not as severe to the "sets" because they were harvested before the peak of thrips populations was reached.

The early investigations on the onion thrips showed that it was an omnivorous feeder, and that cotton, especially seedlings, was one of the plants damaged. Many investigations concerning the onion thrips, Thrips tabaci on cotton followed. MacGill in 1927 made extensive studies on the biology of the Thysanoptera with reference to the cotton plant. It was noted that the average life cycle on cotton required 23 to 31 days, depending largely upon climatic conditions. The length of the cycle decreased with a rise in temperature. It was discovered that the minimum effective temperature was 7° C., while the maximum effective temperature was above 38° C.

Wardle and Simpson (1927) also working with Thrips tabaci Lind. on cotton found that infestations of thrips varied inversely with the amount of water supplied to the plants. Some of the possible deleterious effects of rain water to the thrips were described as: killing of "pupae," washing thrips off plants resulting in destruction, and osmotic alterations of the plants.

In 1929, MacGill in further investigations on cotton, indicated that surface caking of the soil was unfavorable to *Thrips tabaci* Lind. The surface caking of the soil, caused by precipitation, evidently had injurious effects on the pupae in the soil or on the pupation process. Caking or hardening of the soil apparently kills those "pupae" in the soil. Plants growing in tilled soil had significantly higher infestations than those plants in soil which was allowed to cake.

Thrips tabaci Lind. apparently was also causing severe damage to cotton and tobacco in Russia. Fedorov (1929, 1930), investigated the life history of the insect and found that the egg stage was completed in 4 to 4.5 days, the larva in 8 days, the nymph in 2.5 to 3.5 days, and the adults were active for 20 to 25 days. There were generally five or six generations of the insect per season.

In 1930, Eddy and Clark described the damage which *Thrips tabaci* Lind. caused to cotton seedlings. The injury was reported to manifest itself as malformation, crinkling, and erosion of the leaves as well as a blasted appearance of the buds. They also reported that five generations of parthenogenetic development had taken place between May 26th and September 25th, with an average life cycle duration in July of 15 days.

Biological studies of Thrips tabaci Lind. have been made in the Hawaiian Islands because of its relation with "ring spot," a virus disease on pineapples. According to Sakimura (1932), Thrips tabaci was introduced to the Hawaiian Islands and its most important wild host was Emilia sagittata, a reservoir for the virus causing pineapple leaf spot. Occasional migration of the thrips to pineapple resulted in transmission of the disease. Sakimura studied the life history of the thrips on its wild host, found that it normally reproduced parthenogenetically and that the average length of its life cycle was 18.5 days. The eggs, first instar "larvae," second instar "larvae," "prepupal" stages, and "pupal" stages averaged 4.53, 4.57, 4.57, 1.54 and 3.3 days respectively. He also found that the average adult life lasted 32.4 days.

Bourne in 1932, found that infestations which had been developing rapidly were reduced by climatic conditions. Cool wet weather had checked the infestations noticeably and rendered them non-serious. In 1934, Bourne and Shaw found large numbers of thrips adhering to onions about mid-August, which were filled with the fungus, Empusa sphaerosperma. The appearance of this fungus coincided with a sharp decline in thrips infestations.

A comparison of the life cycles of Frankliniella tritici

(Fitch), *Frankliniella fusca* (Hinds), and *Thrips tabaci* Lind., on cotton seedlings, was made by Watts (1934) in South Carolina. He found that all three were serious pests on the seedlings and that the average life cycle of *F. tritici* was passed in 15.01 days, *F. fusca* in 18.5 days and *T. tabaci* in 16.3 days.

An observation by Harris, Drake and Tate (1936) indicated that driving rains greatly reduced thrips populations. Their conclusion was based upon the knowledge that caking soil after heavy rains, killed those forms which sought shelter in the soil, by trapping them beneath a hard surface.

The life cycle and seasonal history of the onion thrips on onions in the vicinity of Tokyo, Japan were studied by Sakimura in 1937. He came to the conclusion that there were ten generations during each season. During the months of August and September the length of each of the stages egg, "larva," "prepupa," and "pupa" was 3.6-6.5, 6.4-13.5, 1.2-2.8, and 3.2-6.3 days respectively.

A similar study was conducted on the onion thrips in India by Rahman, Khan and Batra in 1944. They indicated that each of the stages egg, nymph, "prepupa" and "pupa" was passed in 8-9, 4-6, 1-2, and 4 days respectively. An average of 12-19 days was reported necessary for the completion of the whole life cycle. Each female was capable of depositing fifty to sixty eggs and the most damage to onions took place during the months March to May.

In 1951, Shirck reported that the onion thrips pass the winter principally as adults in the crowns of alfalfa and clover. He also indicated that the severity of winter had no relation to ensuing infestations on onions.

INVESTIGATIONS ON THE BIOLOGY OF THE ONION THRIPS IN THE CONNECTICUT VALLEY

Biological studies of the onion thrips, *Thrips tabaci* Lind., were carried out in these investigations primarily because of the great importance which seasonal histories play in control programs. Previous to these studies, many authors have observed this insect, worked on control measures, and have given only brief descriptions of the habits of onion thrips in northeastern United States. Incomplete information regarding seasonal development and habits has been obvious for the northeast as indicated in the review of literature in the previous section.

It was not the author's intention to secure minutely detailed information regarding each individual instar or stage in this study, but to obtain accurate information of seasonal development, so that control measures could be based upon sound information. For the most part, information concerning the time of entrance of thrips to the onion fields, period of oviposition, length of life cycle, periods of the greatest reproduction and abundance, number of generations and important habits of the thrips which might lead to better control were the facts which were sought in these studies.

The data concerning the seasonal development, life cycle studies, and habits of the onion thrips were gathered from three sources. Seasonal development and population studies were conducted on commercial fields. Information on life cycles and habits was derived from individually isolated caged plants and from observations made on infested leaves which were taken into the laboratory. With the exception of early seasonal development when observations were made on set onions, Spanish onions were used exclusively for these studies.

Observations concerning appearance, reproduction and abundance and seasonal trends in populations were made on commercial plots. Isolated plants were maintained for obtaining such information as the time required to complete one generation, approximate number of generations and habits of the thrips.

The techniques employed for the two types of observations described above were based primarily upon the sort of information desired. For instance, to determine the first appearance of thrips in onion fields, observations were made at least every other day in several fields, throughout the spring until the insects were found. Similar observations were continued to determine oviposition, presence of nymphs, and later in the season for population studies. The data were taken by inspecting thoroughly large numbers of plants for the presence of these forms. However, later in the season when information regarding abundance was undertaken, bi-weekly counts of ten plants from each of four fields were made. Analysis of these data provide excellent information regarding seasonal population fluctuations.

Population Studies

During the summer of 1952 only limited information was obtained concerning the biology of the onion thrips. The first thrips appeared on the 16th of May. Three adults were found on set onions in a plot that was planted earlier than any other onions in the vicinity. The soil was a light sandy loam, slightly elevated and well drained, thus accounting for the early planting. During this same season the first nymphs appeared on the 23rd of May and others continued to appear throughout the season. Further information regarding thrips biology was absent in 1952, except that thrips were found in and about onion fields on volunteer onion plants long after harvest of the crop.

In the spring of 1953, one week before planting time, tests were made to determine the presence of thrips in and about the fields and on seed set bulbs. Dry weeds, leaves and grass along the edge of an onion field were collected and placed in a "Berlese Funnel" for twelve hours. Heat drove all living animals down through the funnel and these were collected in a jar of alcohol. From approximately two pounds of debris only six adult onion thrips were obtained. Fifty seed set bulbs were treated in the same manner for twelve hours and fourteen adult thrips were driven from the onions. In no instance were immature thrips collected. It is important to know that the first nymphs found on onions in the spring always occurred at least one week after the first adults were observed.

The first adults on onions during the spring of 1953 were observed on the 11th of May. This date was nearly a week earlier than the date on which they were found in 1952. In both years they were found on set onions, planted on relatively dry and well drained soil. The first nymphs were found on May 21, ten days after the first adults.

Beginning on the first of June, bi-weekly counts were taken throughout the summer to determine the trend of the thrips populations. These counts were taken on fields that were under no insecticidal treatment but were in close proximity and on similar soil conditions to those onions which were used for chemical control experiments. As explained earlier, at each bi-weekly count, ten onions from each of four plots constituted a sample. In Table 12, the results of each bi-weekly observation are presented as the average number of thrips per plant throughout the season.

Table 12. Population Trends of the Onion Thrips on Spanish Onions, Recorded at Bi-weekly Intervals. 1953.

Date of Observation	Ave. No. of Thrips/Plant
June 1	3
June 15	7
July 1	15
July 15	36
July 31	79
Aug. 14	85
Sept. 1	174
Sept. 15*	88
Sept. 30*	73
Nov. 7*	3**

*Taken from volunteer plants.

**All adults

The data presented in Table 12 indicate that a steady increase in the thrips population takes place during the summer season on Spanish onions until the first of September. A noticeable drop then occurs and a steady decline is evident. The decline in numbers during September is without doubt due to decrease in temperature and lack of onions.

It is evident that the thrips reach their highest reproductive capacity during the middle of August. This is indicated by the rapid increase inpopulation, the peak of which was reached on the first of September. This peak population in September is the result of oviposition of the previous generation about the middle of August.

In order to evaluate properly the reproduction potentials and seasonal trends, it is necessary to observe the data for the whole season. From June 1st to September 1st there was a steady increase in the population. There is no evidence to indicate that there was a change in the reproductive potential of thrips at any time during the summer. If such a phenomena had taken place one would expect the population levels to show sudden and uneven changes in the progression of the population. From all available evidence, the thrips populations tend to increase gradually and evenly throughout the season until climatic conditions in the fall prohibit the normal activities of the thrips.

It is interesting to note that on November 7, long after the first frost, an average of three thrips per plant was taken from a group of volunteer plants in a garden. It so happened that every thrips taken was an adult and if this information is correlated with information presented earlier about overwintering forms, it becomes evident that the adult stage is the most common, if not the only form that overwinters.

Life History Studies

The techniques used for the investigation of life cycles and habits of thrips were quite different from those used for population studies. These observations were made on individual plants in cages to protect them from natural infestation. Under these conditions, the thrips were observed and their habits and life cycles determined. Individual leaves were also removed from the plants and placed in water so that length of various stages could be determined.

The cages used for these observations were wooden frame structures covered on three sides with fine cheesecloth. The top and one side were solid wood, which could be removed for inspection. This cage measured $1\frac{1}{2}$ feet in height and was 10" x 10" in its horizontal plane.

On May 12th four of these cages were erected in the author's garden, several hundred yards from the nearest field of onions. In each of these cages was planted a thrips-free, vigorously growing, Spanish onion which was to serve as a nursery for thrips to be introduced when available. On May 18th adults were obtained from set onions and in two of the cages, two thrips each were placed on the onion plant. In the other two cages were placed six and eight thrips respectively. The reason for varying the number of thrips introduced into each cage was to facilitate the observation of life cycles at different times during the season. Those plants with six or eight thrips would facilitate the observation of oviposition and nymphal study during the early part of the season by way of producing more offspring. Those cages with only two adults would facilitate study later in the season by keeping the number of individuals low and preventing the overproduction of offspring and premature death of the plants.

During the early part of these investigations observations for oviposition and presence of nymphs were made daily. On the 20th of May the first oviposition scars were observed and a leaf showing two of these scars was taken into the laboratory in order to determine the length of the egg stage. These results, correlated with the observations on other individual leaves and observations on growing plants, showed that the length of the egg stage varied from a minimum of 5 days to a maximum of 8 days. These figures were derived from six samples which showed an average of 6.5 days for the egg stage during the early part of the season. In July, similar samples were taken and based on 8 samples, the egg stage had an average of 5.0 days.

Nymphs. The nymphal stage was studied in two parts. The first phase consisted of the period from emergence to the time that the nymphs entered the quiescent stage. The second phase consisted of the period of quiescence in which the thrips transform to adults.

Determination of the first nymphal period was made primarily from thrips on the two caged plants, each of which had been originally infested with two adult thrips. It was found that the other cages had too many adults and that nymphs were emerging from eggs too rapidly to be observed without confusion. Leaves within which eggs had been deposited, were observed under laboratory conditions. When the eggs hatched the nymphs were observed and periodically transferred to new leaves until they entered the quiescent period. Twelve nymphs were observed on both caged plants and leaves taken to the laboratory. The whole nymphal stage varied from a minimum of 10 days to a maximum of 18 days with an average of 14.5 days for 12 nymphs.

Quiescent Nymphs. The quiescent stage in the life cycle of the thrips is designated as that period of time after the active feeding of the nymph and before the active adult emerges. In all true sense of the word, it is not a pupa but a period of quiescence, characterized by the development of wing pads which none of the nymphs possess.

Of the three phases of the life cycle studied, the quiescent stage of the nymph was by far the easiest to handle. Mature nymphs were taken from the plants and placed in a jar with onion leaves. This jar was observed daily and when the quiescent stage had formed they were taken out of the jar, placed on a piece of black cloth in a petri dish and replaced into the cages. As the nymphs transformed to adults they would leave the petri dishes and records were taken of their absence. A total of 14 quiescent nymphs was observed. Of these, two transformed in six days, the others in five days, to the adult stage. Thus, an average of 5.1 days was established for the duration of this period.

Adults.

In order to determine the length of adult life, it was necessary to prepare a cage into which fresh bits of onion leaves could be introduced daily. The cage devised was simply a half-pint milk bottle covered with three thicknesses of fine cheese-cloth. Into this bottle were introduced the quiescent nymphs of the onion thrips and the food daily or every other day. This cage was kept under cover, away from the sun but was otherwise exposed to temperature changes.

Six individuals were used for this test and it was observed that a mimimum of 11 days and a maximum of 32 days were obtained for the adult life duration. An average of 26.4 days was obtained for the six individuals.

Comparable life history studies were determined for thrips during the month of July. Using the same type of equipment and the same methods as those used for the studies during the latter part of May and most of June, it is possible to compare the results with the only variable being the seasonal change. Table 13 lists the averages, maximum and minimum duration for all stages in the life cycle of the onion thrips, for the first 2 generations.

Table 13. Comparison of Seasonal Change on the Developmental Periods Required for the Various Phases in the Life Cycle of the Onion Thrips. 1953.

Generation	Egg Stage			Active Nymphal Stage			Quiescent Period			Adult Stage			Ave. Life Cycle
	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	
May - June	5	8	6.5	10	18	15.5	5	6	5.1	11	32	26.4	27.1
July	3	7	5	9	14	11	4.5	6	5	17	36	28.5	21.0
												Ave.	24.0

Number of Generations Per Year

To establish the exact number of generations of onion thrips as they occur in the field is almost impossible. Since the egg laying period of adults is said to extend over periods of as long as twenty days, it is obvious that overlapping generations are initiated from the very start of the thrips life cycle in the spring. An attempt to follow generation studies in such a maze of individuals in the field becomes even more bewildering by the migration habits of adults. Adults are capable of moving from plant to plant especially when disturbed, as they do even when observations are made or data taken.

Early in the season the thought of generation studies in the field was abandoned. Efforts were then directed toward observation of the prepared cages, especially those in which the infestations were initiated with only two adults. Upon continual observation it was discovered that the first generation had been started with the egg deposition on the 20th of May. The first nymph was discovered on the 26th of May, and from that time on, observation was limited to searching for the first adult. On June 17th, 28 days after the first eggs had been deposited, two adults were observed in the chits of the onion plant.

After the 17th of June adults began to appear more regularly and by the 25th of June there were six adults present in the cage. Allowing for a preoviposition period of 3 or 4 days it was apparent that a second generation would begin about the 20th of June. This supposition was correct and by the 28th of June there were 50 to 60 nymphs on the onion plant together with numerous adults. Continued observation indicated an increase of adults on the 14th and 15th of July. This increase in adults was interpreted as the end of the second generation.

At this time it was evident that the individual generations were rapidly beginning to overlap. This overlapping was primarily due to the long periods of oviposition for the first and second generations. In the following generations the adults and nymphs were completely intermingled. The only change in the character of the thrips population during the period of the third generation was the increase in numbers of all stages of development.

It was no longer possible to determine separate generations on these plants so continued study of generations was abandoned with the hope of the ability to estimate the remaining generations for the season.

The knowledge of the first two generations was complete. This information is presented in Table 14. It must not be forgotten that a period of 3 to 4 days is necessary for the preoviposition period. This period accounts for the variation obtained between the information presented in Table 13, which did not take into consideration this period, and the information presented in Table 14.

Table 14. The Duration of Two Generations of Onion Thrips Which Commenced on the 20th of May. 1953.

	Duration of 1st Generation		Duration of 2nd Generation	
	Eggs	Adult	Eggs	Adult
	May 20 -	June 17	June 19 -	July 14
No. of Days	28		27	

Upon the reinspection of Table 13 it is evident that the average duration of the life cycle for May-June is approximately 25 days. If this figure is accepted as the average duration for one complete generation of the onion thrips throughout the summer period, it is possible to estimate the number of generations per season. By adding 25 days for each generation to two complete generations that were observed and presented in Table 14, a reliable estimate should be obtained.

The only flaw in this method of generation estimation lies primarily in the variation of duration, of a generation which may occur in late summer and early autumn. The important questions one must ask are: When does the duration of a generation begin to lengthen and when does reproduction cease? The only information pertaining to this topic is presented in Table 12. In this table it is obvious that the peak population occurred about the first of September, with rapid decreases thereafter. This fact alone indicates that reproduction and continued activity have persisted up to the first of September and that the high populations at that time were indicative of the peak of the last vigorously reproducing generation.

In the author's estimation, it is safe to assume that the end of the last important generation of thrips takes place during the first or second week of September. This assumption is based on the fact that a sudden drop in the nymphal population takes place sometime after the first of September is indicated in Table 12. This sudden drop in the nymphal population recorded for September 15 indicates that the final major cycle was past when the last of the nymphs, of those counted on September 1st, had transformed into adults. The sudden drop of the nymphal population recorded on September 15 also indicates a previous drop in oviposition.

In order to present the estimated generation periods as they occur throughout the summer, Table 15 has been constructed. It is estimated, that at least four generations of thrips which may be destructive to onions, occur in the Connecticut Valley. There is no doubt that some of the generations start earlier and some end later than those indicated in Table 15, but during the summer of 1953 it appeared that the generations most destructive to the onion crops occurred at the designated periods.

Table 15. Thrips Generations As They Occur in the Connecticut Valley of Massachusetts. 1953.

No. of Generation	Period of Generation
1	May 20 - June 17
2	June 17 - July 14
3	July 14 - Aug. 10
4	Aug. 10 - Sept. 7

The four generations proposed in Table 15 may be considered as the number of important generations of the onion thrips, as they occur on onions in Massachusetts. These periods have been deduced largely from information obtained under conditions subnormal to the onion thrips, in that, infestations from which this information was taken were artificially initiated. It is obvious, however, that reproduction could have started somewhat earlier in natural infestations and that overlapping of consequent generations takes place. Under such circumstances, an early beginning of reproduction could and usually would, mean that five or six generations of onion thrips could exist on late onions or other plants during the growing season.

The information presented in this study, however, was based on infestations presumably started later than those that might have started in the field. The majority of generations occurring naturally, took place at approximately the same time that the artificial generation was initiated in the cages. These facts are brought out in population studies which indicated that the presence of overwintering adults in onion fields, reaches a high point during the last of May and first of June. As a result, the progeny of this peak obtained in early population records, will constitute the bulk of the forthcoming seasonal population, and in effect will constitute the proposed generations of the onion thrips presented in Table 15.

Life Cycle and Habits

In order to bring together the information obtained in the biological studies of the onion thrips, a brief summary will be presented.

The overwintering adult thrips are usually found on onions during the middle and latter part of May, depending largely upon the climatic conditions of the season. Once on the onions, the adults feed by chewing and tearing the epidermis of the leaves, and then sucking up the juices of cells that have been broken. This type of feeding is truly a rasping-sucking method of obtaining nutrients and is very injurious when large numbers of thrips are present.

The feeding of the thrips is accompanied by oviposition. The female, equipped with a saw-like ovipositor, seeks out the tender tissues of the growing leaves and cuts tiny slits in the outer surface. In each slit she deposits a single egg, entirely hidden from view except for a very tiny end of each egg which stands out because of its pearly white color and very shiny appearance. The development of the egg progresses very rapidly and one or two days after oviposition the exposed end of the egg commences to show signs of the reddish eyes which are quite distinct. The eggs average 0.25 mm. in length and 0.125 mm. in width. They are typically elliptical and curved and somewhat bean-shaped. The duration of the egg stage averages approximately 6.5 days during the first generation and 5 days during the second generation.

The young thrips emerge from the egg and begin to feed immediately, sucking the juices of the plant in the same manner as the adults. They feed continuously for 11 to 15 days with at least 2 molts and then enter a quiescent stage in which no feeding takes place.

This quiescent period has repeatedly been referred to as the "pupal" stage. However, the transformation from the nymph to adult is gradual with similar appearance of the nymph to the adult except for the lack of wings. It is not, therefore, a holometabolous insect and the quiescent stage can hardly be called a "pupa," although apparently this term was used quite extensively in studies on the order Thysanoptera.

There are at least two molts during the quiescent period in each of which the wing pads become progressively larger. The final molt produces the adult with its wings fully formed. The whole of the quiescent period has an average duration of approximately 5.0 days.

The life cycle, from the time of oviposition to the appearance of the adult, has been found to average 27.5 days, for the months of May, June and July, in the Connecticut Valley of

Massachusetts. Based on the assumption that the following generations have approximately the same duration, and information obtained on population studies, it appears that there are four major generations per season, with the possibility of five, depending largely on climatic conditions.

With the advent of cool weather during the latter part of September and October, the thrips' activity and reproduction are greatly reduced. Thrips on onion plants seek shelter during this cold weather and can be found deep in the leaf sheaths in a semi-active condition. The majority of the population in the cooler months tend to be adults. As winter approaches, these insects hibernate deep in leaf sheaths of onions and in debris which they can find in the fields. Here they spend the winter and apparently mortality of adults is very low in regard to climatic conditions, as indicated by debris examination.

In the spring the thrips generally are slow in emerging. They do not migrate actively to onion fields until the middle of May. However, once they are found in the onions, reproduction occurs at a rapid pace and infestation of the forthcoming crop is on its way.

CONTROL OF THE ONION THRIPS

REVIEW OF LITERATURE

"White-blast" of onions was described as the result of thrips injury by Thaxter in 1889, and not as a fungous disease as had been believed earlier. A kerosene emulsion was recommended as a remedy for the pest on onions.

Heavy infestations of thrips on onions in Colorado led to investigations of control measures. Gillette (1893) reported that the most successful remedy consisted of applying kerosene emulsion under pressure to the plants. He recommended that the axils of the leaves should be thoroughly wetted and applications applied early in the morning or in the evening at which time the thrips congregated and were least active.

A thorough study of the onion thrips was made by Osborn and Mally (1895) in Iowa where thrips had seriously endangered the future of onion culture. Their primary recommendation for the control of this pest consisted of a kerosene emulsion spray applied when thrips began to become numerous and again four to five days after to destroy newly emerged individuals. They also indicated that some benefit might be obtained by cleaning up and burning all onion tops and refuse as soon as the crop was harvested. In the case of a localized infestation, it was recommended that the center of infestation should be destroyed by pulling and burning all infested plants in order to prevent further spread of the thrips.

Lintner in 1896, indicated that severe damage by thrips on onions could be prevented, if, at first detection of thrips, the plants were sprayed thoroughly with fresh pyrethrum in water. Pyrethrum used at the rate of one ounce to two gallons of water was found to be sufficient. Lintner, in the same paper, indicated that spraying with a kerosene emulsion would also be effective.

The first extensive study of several insecticides for use against the onion thrips was carried out by Quaintance in 1898 in Florida. Thrips were successfully controlled by the use of whale oil soap (Anchor Brand), at the rate of one pound of soap to four gallons of water, and kerosene emulsion. "Rose Leaf Insecticide," a concentrate of tobacco extracts, was also found to be effective when used at the rate of one pint to four gallons of water. Directions for spraying emphasized the need for thorough coverage of the plant as well as the soil where pupae were known to hide.

Many of the investigators on onion thrips recommended general precautions and remedies to combat this onion pest. Pettit (1905), Smith (1908), Chittenden (1907), Slinderland, Herrick and Crosby (1910) and Sanborn (1912), all indicated that kerosene emulsion, whale oil soap, tobacco extracts, and drenching with water, were useful in preventing serious infestations.

In 1913 Lovett recommended the use of "Black Leaf 40," a 40 per cent solution of nicotine sulfate, for use against onion thrips in Oregon. The concentrate was to be diluted with water at the rate of 1:1600. Other practices for control of onion thrips included the use of a 7 per cent kerosene emulsion and the use of whale oil soap at four pounds per hundred gallons of water.

Tests carried out in Connecticut by Britton and Walden (1914) indicated that there was no apparent difference between those onions sprayed for thrips and those unsprayed. Test plots were treated with "Black Leaf 40," with and without soap at the rate of 1:768 and 1:950 respectively, Scalecide 1:50, and lime sulfur at the rate of 1.5:50 of water with a paste spreader.

Further tests by Fernald and Bourne (1914) in Massachusetts indicated that whale oil soap, kerosene emulsion and tobacco extracts plus whale oil soap were of little value in fields of large acreage as those found in the Connecticut Valley. The manner in which onions were grown prevented the entrance of equipment into the field because of damage to plants at a time when thrips damage was most serious. The cooperative practice of clean culture and burning-over of grass around onion fields indicated promising results after several season's trials.

In 1916, Sayre obtained control of onion thrips with nicotine sulfate applied with a high pressure mist nozzle. Two or three applications of 5 ounces of nicotine sulfate, and 4 pounds of whale oil soap in 50 gallons of water were necessary. Kinsey (1917), Watson (1917), Smith (1917) and Chittenden (1919) also reported nicotine sulfate and whale oil soap mixtures to be valuable against the onion thrips. Chittenden also indicated that clean methods of farming, growing seed onions distant from set onions, crop rotation and proper fertilization all contribute to better control of the onion thrips.

The use of nicotine sulfate dust for the control of onion thrips on onions was highly successful in California. Campbell (1921) indicated that a 2 per cent dust gave 87 to 97 per cent control in the first trials. Dust machinery drawn by ponies or burros far out-maneuvered cumbersome spray machinery for thrips control. In Virginia, Geise, Zimmerly and Spencer (1922) found that two heavy applications of 3 per cent nicotine dust controlled <u>Thrips tabaci</u> successfully.

Experiments carried out by Horsfall and Fenton (1922) in Iowa, indicated that spraying, even though successful against the onion thrips early in the season, was not necessarily successful later in the season during drought periods. Their experiences showed that "Black Leaf 40" used at the rate of 4.5 ounces plus 4 bars of laundry soap in 50 gallons of water gave excellent control of the thrips only in the early season. The explanation of this phenomenon given by the authors is based primarily on climatic conditions. They maintain that drought conditions favor thrips reproduction to such an extent that the thrips which survive the spray operations are capable of reinfestation and reproduction especially when there are large numbers of eggs and pupae which are not reached by the spray. Horsfall and Fenton, therefore maintain that spraying may be only one of the many methods which, when combined, could save crops in epidemic years. They place emphasis upon preventive measures such as keeping set onions away from seed onions, destruction by burning of all crop debris after harvest and burning over all grass areas around onion fields in the fall or spring.

The use of nicotine dusts for onion thrips continued in experimental studies largely because of its greater ease of application. Russel and Morrison (1923), working with nicotine dusts in Wisconsin, found that 87 to 90 per cent control was obtained with 5 to 10 per cent formulations. However, Headlee and Rudolfs (1923) found that a 1.5 per cent dust of free nicotine gave unsatisfactory results against the onion thrips.

In 1924, Pettit indicated that either nicotine dust or nicotine spray was the most successful treatment available at that time for onion thrips control. However, he hoped that a sweetened arsenical spray would be developed so that a prolonged residual action would be possible and thus kill more of the newly hatched nymphs and newly emerged adults which escaped the nicotine applications.

Extensive research was carried on by Bourne (1926), of the comparison of dusts and sprays for the control of onion thrips. He came to the conclusion that from both the standpoint of cost and effectiveness dusts did not give satisfactory control. On the other hand, nicotine sulfate used at the rate of 1:1500 with Good's No. 3 Potash Fish Oil Soap added at the rate of 3 to 4 pounds pef 50 gallons of water gave the best control. A second spray, seven to eight days after the first was found advisable for control of emerging larvae and adults.

In Bermuda similar results were obtained with the use of dusts and sprays. Ogilvie (1927) reported that a severe attack of Thrips tabaci Lind. was successfully arrested by two applications of nicotine spray used at the rate of 1/2 pint of 40 per cent nicotine with 2 pounds of soap in 50 gallons of water. In comparison, no control was obtained with nicotine dust.

Similar successful control of the onion thrips with nicotine and soap was reported by Vinson (1929) and Pearson (1930). In Texas, Clark (1929) also indicated that onion thrips was not satisfactorily controlled with nicotine dusts.

Continued investigation of the thrips problem in Massachusetts by Bourne (1929) brought out the fact that nicotine combined with a fish oil soap gave superior control of thrips. The development of a self-propelled power sprayer capable of spraying 6 rows was demonstrated and exhibited excellent promise in control of the onion thrips. In 1932, Bourne obtained continued success with the use of nicotine-soap combinations for thrips control.

Extensive studies were carried out by Maughan (1932) in which comparisons of insecticides for thrips control were made. His results showed that nicotine dusts and sprays were most effective and that kerosene emulsions, pyrethrum, naphthalene and copper sprays gave high control, and some acted as repellents. In 1933, Maughan found that crude naphthalene applied directly to the rows at the rate of 300 pounds per acre gave effective control. He found that small particles lodged in the leaves when applied in this manner. The material apparently was more toxic and repellent to larvae than to adults and three applications at eight-day intervals gave satisfactory results.

New methods of insecticide application were developed in California during the early 1930's. Preliminary work reported on by Herbert (1933), indicated that airplane spraying of onion thrips would give better control than any other method.

Preliminary results of a new insecticide were reported on by Breakey in 1934. Halowax, a chlorinated naphthalene, acted as a contact insecticide and when compared against other insecticides used for thrips control, appeared very satisfactory. It was as effective as nicotine sulfate used at the rate of 1:800 or pyrethrum used at the rate of 1:600. One hundred per cent kill was obtained in the laboratory.

In 1934, Maughan found that control of thrips on onions was obtained by using a mixture of crude chipped naphthalene with hydrated lime and talc at the rate of 200 pounds per acre. Five applications were necessary. The following year Turner (1935) reported that no control of thrips was obtained on onion plots dusted with a mixture of 40 pounds crude chipped napthalene and 60 pounds of lime. This mixture was applied three times to set onions and four times to seed onions.

Pepper (1937), working on the control of wireworms and onion thrips in New Jersey, found that naphthalene and paradichlorobenzene carried in carbon disulfide appeared to be promising insecticides. Carbon disulfide-naphthalene and carbon-disulfide-

PDB emulsions were found to be more effective than the nicotine-soap solutions.

Based on one season's work by Turner and Walker (1938), it appeared that a suspension of pure, ground cube root with a suitable spreader protected onions from thrips injury better than did nicotine sulfate solution. The cube was used at the rate of one pound per 25 gallons of water and best results were obtained if spraying was started before the onion plants became heavily infested. Once heavily infested it was difficult or impossible to decrease the infestation satisfactorily.

In 1939, Nelson and Weigel, working on the control of the gladiolus thrips found that a combination of tartar emetic and sugar gave good control of the thrips. Upon this paper were based a host of other works dealing with control of the onion thrips by the use of tartar emetic. The first research work in which tartar emetic was used for onion thrips was reported on by Anderson and Walker in 1940. They indicated that 2 pounds of tartar emetic and 8 pounds of brown sugar in 50 gallons of water gave excellent control of the thrips in the greenhouse, but less effective control in the field.

Other workers, who found tartar emetic plus sugar more effective than older sprays included Eichman (1940, 1942), Wilson (1941), and Watkins and Ewart (1941). In New York, Ewart, Watkins and Ashdown (1944), reported after five years of testing that tartar emetic was superior to other controls used for onion thrips control. The materials gave best results when used at the rate of 2 pounds of tartar emetic with 4 pounds of brown sugar per 100 gallons of spray. The spray was applied at the rate of 125 gallons per acre with a pressure of 150 pounds per square inch.

In India, Rahman and Batra (1944) found that 3 per cent nicotine sulfate dusts were not as effective as nicotine sulfate and soap sprays.

The new synthetic organic insecticides came into use against Thrips tabaci Lind. in 1944. Smith (1944) found that DDT was less effective than tartar emetic plus sugar, against the onion thrips. Lange (1944), in California found that a spray containing 0.13 per cent DDT was far superior to all old recommended insecticides against onion thrips. Chapman, Fife and McGarr (1945), using DDT for thrips, found that a 5 per cent DDT pyrophyllite dust gave significant reductions in thrips damage. The degree of reduction increased as the application of the dust was increased from 9 to 27 pounds per acre. In Massachusetts, Bourne (1945) found that dinitro-o-cyclohexylphenol reduced infestations of thrips by 97.5 per cent. 3 per cent DDT dust reduced them by 44 per cent, and sprays of nicotine sulfate and DDT reduced thrips by 97 per cent and 91.4 per cent respectively. DDT used as a dust was not as effective as its spray form. All applications in these tests were made with hand equipment.

Extensive investigations on thrips control were carried out in California in conjunction with new insecticides. It was found by Lange (1946) that DDT oil emulsions gave better results than those obtained with wettable powders. It was also indicated that DDT dust combined with sulfur rather than inert ingredients was superior in its action. Borden (1946) was able to show that most combinations of DDT sprays were very effective, especially if spreaders or stickers were incorporated into the spray. He also came to the conclusion that the use of a 5 per cent dust was superior to the 3 per cent preparation.

In Ohio, Sleesman (1946) working on onions which were located in muck lands summarized his work by saying that DDT gave more outstanding performance against onion thrips than any other insecticide of the previous 15 years. In comparing wettable powders, emulsions and dusts, he found that equally good thrips control and yields were obtained with all three formulations.

Peay and Sorenson (1946) found that the yield of onion seed was tremendously increased by treating the flowers for thrips. Flower heads treated with a 10 per cent DDT dust increased yields from 92 pounds per acre for the untreated, to 236 and 300 pounds per acre for the treated.

Investigation on DDT and other new organic synthetics continued as rapidly as insecticides were released. Workers such as O'Kane (1947), Chapman, Richmond and Fife (1947), Hoerner and Edmundson (1947) and Sun, Rawlins and Norton (1948) all found that DDT as well as other insecticides such as benzene hexachloride, gave highly significant yields and thrips reduction over untreated onions. In the New York muck lands, Ashdown and Watkins (1948), after considerable testing, stated that the best thrips control program for that area was a 5 per cent DDT dust applied at 35 pounds per acre. The first application should be made when there are 5 to 6 thrips per plant and a second application 5 to 6 days later. They also indicated that BHC was as effective as DDT and that airplane application was as effective as ground application for thrips control.

Wilcox and Howland (1948) made investigations on thrips control in California. Their results indicated that a 10 per cent DDT dust applied at 30 pounds per acre gave excellent control. Recommendations emphasized that the first treatment should take place when onions were 10 inches high and every 2 weeks thereafter.

Wilcox, Howland and Campbell (1949), found that DDT dusts and sprays were effective in controlling thrips in flower heads of onions grown for seed. The cost for treating was not prohibitive in relation to the increase in yield. In the same year Elmore (1949) also found that 10 per cent DDT dust increased seed yields on onions grown for seed. He indicated that thrips damaged the buds and flower pedicels by their rasping sucking method of feeding. There was apparently no injury to pollinating insects from the DDT for there was no reduction in seed production due to the lack of pollination.

Douglass and Shirck (1949) investigated the thrips problem on onions in Idaho and ran extensive tests of many insecticides. The onion thrips definitely limited onion culture in Idaho and insecticidal treatments were necessary. Outstanding increases in yield were obtained with a spray containing DDT and nicotine sulfate. The above combination was superior to nicotine sulfate, DDT, or tartar emetic alone. Promising results were obtained with benzene hexachloride, chlordane, chlorinated camphene, and a mixture of DDT and hexaethyl tetraphosphate. The methoxy analog of DDT was relatively ineffective.

In California Wilcox and Howland (1950) determined that the addition of sulfur to DDT dust did not provide control of onion thrips that was statistically significant. They reported that there was a slight increase in control under certain conditions and believed that it was directly associated with the temperature. The higher the temperature, the more effective the sulfur-DDT mixture.

Low volume spray experiments for the control of onion thrips in Texas were conducted by Mayeaux and Wene (1950). Comparisons of low volume sprays applied by both ground and air equipment were found to be just as effective as dusts. Effective control of thrips was also obtained when the low volume sprays were applied during windy weather with ground sprayers. Effective control of thrips with low volume application was obtained with DDT, toxaphene, heptachlor, aldrin, dieldrin, chlordane, methoxychlor and gamma benzene-hexachloride.

Wilcox and Howland (1950) working with new insecticides in California came to the conclusion that most of them were effective against the onion thrips. Their results indicated that dusts containing 20 per cent of toxaphene, 2 per cent of parathion, 2.5 per cent of aldrin, 10 per cent of chlordane and 2 per cent of lindane may be more effective than a 10 per cent DDT dust. Both methoxychlor and TDE at 10 per cent were less effective than 10 per cent DDT.

Sloan and Rawlins (1951) conducted experiments in New York in order to find an insecticide which would be more effective against onion thrips than was DDT. In 1949 experiments, they found that dieldrin and heptachlor dusts maintained 50 per cent thrips reduction 10 days after treatment, while DDT, aldrin and parathion rapidly lost their effectiveness 2 days after treatment. In 1950 experiments conducted with emulsions, wettable powders and dusts all indicated that dieldrin and heptachlor were superior to any of the other insecticides tested. In one small plot experiment, aldrin appeared significantly better than DDT, parathion and an unknown test material.

Another investigation dealing with newer insecticides and their relative effectiveness against onion thrips was carried out by Merril (1952). He found that the most effective of the materials tested as a 1½ per cent dieldrin dust. This material is credited with having a lasting residual action combined with a high toxicity to thrips. Other insecticides which gave significantly better control than 5 per cent DDT were 5 per cent chlordane, 1 per cent lindane, 1 per cent parathion, 2½ per cent aldrin, and 1 per cent EPN-300.

In Texas, Richardson and Wene (1952) worked with both dusts and sprays for the control of onion thrips. They found that 5 per cent heptachlor, 2.5 per cent dieldrin, 20 per cent toxaphene and 2.5 per cent aldrin all gave good control Applied as high volume sprays heptachlor, dieldrin, aldrin, toxaphene and DDT all gave effective thrips control. In the following year Richardson (1953) found that 5 per cent heptachlor and 1.5 per cent dieldrin dusts were the most effective chlorinated hydrocarbons tested in Texas. Two-and-one-half per cent aldrin, 20 per cent toxaphene and 1 per cent lindane plus 5 per cent DDT gave good commercial control. Malathion, metacide, EPN and parathion all gave good initial control of onion thrips. Sulfur used as a diluent apparently was of no advantage in combinations with other insecticides. Seven-day intervals between spray applications was considered to be the most satisfactory.

INVESTIGATIONS ON ONION THRIPS CONTROL IN 1951 AND 1952

The onion thrips, *Thrips tabaci* Lind. is as outstanding a pest on onions in the Connecticut Valley as it is in other onion producing areas. The damage that this insect produces is characterized by a silvering of the foliage. The silvering is the result of feeding by great numbers of thrips, which, with rasping-sucking mouthparts tear away epidermis of the leaf and suck the juices out of the cells. These injured areas give the foliage the characteristic appearance which is typical of thrips injury.

The most serious damage caused by thrips is the indirect effect upon the onions. This damage is the premature ripening of the onions, which causes a low yield. Heavy infestations of thrips tend to weaken the plants and during hot, dry weather when photosynthesis should be at a maximum the onions ripen prematurely and fail to develop fully. This type of injury coupled with the direct effects of lowered photosynthetic output, incriminates the onion thrips as a dangerous invader.

Plates VIII, XVII and XVIII show the typical appearance of foliage which has been infested with onion thrips. Plate IX shows the appearance of normal foliage which is relatively free of thrips injury.

The ravage of the onion thrips was one of the factors influencing the change from seed onion culture to set onion culture in the Connecticut Valley. Seed onions as explained earlier, do not normally mature until the middle and latter part of August. This late maturity allows the peak of the thrips population in the latter part of July to damage growing onions very severely, thus reducing the necessary growth period for seed onions. Set onions, on the other hand, mature during the middle of July, just about the time that the onion thrips population would be most injurious and thus escape the most destructive period of the thrips population. The change to set onion culture in the Connecticut Valley would probably not have been as rapid, if an economical control method for thrips had been available at the time.

In the search for newer crops, many growers have taken a fancy to the "sweet Spanish" onion within the past three or four years. These onions, although grown from transplants, like seed onions require a long growing season. In this area, harvest of Spanish onions takes place during the latter part of August and the first part of September, depending largely on the climatic conditions. The late maturity of these onions also makes them susceptible to the heavy attack of onion thrips. It was obvious from the start that some attempt to control the thrips populations was to be necessary if successful crops of Spanish onions were to be obtained. The immediate necessity to control thrips in the Connecticut Valley had a direct bearing upon the origin of this research.

The majority of investigations concerning thrips control was carried out on seed and Spanish onions because they are the onions which are most severely injured by thrips. Both of these varieties require a long growing season and thus make excellent hosts for the thrips during the late summer season. Some farmers trying to return to the production of seed onions and others interested in developing the sweet Spanish variety, proved to be very valuable cooperators in the experiments for the control of thrips.

The objective of the following experiments was to try to develop sound methods of chemical control for the onion thrips. These methods of control were equally as dependent upon insecticides and chemicals as they were on the types of machinery with which the chemicals could be applied. It was necessary to take into consideration the types of available equipment, primarily because the onion farmer is very hesitant to buy expensive machinery. The majority of these onion farmers are either small acreage farmers or ones who distribute their efforts between a number of crops. Perhaps the most prevalent type of insecticide dispersing equipment to be found in the Connecticut Valley is the tractor-powered potato sprayer. Other types of equipment include weed control sprayers which are mounted on small riding or walking tractors and a number of hand operated pieces of equipment which still may be seen in use today.

The practical control of onion thrips in the Connecticut Valley did not mean merely development of the proper type of spray equipment. Prior to this step it became necessary because of the number of new insecticides which were "thrown" at the farmer, to evaluate the insecticides against the thrips. As noted in the Literature Review, many insecticides have been recommended for onion thrips control from year to year, under many types of climatic conditions.

The first step to this problem, therefore, was to evaluate the insecticides. This investigation was carried out on small plots where insecticides were applied with hand equipment, using many replicates and many tests.

Once this preliminary screening was complete, the most promising insecticides were used in commercial plantings to determine the reliability of small plot experimentation. Utilization of these promising insecticides further segregated the insecticides most suited for a particular type of application machinery. The final step consisted primarily of comparing the two or three insecticides that possessed the best control properties for onion thrips in the various types of equipment that were available for general use.

To carry out this procedure required the cooperation of many farmers and the frequent use of their equipment in order to evaluate correctly methods and chemicals which were used. In every application applied as a spray, the spreader Triton B-1956, was included to increase the wetting ability of the spray. It was used at the rate of 8 ounces per 100 gallons of spray.

Aircraft Application of Insecticides for Onion Thrips Control

During the summer of 1951 many farmers in the onion growing area of the Connecticut Valley independently obtained the services of an aviation company to spray their onions by means of a helicopter. The program was directed primarily toward the control of thrips on Spanish onions, which apparently had suffered heavy losses from the pest during the previous season.

The undertaking itself was an experimental one for previous to this program onions never before had been treated by this method in the Connecticut Valley. Recommendations from the Experiment Station at the University of Massachusetts indicated that three insecticides aldrin, dieldrin and parathion should kill thrips if the application by the above-mentioned equipment proved satisfactory.

The helicopter was furnished by the Eastern Coast Aviation Company of New Bedford, Massachusetts. It was equipped with a spray boom capable of covering 30 rows of onions with each swath. The application rate was 5 gallons per acre, dispersed 4 to 5 feet above the ground.

The program of spraying had been well on its way before the author was aware that it was taking place. It was necessary, therefore, to make observations wherever and whenever possible, since actual experimental plots had not been planned. The information which was obtained consisted primarily of checking plants in areas that had been sprayed as well as those that had not been sprayed. Counts presented in Table 16 represent the average number of thrips per plant which were obtained from 10 plants per plot.

The original plan was to have two applications of insecticide applied to all of the onions which had been included in the program. However, shortly after the second application some 3 weeks after the first had begun, the application machinery broke down and further treatment was abandoned.

The three insecticides chlordane, aldrin and parathion were applied to certain plots during the first spraying. During the second spraying only a few plots were sprayed with chlordane. No other insecticide was applied. The rates of application included chlordane at 1¼ pounds of actual per acre, parathion at 1 pound actual per acre and aldrin at 1 pound actual per acre. All three insecticides were diluted with water, the recommended pounds per acre delivered in 5 gallons of water. The results observed on the thrips populations for each of the applications are presented in Table 16.

Table 16. Results of Helicopter Application of Insecticide for the Control of Thrips on Spanish Onions. June 11, 1951.

Treatment	Lbs. of Toxicant/Acre	Ave. No. Thrips/Plant 2 Days After Treatment
Chlordane	$1\frac{1}{4}$	4
Check	--	55
Aldrin	1	25
Check	--	45
Parathion	.1	1
Check	--	20

Examination of Table 16 indicates that helicopter application of insecticides was very successful with chlordane and parathion. Aldrin, by comparison, showed only about 45 per cent control and should be considered as ineffective.

On June 26th, a second application of chlordane was made to a few plots previously treated with chlordane on the 11th of June. It was evident from counts taken two days after the application that the amount of control was far lower than for plots sprayed with chlordane after the first application.

Table 17. Results of Helicopter Application of Chlordane for Thrips Control on Spanish Onions. June 26, 1951.

Treatment	Lbs. of Toxicant/Acre	Ave. No. Thrips/Plant 2 Days After Treatment
Chlordane	$1\frac{1}{4}$	32
Check	--	60

Examination of Table 17 indicates that chlordane treatments were unsuccessful after application on June 26th. Factors concerning the discrepancy between the results obtained on June 11 and those obtained on June 26 are unknown. Sufficient experience and observations could not be made to be certain of results obtained and the efficiency of air application.

Some of the factors, however, concerning this method of insecticide application were observed during the operation. The actual spray pattern which was discharged by the helicopter appeared to be very uniform in density but was very fine and light. It was obvious upon inspection of the onions immediately after the spray application that only a very slight deposit was evident on the leaves. Whether there was any penetration into the tight leaf axils where thrips are found, was doubtful. Under these circumstances it is the author's opinion that more work with this type of machinery would be necessary before any conclusions could be made regarding the efficiency and effectiveness of such machinery in the control of onion thrips.

Hand Spraying - Small Plots

During the summers of 1952 and 1953 plots were arranged in commercial plantings for the purpose of testing the effectiveness of a large number of insecticides against onion thrips. Each plot consisted of four rows of onions, 20 feet in length. The insecticidal materials in these tests were all applied with a three-gallon, compressed air, knapsack sprayer. The pressure was maintained as close as possible to 40 pounds per square inch and one gallon of spray was applied to each plot.

The majority of tests using hand equipment were carried out on Spanish onions. These onions were particularly adapted to these investigations for several reasons. First, these onions possess a long growing season which is necessary for the development of a satisfactory thrips population, desirable for tests of this type. Second, Spanish onions are cultivated in such a fashion as to have the rows spaced far enough apart so that they are easy to work in. Third, the onions themselves are upright in growth, the leaves do not droop and intermingle with other plants, as is true with certain varieties of onions.

Most of the tests carried out in this small plot method of investigation were one-treatment trials. The plots were arranged, treated and the thrips counts were taken two days, one week, two weeks, and in some cases three weeks, after the treatment. This type of program made it possible to determine not only the immediate amounts of control but also the residual or lasting effects of the particular insecticides involved.

During the summer of 1952, a number of insecticides were tested in the manner described above. The four-row plots were arranged on a piece of Spanish onions approximately two acres in size. The commercial grower had allotted as much of the two acres as would be necessary for the planned treatments. The plots were arranged in the field in such a way that none of the four replicates of each insecticide were contiguous to each other. Checks were maintained for each replicate and concentrations of the sprays were used at the rates recommended by the manufacturer.

The population counts during the early part of the 1952 season consisted of the number of thrips per 20 plants. The twenty plants were chosen at random from each plot. The thrips counts were made in the field without uprooting the onion plants, and records were taken only of the nymphs since they constitute about 98 per cent of the population. The adults were not counted because of their great mobility and ability to migrate.

Table 18 indicates the results obtained with some of the more common insecticides during the early part of the season in 1952.

Table 18. Average Number of Thrips per 20 Plants on Hand-Sprayed Plots During the Summer of 1952.

Treatment	Lbs. Toxicant per Acre	Ave. No. Thrips/20 Plants		
		2 Days	1 Week	2 Weeks
Dieldrin	0.5	8	10	26
Chlordane	1.0	12	16	46
DDT	0.6	32	38	120
Lindane	0.2	14	95	284
Toxaphene	1.5	25	63	346
Check	---	560	468	628
LSD - 5 per cent level		66.0	34.1	79.7

The above treatments were made on July 12 and the data were taken on the 14th, 19th, 26th of July. The weather during the 2-week period was relatively dry with no appreciable precipitation.

The data were analyzed in Table 18A of the Appendix using analysis of variance. The high F value indicates that the chances are 99 to 1 that treatments are from different populations. In other words, there is a difference between some treatments. The least significant difference (LSD) of averages for counts two days after treatment indicates the chances are 19 to 1 that there is no significant difference in the thrips population among the insecticides. However, the LSD of 66 shows that all insecticides are significantly different than the checks. One week after treatment significance between some insecticides appears. Two weeks after treatment all insecticides except dieldrin and chlordane are significantly different in their effects upon the thrips populations.

Dieldrin and chlordane were outstanding in this test, giving relatively good control for two weeks after the application. The thrips population built up very rapidly on plots treated with lindane and toxaphene. After one week the population had begun to rise very rapidly, consisting almost entirely of newly hatched or very young thrips. This fact indicates that toxaphene and lindane have a short residual period and that the eggs are not affected by the materials. On the other hand, dieldrin and chlordane, possessing good control, must either have a long residual effect or they must have some lethal effects upon the eggs that have been deposited in the onion tissue.

In the latter case, the reinfestation of plants can take place only by the introduction of adults. The effects of the insecticides cannot last very long regardless of the length of the residual period, because of the new growth which is unprotected. The new and developing leaves are readily reinfested.

Another test with exactly the same procedures, but with more insecticides, commenced on the 22nd of July. In addition to those insecticides of the preceeding test, malathion, aldrin and heptachlor were used. A three week's observation was made on this set of insecticides, and as shown in Table 19, the control of thrips after two weeks was relatively poor or lacking.

Table 19. Thrips Populations per Plant, Over a Three-Week Period, in Plots Treated with Emulsion Sprays.

Treatment	Lbs. of Toxicant per Acre	No. Thrips per Plant		
		1 Week	2 Weeks	3 Weeks
Dieldrin	0.5	4.6	12.6	28.5
Chlordane	2.0	5.2	18.9	33.2
Heptachlor	0.5	10.5	24.5	38.9
Malathion	0.25	12.8	38.3	51.0
Aldrin	0.75	16.5	39.0	47.5
DDT	0.6	16.6	26.5	45.8
Lindane	0.2	21.2	48.0	58.2
Toxaphene	1.5	27.5	53.8	54.0
Check	---	58.0	66.2	60.5
LSD - 5 per cent level		2.99	2.95	3.05

The data in Table 19 show that both dieldrin and chlordane gave consistently good control during the first week after treatment.

During the second week it was apparent that new growth was present for the young thrips to develop upon and the thrips population began to increase. Three weeks after treatment with these two insecticides the populations were obviously increasing quite rapidly and it was evident that these insecticides were of little value.

The least significant difference of averages given in Table 19 was derived by the analysis of variance which is presented in Table 19A of the Appendix. Treatments in which the average number of thrips varies by more than the amount shown for the LSD, indicates that there is a 19 to 1 chance that the treatments concerned are significantly different and not due to external causes.

Heptachlor, malathion and aldrin showed little variation in their pattern of effectiveness, but DDT apparently is slightly different in its action. One week after treatment with DDT, the thrips population was decreased by approximately the same amount as with aldrin. However, by the second week after treatment, the reduction in the population of thrips by DDT appeared relatively much greater than the reduction of thrips by insecticides with which it was comparable after the first week. This fact tends to indicate that DDT possesses a longer period of residual action than some of the other insecticides used.

With such insecticides as toxaphene and lindane it is evident from Table 19 that the population of thrips began to build up rapidly one week or less after the treatment was applied. This fact indicates that the insecticidal value of the chemicals had been lost and that the thrips were free to reinfest the onion plants. Since the initial infestation of thrips was greatly reduced by the treatment, one would expect the population to be very low at the point where the insecticides lost their effectiveness. Thus, the thrips population began to increase and within a short time the infestation reached the point where damage to the plants was of importance. Because of these facts it is desirable to find an insecticide having residual effectiveness of considerable duration.

<u>Use of Dusts in the Control of Thrips</u>

Several plots of Spanish onions were used for testing the effectiveness of dusts for control of the onion thrips. All applications of the dust materials were applied with a hand rotary duster. Plots were arranged as described previously except that three, instead of four, replicates were used. Five per cent DDT, 1 per cent lindane, $2\frac{1}{2}$ per cent heptachlor, 2 per cent aldrin, 2 per cent dieldrin and 5 per cent chlordane were applied at the rate of approximately 20 pounds per acre.

The use of dusts in the Connecticut Valley has never been extensive on any vegetable crop. Most farmers apply their insecticides with water as a medium, and dusting equipment is very scarce. For this reason, the information gained by these tests would probably never be used by large-scale farmers. However, this information can be used by the home gardener or a farmer with a small plot of onions, that is of one acre or less. It would be very economical for this type of grower to use a hand duster, rather than nothing at all.

All applications of the materials were made in early morning hours in the presence of a moist surface, or on days after showers.

It was evident from the data that were taken that the dust applications were not as effective for the control of thrips as were spray programs. The initial kill was far lower than on those plots that were sprayed with the same insecticides. This fact tends to indicate that the dust materials do not penetrate as deeply into the chits of the onions as do the spray, thus leaving the congregated nymphs within the chits free to mature and reproduce. Residues of dusts are also not as lasting as sprays.

In the use of sprays the chits are far more vulnerable to penetration. Sprays applied to these areas are under pressure and if not forced into these leaf axils may flow there by gravity, especially with the presence of a spreader such as Triton B-1956. The spreader lowers the cohesion of droplets, thus allowing them to spread evenly.

Table 20. Onion Thrips Populations in Plots Treated with Dusts.

Treatment	Lbs./Acre	No. of Thrips/Plant Days After Treatment 2 Days	1 Week	2 Weeks
Dieldrin 1%	20	3.5	9.8	28.5
Heptachlor 2½%	20	8.2	18.4	33.6
Chlordane 5%	20	8.9	14.6	32.5
Aldrin 1%	20	10.3	22.5	41.0
Lindane 1%	20	8.5	31.0	47.3
DDT 5%	20	18.2	46.0	42.8
Check	--	53.2	46.0	56.0
LSD - 5 per cent level		5.99	1.63	11.1

The data in Table 20 show that the dust formulations gave an appreciable amount of control two days after treatment. Of these materials dieldrin gave the best initial reduction of thrips, with heptachlor, lindane and chlordane producing less initial decrease in the thrips population. Aldrin, DDT and lindane showed the least amount of control one and two weeks after applications of the insecticides.

Treatments in which the average number of thrips vary from one another by more than the amount indicated for the least significant difference at the 5 per cent level indicates a significant difference between the treatments. The chances are 19 to 1 in those cases that the difference is real and not of unknown origin. Least significant figures presented in Table 20 were derived by the analysis of variance presented in the Appendix in Table 20A.

All treatments indicated loss of insecticidal activity during the two weeks, with the dieldrin and heptachlor plots having the lowest population counts. The evidence indicates that the initial reduction of thrips population is very temporary and increases begin to take place a few days after the treatment. The reinfestation is rapid and may be indicative of poor insecticide penetration between the leaves where the young thrips develop after hatching from the eggs.

A treatment of this type is without doubt an effective means of reducing thrips populations but the use of this method is, of course, limited to the availability and type of dusting equipment, as well as the size of the onion plots to be treated. For instance, it may be futile to expect a farmer to treat ten acres of onions with a rotary hand duster, while the use of this type of equipment may be highly recommended for onion plots of one acre or less.

Power Sprayers for the Control of Onion Thrips

Potato Sprayer

During the summer of 1952 large plot tests for the control of onion thrips were undertaken. Four insecticides reportedly giving control of thrips were used in these tests as emulsion sprays. Dieldrin, aldrin, heptachlor and chlordane were applied to plots approximately 1/5 of an acre in size. Each plot consisted of 12 rows and treatments were made with an Iron Age sprayer. Each plot representing a different treatment, was replicated three times, and the interval between the five spray applications during the season varied between 10 and 15 days depending largely upon the rate of reinfestation after treatment.

These tests were conducted with the cooperation of a commercial farmer who was raising sweet Spanish onions. In the previous year thrips had damaged his onions so badly that the tops had dried and it was necessary to harvest the onions three to four weeks sooner than they should have been harvested.

Early in the spring of 1952 this commercial grower agreed to space his onions at planting so that a tractor-powered potato sprayer could be used to spray these onions throughout the season.

The onions were spaced so that the tractor and sprayer straddled four rows for each swath through the field. Under these conditions it was possible to use this heavy equipment in the onions without producing any damage to the crop as would be the case if the proper spacing during planting had not been carried out.

The equipment that was used in these tests was calibrated to discharge approximately 100 gallons per acre at 400 pounds pressure. At this rate it was observed that the onions were thoroughly wetted, and the pressure was great enough to drive the spray deep into the leaf axils where the immature nymphs seek protection. This high pressure also tends to spread and move the leaves about sufficiently to open the leaf axils and allow the spray to penetrate freely. The application equipment is pictured in Plate X, and shows the arrangement of the nozzles on the boom.

The tractor and sprayer are shown in Plates XI and XIX while in operation. The spray pattern and heavy discharge, factors in effective control obtained with this type of equipment, are conspicuous.

The thrips counts were taken one week after the application of each treatment, and each of the four treatments was applied on the same day. The counts were made by randomly choosing 20 plants from each plot and counting the number of thrips nymphs present on each plant, without uprooting the onions. The twenty plants were chosen along a diagonal of each plot. This method took into consideration any variation in application of the treatments, or other physical factors present which might have had influence upon the distribution of thrips in each plot. The average number of thrips per plant for each plot is recorded as the accumulated average of five counts taken one week after each of the five applications. The check plots were allowed to continue throughout the summer with no insecticidal applications. The results of this test may be observed in Table 21.

In all treatments applied with the potato sprayer on commercial plantings, the fungicide Dithane D-14 was included for the control of mildew and blast. Dithane was used at the rate of 2 quarts of Dithane D-14, plus 3/4 of a pound of zinc sulfate to every 100 gallons of spray.

Table 21. The Accumulated Average for Thrips of Five Counts Taken One Week After the Insecticidal Application of Four Insecticides. 1952.

Treatment	Lbs. of Toxicant per Acre	Ave. No. Thrips per Plant	100 Lb. Bags per Acre
Dieldrin	0.5	4.2	324
Chlordane	2.0	6.8	328
Heptachlor	1.0	12.5	306
Aldrin	0.75	13.1	295
Check	---	55.8	286
LSD - 5 per cent level		3.7	14.25

Statistical analysis of the data in Table 21 is presented in the Appendix in Table 20A. By the method of analysis of variance the least significant difference between averages of thrips per plant and number of 100 pound bags for each treatment is presented in Table 21. Any of the averages which differ by more than the amount given for the LSD are considered to be significantly different at the 5 per cent level. This fact indicates that the chances are 19 to 1 that differences are real. Dieldrin and aldrin used in these tests are apparently not significantly different from each other since the difference between the average number of thrips per plant does not exceed 3.7.

Although dieldrin appears to be more effective than chlordane in reducing the thrips population, it is evident that there is no significance in the amount of yield between the plots treated with these insecticides. Heptachlor appeared to be less effective than dieldrin and chlordane in both control of thrips and the yield produced. It is obvious that treated plots are much more productive than those not treated with insecticides. The actual yield is of course, not the only criterion by which it is necessary to evaluate the effectiveness and advantages obtained by treating onions. The condition and appearance of these onions is also a primary factor. For instance, badly infested onions not only may be dwarfed but may be malformed. As indicated by Chittenden (1919), the condition of "thick neck" onions and "scallions" are the result of thrips infestation. Plates XX and XXI indicate in color the effect produced by sprayed and unsprayed onions.

Weed Control Sprayers

Thrips control during the 1952 season was also conducted with equipment known as weed control machinery. This equipment, as explained in the maggot control section, is a low pressure, low gallonage type of sprayer. The tanks, pump and nozzle are mounted on an Allis-Chalmers model G tractor. The pump, a rotary gear type, is powered directly from the motor and is capable of delivering 80 pounds of pressure.

This equipment was used in tests for the control of thrips on set onions. The cooperating grower was willing to arrange plots for the use of four insecticides with three replicates of each insecticide. Each plot consisted of eight rows and was the result of a round trip through the field. The insecticides were applied at the rate of approximately 20 gallons per acre with one cone-type nozzle per row. The nozzles were arranged on the boom so that each nozzle was directly above the row being treated. Throughout the season it was necessary to raise the boom to keep pace with the growing onions, and at all times the nozzles were an inch or two above the tops of the onions.

Three applications of the insecticides were made during the season at 8-day intervals and counts were taken six days after the application. More treatments would have been applied, but the rapid growth and tendency for the foliage of set onions to fall over and spread out, prevented the machinery from going into the field because of damage that would occur to the onions.

The thrips counts were recorded as the number of thrips per twenty plants, per plot, and the twenty plants were chosen at random along a diagonal of each plot. The data in Table 22 are presented as the seasonal accumulated average of thrips per plant for each treatment.

Table 22. The Effectiveness of Three Insecticides for the Control of Thrips, Applied Three Times with a Weed Control Sprayer. 1952.

Treatment	Lbs. of Toxicant per Acre	Ave. No. Thrips/Plant for 3 Treatments 6 Days after Each Appln.
Dieldrin	0.5	18.5
Chlordane	2.0	24.0
DDT	0.6	33.1
Check	---	39.0
LSD - 5 per cent level		7.6

Although the thrips population was reduced during period of treatment, it is obvious that good control had not been obtained even with treatments only a week apart. Two weeks after the last insecticidal application it was apparent that the thrips popultion had reached such a level as to constitute a hazard.

Analysis of the data presented in Table 22A shows that there was no significant difference between dieldrin and chlordane applied with the weed control sprayer. However, both dieldrin and chlordane appeared significantly better than DDT.

Although the same amount of actual toxicant per acre was applied in these tests as those with high volume and pressure, the data indicate that the insecticides were not as effective. They are without doubt, not being deposited in the proper places to be fully effective. The pressure is not capable of driving the insecticide into the leaf axils where the immature forms are present in greatest numbers. It is also important to notice that one nozzle per row is not adequate to cover thoroughly the foliage of maturing plants.

INVESTIGATIONS ON ONION THRIPS CONTROL IN 1953

Following the summer of 1952, plans were developed for thrips control experiments for the summer of 1953. The problems to be solved were many and the following investigations were carried out:

1. The screening of more insecticides with small plot tests.
2. The screening of more promising insecticides for commercial use.
3. The comparison of commercial application methods for thrips control.
4. The development of a practical spray program, including the timing and the number of spray applications necessary during a season.

The cooperation obtained from various onion growers was excellent. The three that cooperated most closely were willing to arrange their fields in any manner that was necessary to obtain the information which was sought. However, from the previous year's experience, it was noted that small plot tests required a great deal of movement in and out of the onions for the spraying and counting procedures and many of the plants were knocked down and stepped on.

In order to avoid such a course of conduct with cooperators, the author decided to grow one-half an acre of onions of his own which he would treat as seen fit. This was done primarily to allow freedom of the use of insecticides, concentrations, and other factors that may not have been practical on the property of someone else.

All other standard spraying procedures were carried out on onions grown by cooperating growers.

Small Plot Tests

These tests were carried out on the author's planting of Spanish onions. During the 1952 season all materials were used in the emulsion form. It was necessary, therefore, to obtain information relating to the effectiveness of different forms of the same insecticide. Wettable powders and emulsions were compared for their effectiveness against thrips.

The procedure used in these tests was the same as that described for small plot, hand sprayed, onions during 1952. The insecticides used in these tests, in the comparisons of wettable powders versus emulsions, were DDT, lindane, heptachlor, dieldrin and chlordane. Each of the insecticide formulations was treated as separate and different insecticides and applied in a randomized block pattern. The data obtained in these tests were taken two days, one week and two weeks after the spray applications.

The onions were treated on July 15 and thrips counts were taken on July 17, 22, and 29. The results as they occurred are presented in Table 23.

Table 23. Relative Effectiveness of Wettable Powders Versus Emulsions for the Control of Onion Thrips. 1953.

Treatment	Lbs. of Toxicant per Acre	Ave. No. Thrips per Plant		
		2 Days	1 Week	2 Weeks
Dieldrin	0.5	1.4	4.7	11.6
Dieldrin W.P.	0.5	2.6	6.9	18.1
Chlordane	2.0	1.7	6.1	14.5
Chlordane W.P.	2.0	3.9	10.2	18.8
DDT	0.6	1.9	4.2	10.2
DDT W.P.	0.6	4.1	7.3	19.7
Heptachlor	0.5	2.3	6.3	17.5
Heptachlor W.P.	0.5	4.2	12.1	18.1
Lindane	0.2	2.1	8.5	22.0
Lindane W.P.	0.2	5.3	16.5	27.1
Check	---	43.0	54.5	51.0
LSD - 5 per cent level		3.15	2.30	6.19

Statistical analysis, by Analysis of Variance of the data in Table 23 is presented in the Appendix in Table 23A. The least significant difference of the averages of thrips occurring two days after treatment with insecticides indicates that only the two lindane preparations are significantly different in their effectiveness. After one week it is evident for all insecticides that the emulsion gave significantly more control than the wettable powder. After two weeks only dieldrin and DDT showed significantly more control with emulsion preparations.

The basis for the greater effectiveness of emulsions over wettable powders is not completely understood. Some of the factors influencing this phenomena can only be guessed at, at the present. It is possible that the emulsion penetrates the leaf axils of the plants more readily and therefore reaches the immature populations found there. Another supposition which appears possible is that the emulsions with their oil phase may penetrate the eggs which are imbedded in the leaf. This latter theory is perhaps a very important factor, for some of the eggs are deposited completely beneath the surface of the epidermis and others have been found that protrude slightly from the oviposition scar. With these facts in mind, it appears that any eggs protruding from the epidermis may be the only eggs affected by the emulsion sprays. Investigations to determine the exact action of some of these insecticides appear worthy for the basic information that would be obtained.

As indicated by the literature review of thrips control, several organic phosphate insecticides have appeared very promising for the control of this onion pest. As the result of this information, several tests were developed to compare the insecticides already in use with some of the more toxic phosphate insecticides. These tests were carried on in the same manner as other small plot tests, using hand spray equipment and the same procedure previously described.

The screening of insecticides by the use of small plots and hand spray equipment cannot always be the basis of recommendations for the commercial use. However, it is generally possible to predict whether an insecticide should be considered for commercial use and further tested with the type of equipment and application that is used by the commercial groups.

It is apparent then, that these small plot tests are a preliminary step towards the development of desirable recommendations for the use of insecticides on onions for the control of onion thrips.

The following test was conducted on sweet Spanish onions grown by the author, using the small plot, hand sprayed type of plot. Amounts of spray per plot and the arrangement of plots has been described previously. Table 24 presents information regarding the effectiveness of a variety of insecticides. Two types of insecticides were used in this test, the chlorinated hydrocarbons consisting of dieldrin, chlordane, heptachlor, toxaphene, DDT and lindane, and the synthetic phosphate compounds including parathion, malathion, TEPP, EPN and metacide.

Table 24. The Relative Effectiveness of Certain Insecticides in the Control of Onion Thrips Using Hand Application. 1953.

Treatment	Lbs. of Toxicant per Acre	Ave. No. of Thrips per Plant After Treatment		
		2 Days	1 Week	2 Weeks
Parathion	0.25	0	0.5	1.5
Metacide	0.20	0.1	0.8	2.3
Malathion	0.25	0.1	2.2	7.1
TEPP	0.25	0.9	3.8	5.8
Dieldrin	0.5	0.4	5.2	6.8
DDT	0.6	0.4	2.5	7.5
EPN	0.25	0.3	3.0	6.9
Chlordane	2.0	0.8	9.7	14.5
Heptachlor	0.75	0.5	11.8	18.3
Toxaphene	1.0	1.0	4.9	19.1
Lindane	0.2	0.8	12.2	26.5
Check	---	77.5	43.4	58.4
LSD - 5 per cent level		5.8	5.1	7.3

Upon the inspection of the data presented in Table 24, it is evident that the organic phosphate insecticides are very effective against onion thrips when applied with a hand sprayer. It is also evident that after two days the entire list of insecticides gave excellent control. This exceptional control can be explained by the fact that the plants were thoroughly soaked with the spray, and it is possible that many of the thrips were washed away and a large kill was obtained. The actual amount of insecticide used was comparable to usual amounts but the amount of water was doubled to get better coverage.

The data presented in Table 24 were analyzed by the method of Analysis of Variance in Table 24A in the Appendix. The least significant difference for averages of thrips two days after treatment shows that none of the treatments were significantly different from each other. One week after treatment all those averages differing by 5.1 thrips per plant indicate that a significant difference existed between those insecticides. The same significant difference exists for those insecticides two weeks after treatment that have averages of thrips differing by 7.3 thrips per plant.

Both DDT and dieldrin appeared to give control comparable to the phosphate insecticides although slightly lower in effectiveness. Toxaphene and lindane, as has been experienced previously, are able to give substantial control of thrips during the first few days after treatment but their residual value appears to be lost rapidly and the thrips populations build up noticeably during the first week. Generally, heptachlor has given somewhat better control than that indicated in this test. No explanation can be given for this observation and perhaps the following tests will either corroborate or refute the evidence present in this particular test.

Table 25 presents the information of a parallel test using somewhat fewer insecticides but identical in every other respect with the exception that thrips counts were taken two days and ten days after treatment.

Table 25. Onion Thrips Populations Two and Ten Days After Application of Several Insecticides With a Three-Gallon Garden Sprayer. 1953.

Treatment	Lbs. of Toxicant per Acre	Ave. No. Thrips per Plant	
		2 Days	10 Days
Parathion	0.25	0.2	0.4
Metacide	0.20	0.2	1.3
EPN	0.25	0.8	3.0
Dieldrin	0.5	1.4	4.7
Chlordane	2.0	1.9	6.1
Lindane	0.2	2.1	9.3
Heptachlor	0.75	5.0	11.8
Check	---	54.0	44.3
LSD - 5 per cent level		2.6	5.3

As the previous test, this one was also carried out with a double amount of water as a carrier. It is obvious that the results are comparable to those obtained in the previous test, and it is evident that the phosphate insecticides are exceptionally effective against the onion thrips, in hand sprayed plots.

Analysis of data in Table 25A show that only heptachlor is significantly different than the other insecticides in its effect against thrips two days after the treatment. Ten days after treatment those insecticides having a thrips average per plant which differed by 5.3 were significantly different from each other.

Power Application of Insecticides for Onion Thrips Control

During the summer of 1953 a number of tests were performed using powered equipment for the application of the insecticides. In order to arrange the proper number of replicates and carry out tests that would be of value, it was necessary to reduce the number of insecticides used in each test because of the lack of large plantings of onions on which to arrange large test plots. It was necessary, therefore, to choose insecticides that appeared to be most promising for the control of onion thrips.

One test utilizing a sprayer mounted on a Bollens Garden tractor was made on seed onions. The pump, a rotary gear pump, powered by the 5 H.P. motor was capable of delivering 60 pounds pressure to four nozzles. Each nozzle was centered above a row and elevated two to three inches above the tops of the plants. The nozzles delivered a cone-type spray and were the type used for weed control sprays. This equipment was calibrated to deliver 20 gallons of liquid per acre.

The plots were arranged the length of the field, each plot being represented by four rows of onions which were replicated three times. Dieldrin, chlordane and malathion were used in these tests as indicated in Table 26. Each treatment was applied four times, being limited to this number by the growth of the tops, which prevented the entrance of the equipment into the field after July 6th.

Thrips counts were taken one week after the application of each treatment and three weeks after the final application. In making thrips counts ten plants were taken as samples at random from each plot and the number of thrips recorded. Table 26 indicates the accumulated average of thrips per plant from counts taken one week after each of the four insecticidal applications.

Table 26. The Effectiveness of Insecticides Applied with a Low Volume, Low Pressure Type of Equipment on Seed Onions. 1953.

Treatment	Lbs. of Toxicant per Acre	Accum. Ave. of Thrips per Plant One Week After Application	No. of Thrips 3 Weeks After Last Appln. July 27
Dieldrin	0.5	8.6	38.4
Malathion	0.25	14.9	36.2
Chlordane	2.0	17.2	41.4
Check	---	27.5	40.1
LSD - 5 per cent level		4.2	

Analysis of Variance of the data in Table 26 presented in Table 26A of the Appendix, indicates that the chances are 99 to 1 that all treatments are not of the same effectiveness. The LSD indicates that the dieldrin treatment is significantly better than any of the others and that there is no significant difference in the effectiveness of malathion and chlordane, applied in the manner described.

The evaluation of low pressure, low volume equipment for the control of onion thrips is not difficult. Obviously, this method of control is not particularly suited to give the amount of control necessary in the culture of onions. It is apparent that this type of equipment is neither capable of applying insecticides in such a manner as to give good control of thrips nor is it adaptable to applying insecticides throughout the growing season. The period 3 to 4 weeks before harvest is of most concern to onion growers for it is during this time that the thrips populations build up to dangerous levels, and affect the proper growth and "heading" of seed onions. It is imperative, therefore, to use equipment capable of applying insecticides effectively throughout the growing season of the onions.

A similar type of low pressure, low volume spraying equipment mounted on an Allis Chalmers model G tractor, described under the 1952 experiments for control of thrips on set onions, proved to be a failure in experiments for the control of thrips on Spanish onions in 1953. The plots were all arranged during the planting season of 1953 for use of this sprayer, but before the thrips population had built up to a point where spraying was warranted, the onion foliage was too tall for the passage of this tractor through the field without considerable damage to the tops. This test was abandoned, therefore, and the use of low volume sprayers for thrips control on Spanish onions appears to be an impossibility.

The use of potato sprayers for the control of thrips on onions has proven to be a versatile piece of equipment in both its capability of applying insecticides and its continued use throughout the growing season. The following data (Table 27) were taken from experiments during 1953 in which the most promising insecticides for the control of thrips were used. Methods of application and of plot arrangement were the same as those described for the 1952 experiments with this tractor-powered, 8-row potato sprayer.

Table 27. The Effectiveness of Insecticides Applied with a Potato Sprayer, With Thrips Counts Taken One Week After Each Treatment, to Obtain an Accumulated Average of Thrips per Plant.

Treatment 5 Applications	Actual Toxicant per Acre	Seasonal Accumulated Average of Thrips per Plant
Parathion	0.25	2.1
Dieldrin	0.50	3.6
Malathion	0.25	3.9
Chlordane	2.0	6.8
Check	---	44.0
LSD - 5 per cent level		1.8

The data presented in Table 27 indicate that excellent control of thrips was obtained on sweet Spanish onions with the insecticides parathion, dieldrin and malathion. Chlordane was slightly less effective than the above materials but also gave very good control over the 5-treatment period.

Analysis shows the above data indicate that all treatments were significantly different from each other except dieldrin and malathion. In the case of these two insecticides, no significant difference was observed.

The use of the potato sprayer for the control of thrips in onions is without doubt the most effective equipment that has been employed in these tests. Its ability to discharge high volumes of liquid under high pressure appears to be a necessity in the control of this pest. The thorough coverage obtained with this method of insecticide application was without doubt a major influencing factor of the exceptional control which was obtained. The most important factor governing the possibility of either obtaining control or not obtaining control lies in the habits of the thrips themselves. Their habit of seeking shelter deep within the axils of the leaves makes it necessary to use equipment which will discharge spray materials in such a fashion as to reach the inner axils and destroy the developing thrips in their place of shelter. Only the potato sprayer possesses the necessary requirements for this job.

Timing Sprays for Thrips Control

The experiments up to this point have been directed towards two objectives. The first, towards determining the most effective insecticides for the control of onion thrips. These tests consisted primarily of screening many insecticides for their effectiveness against thrips by employing the use of small plots and hand applied insecticides. This manner of testing permitted the examination of large numbers of insecticides on relatively small plantings of onions, and with a minimum expenditure of time and materials.

The second phase of experiments was designed to compare the insecticides that appeared most promising for the control of onion thrips in commercial plantings and applied with commercial equipment. Under these conditions those insecticides that gave the best results in the small plot tests were applied to large plots with equipment such as potato sprayers, tractor mounted sprayers and garden tractor sprayer. Tests of this kind provided information relating to the effectiveness of insecticides in commercial use. They would determine which insecticide should be recommended to growers for the control of onion thrips.

All of this preliminary work leads to the necessity of determining when and how many sprays should be applied during the growing season to control effectively the onion thrips population. The two primary questions which concern the farmer are: (1) When should he start spraying, and (2) How often should he spray? The two following experiments attempt to answer these questions with respect to potato spraying equipment used in these tests.

In the two tests that follow, dieldrin was the insecticide chosen to determine the proper interval between sprays and the time that the first spray should be applied. In order to determine when the first spray should be applied, it was necessary to set up plots, on which the first spray was delayed according to the development of the onion thrips.

The first plot was sprayed on May 12, a time when the Spanish onions were well developed but no or very few thrips were present on the onions. The second plot was first sprayed on the third of June, at which time there was an average of three thrips per plant. The third plot was first sprayed on the 17th of June, at which time there was an average of ten thrips per plant. Each of the above plots was replicated three times and repeated applications were applied to each block approximately ten days apart. Thrips counts were taken one week after each spray application. There were five applications on each of the three blocks, all applied under conditions as those described for potato sprayer on page 51.

Table 28 indicates the effect that the timing of the first spray has on the average thrips population throughout the season when all other conditions are equal.

Table 28. Onion Thrips Population per Plant on Plots with Varied Timing of the First Spray and Succeeding Applications Made at Approximately 10-Day Intervals Using Dieldrin. 1953.

Date First Spray	Lbs. Toxicant per Acre	Interval Between Sprays Days	Ave. Thrips per Plant at First Spray	Accum. Ave. for Season Taken 1 Week After Appln.	100 Lb. Bags per Acre
May 12	0.5	10	0+	3.3	338
June 3	0.5	10	3	4.0	341
June 15	0.5	10	10	9.7	329
Unsprayed	---	--	--	78.6	308
LSD				5.3	

Analysis of data in Table 28 indicates that there is no significant difference between the average thrips populations of plants which had commenced to be sprayed on May 12, June 3 and June 15.

The data in Table 28 indicate that there is no apparent advantage in spraying onions before the thrips appear in the field, as long as they are sprayed before there is an average of more than 9 thrips per plant. It is obvious from Table 28 that if the spray program is not started until the middle of

June, less effective control would be obtained. The basis for these facts lies in the reproductive capacity of the onion thrips. Once the thrips population has reached an average of ten thrips per plant it is obvious that there is a tremendous reproductive capacity that has already been in motion. That is to say, those females already present by the middle of June have each deposited a great number of eggs beneath the epidermis of the onion leaves. Even though a spray is now applied to these onions, it will be impossible to kill all those that are present as nymphs and those as eggs protected by the epidermis of leaf. This reservoir of individuals will forever be present throughout the season and a relatively high thrips index will be obtained for a seasonal accumulated average per plant.

On the other hand, if the first spray is applied prior to the peak of the oviposition period, as was the case of the spray applied June 3 in Table 28, it is possible by continued spray applications at 10-day intervals to keep the seasonal average of thrips at a very low and insignificant number. Therefore, it is the author's opinion that the first spray for a thrips control program should be applied before the thrips population reaches an average of 9 thrips per plant. Generally, this situation is present in the first two weeks of June.

In order to determine the proper interval of time that should lapse between spray applications, a test was devised in which certain plots were sprayed at 7, 10, and 14-day periods. Each of these plots was replicated three times and dieldrin was used at the rate of 0.5 pounds per acre as a standard in all of the tests. The first spray was applied June 5th by the potato sprayer method, as previously described. Thrips counts were taken one week after each application of insecticide. The thrips populations were averaged for each interval of application and presented in Table 29 as the seasonal accumulated average of thrips per plant taken one week after each treatment.

Table 29. Average Number of Thrips per Plant, Taken One Week After Treatment on Plots Sprayed at Seven, Ten and Fourteen-Day Intervals.

Interval Between Sprays	Lbs. of Toxicant per Acre	Accum. Ave. of Thrips per Plant 1 Week After Treatment	100 Lb. Bags per Acre
7 Days	0.5	2.3	332
10 Days	0.5	5.7	330
14 Days	0.5	12.7	311
Untreated	---	69.6	303
LSD - 5 per cent level		6.1	

The evidence presented in Table 29 indicates that there would be no advantage to spray for thrips every seven days. Analysis shows no significant difference in the average number of thrips per plant for the 7-day and 10-day programs, and therefore would not warrant the extra effort needed to apply the insecticides. However, the significant increase in the thrips population for those plots sprayed every 14 days indicates that this interval is somewhat long and allows the production of an increasing thrips population. It is also at this point that the yield of onions appears to take a substantial drop. The drop in yield for those plots sprayed every 14 days is approximately 20, one hundred pound bags per acre. This figure represents an amount which might easily determine whether a grower could afford to grow onions or not by considering his total profit per acre.

In order to answer the two questions which were brought forth at the beginning of this section, i.e., when should the first spray be applied and how often should the spray be applied - it is necessary to observe both Table 28 and 29. In Table 28 it was observed that the latest possible date that the first spray should be applied was during the period when the thrips population was no greater than 9 nymphs per plant. This figure was based not only on the results obtained from Table 28, but from life history studies which indicated that this period was the beginning of intensive oviposition by the adult thrips. In terms of dates, it is estimated that the first spray should be applied near the first of June.

The second question may be answered by observation of the data presented in Table 29. Here it is evident that a 10-day interval is the maximum amount of time that could safely elapse between sprays.

In summing up these experiments it may be stated that the first spray should be applied about the first of June and continued at 10-day intervals throughout the growing season. It should be pointed out that these figures have been determined for dieldrin only, and that other insecticides which give relatively good control are not necessarily of comparable effectiveness. One cannot say that these specifications using other insecticides, would be as effective against the onion thrips as is dieldrin. Malathion, parathion and chlordane have properties which lead me to believe that they could be used effectively under these conditions, but data supporting this supposition are not available.

RESISTANCE OF ONIONS TO THRIPS ATTACK

LITERATURE REVIEW

The subject of onion plant resistance to thrips attack has been the topic of many research investigations. The prime purpose of these studies has been to find a variety of onions which, by virtue of their resistance, could be cultivated without the occurrence and injury of thrips which threaten the present varieties of commercial onions. As stated by Jones, Bailey and Emsweller (1935), the thrips presents a difficult problem because of its large number of hosts, parthenogenetic characteristics, overlapping generations, lack of natural enemies, adaptability to a wide range of climate and manner of living in a protected micro-environment.

Plant resistance to insect injury is accomplished by a variety of methods. McColloch (1924) recognized six factors by which onions are resistant to thrips.

1. habit of growth
2. morphological characters of the plant
3. physiological characters of the plant
4. mechanical factors
5. ability to recover from injury
6. external or environmental factors

Any one of these six types of resistance could lead to plant immunity from insect attack.

Wardle, Simpson and MacGill (1927) indicated that the onion thrips preferred the lower side of cotton leaves. Their investigations showed that this preference was exhibited primarily because of the difference in the thickness of the epidermal layer. The epidermal layer of the lower leaf surface was thinner and much more succulent than the upper surface. The upper surface therefore, could be termed more resistant than the lower surface because of morphological factors.

In the case of onions, MacLeod (1933) and Jones, Bailey and Emsweller (1934), were able to demonstrate very conclusively that thrips showed a definite preference for one variety of onions over another. The basis for such a preference, or resistance, in some varities was based primarily on the growth pattern of the plants. Those plants that showed resistance to thrips invariably possessed an open type of foliage growth pattern. The support for this resistance in onions was based upon the morphological characters involved. The absence of contiguous leaves prevented the formation of a hiding place or micro-environment, which is present in those varieties of onions which show susceptibility to onion thrips. Other factors or characters of the onion plants showing resistance have been determined.

Jones *et al.* (1935), have indicated that thick leaf tissue, circular leaves, and maturing habits all have been correlated with resistance of onions to thrips injury. Sleesman (1943), after extensive variety study indicated that the varieties of onions most susceptible to thrips injury were those onions of greatest economic importance in the United States.

INVESTIGATIONS ON ONION RESISTANCE TO THRIPS

Observations of resistance of eight varieties of onions were made in the Connecticut Valley in 1953. Five varieties of seed onions, two varieties of sets and one variety of Spanish onions were used in these experiments. The plots were arranged side-by-side and four counts of the thrips were taken on the onions at bi-weekly intervals, the first of which was taken on June 4. The number of thrips from ten plants was taken from each plot at each bi-weekly count. The data presented in Table 30 represent the average number of thrips per plant for each variety.

Table 30. Relative Resistance of Eight Varieties of Onions to Thrips Attack.

Onion Variety	Type of Onion	Seasonal Average Number of Thrips per Plant
Ebenezer	Sets	8
Yellow Globe	Sets	10
Asgrow Y41	Seed	12
Hybrid No. 7	Seed	15
Brigham Yellow Globe	Seed	15
Autumn Glory	Seed	21
Early Yellow Globe	Seed	22
Sweet Spanish (Valencia)	Transplants	24

Inspection of Table 30 indicates that the set onions were the most resistant and Spanish onions most susceptible to thrips attack. Seed onions were apparently intermediate in these investigations, with the variety Asgrow Y41 more resistant than others with which it was compared.

Probably the fact that set onions matured three to four weeks earlier than the other varieties influenced the results obtained. Earliness in maturity of the set onions provided a means of escape from the heaviest populations of thrips. Nevertheless, this is a true means of resistance and if factors regarding seasonal variations are important, they should be noted.

In contrast, those onions which did not mature early were subject to the full attack of the onion thrips. The sweet Spanish variety in particular was subject to late seasonal infestations and therefore falls in the category of highly susceptible to attack.

It may be interesting to note that the results obtained in these experiments are not in accord with the results obtained by Maughan and MacLeod (1936) and Beaumont, Snell, Doran and Bourne (1935). The data that both groups of workers obtained indicated that the sweet Spanish onions were highly resistant to thrips attack in comparison with the variety Ebenezer. Whether climatic conditions, methods of investigation or differences in the varieties had any effect upon the results obtained is not known.

ECONOMY OF CONTROL MEASURES

The cost of insecticide application for the control of onion thrips and onion maggot must be considered independently of each other with regard to various insecticides and methods of application. The cost for the control of onion maggot must be considered for both seed treatment and for spraying, with the various insecticides which gave effective control. For the control of thrips it is necessary to consider the costs of spraying. The insecticides here considered will be only those that have shown effective control of the respective pest. The cost of equipment will not be considered in this study because it is assumed that most farmers already have the equipment with which to apply the insecticides. In all cases prices of insecticides are based upon those of the Eastern States Farmers' Exchange.

Onion Maggot

The first method of insecticide application to be considered in the study of onion maggot control is the dry seed treatment for seed sets. In this method, no application machinery is necessary as the insecticide is mixed directly with the seed and sown at the time of planting. As indicated in Table 4, DDT and dieldrin gave the most exceptional control and will here be considered as to their relative costs. There were five formulations which gave very effective control. These five formulations listed in descending order of effectiveness and the costs per acre are presented.

Table 31. Costs of Seed Treatment of Maggot with Various Insecticides.

Insecticide	Lbs./Acre	Cost/Acre
5% DDT	25.0	$ 1.37
10% DDT	12.5	0.96
1% Dieldrin	12.5	3.10
1% Dieldrin	25.0	6.20
10% DDT	25.0	1.92

This method of insecticide application is exceptionally economical when viewed from the standpoint of the expense in applying the insecticide. There is practically no expense involved. The only necessary labor is to mix the seed and insecticide at the time of planting. The total amount as compared with actual sowing is negligible and can therefore be eliminated from the total expense. Therefore, it is found that "Dry Seed Treatment" method costs are very low and effective control at about $2.00 per acre could be obtained with the use of 10 per cent DDT.

In comparison, spraying with high pressure machinery involves much more labor and the cost of insecticides is somewhat increased. In order to obtain effective control of onion maggot, a minimum of 4 spray applications is necessary. DDT, dieldrin and chlordane gave considerable control with 4 applications and the following information presents the cost of insecticides in such a program.

Table 32. Costs of Spraying with Dieldrin, DDT and Chlordane.

	Pounds per Acre	4 Applications Cost/Acre
Dieldrin	0.5	$ 12.40
DDT	0.6	2.21
Chlordane	1.0	4.28

Addition of about $2.00 per acre for labor and cost of running equipment would be necessary in determining total cost.

Inspection of the cost of controlling onion maggot by seed treatment and spray treatments indicates that the seed treatment is by far the most economical method both with respect to amount of control obtained and to cost. Dieldrin at the rate of $12.40 per acre is a much more significant expenditure than $1.92 for DDT per acre per season.

There is, however, one advantage to the spray method. If a disease such as mildew should happen to break out, addition of a fungicide to the spray could easily be made and the crop could be saved. No such application can be made by way of seed treatment.

<u>Onion Thrips</u>

Spraying is the only method by which thrips can economically and effectively be controlled in the Connecticut Valley. The spray may be applied by several different types of equipment but the amount of insecticide and labor involved is the same in all cases. The information, therefore, that is presented will take into consideration only the cost of the insecticide per acre per season. The estimated labor cost of $2.00 per acre per treatment of operating machinery may be added to the cost of material to obtain a total.

Of a long list of insecticides tested for their effectiveness against onion thrips, the following have shown effective control: dieldrin, chlordane, parathion, DDT, malathion and heptachlor. The cost of treating for thrips with each of these materials is given as a total for the season using both 5 and 7 applications.

Table 32. Cost of Insecticidal Materials for 5 and 7 Applications of Spray for Thrips Control.

		Cost/Acre - Material	
	Lbs./Acre	5 Appln.	7 Appln.
Dieldrin	0.5	$ 15.50	$ 21.70
Chlordane	1.0	5.35	7.50
Parathion	0.25	2.00	2.80
DDT	0.60	2.65	5.70
Malathion	0.25	3.75	5.25

With respect to cost and the amount of control obtained with these various insecticides, it appears that chlordane, parathion or malathion could be used for effective and economical control of thrips on onions. Parathion should not be used unless the consumer is equipped to observe and practice all the necessary precautions in handling this very toxic material. Although dieldrin appears to give the best control of thrips, its cost may prove to be a prohibitive factor in large-scale use.

SECTION III. OBSERVATIONS ON SOME DISEASES OF ONIONS FOUND IN THE CONNECTICUT VALLEY

Onions, just as most other plants, are subject to a number of destructive fungi. The presence of downy mildew, white rot, and smut was noted in the Connecticut Valley during the three years that research was conducted on onion insects. Of the three diseases the first two, downy mildew caused by the pathogen *Peronospera destructor* Berk. and white rot, caused by the pathogen *Sclerotium cepivorum* Berk., were observed to cause considerable loss during the 1953 season. The third, smut, caused by the pathogen *Urocystis cepulae* Frost was detected as affecting only a few plants in a single plot of seed onions.

Downy Mildew

The infection by *Peronospera destructor* Berk. was detected early during the 1953 season on seedlings of Spanish onions which had been imported as transplants from a distributor in Georgia. Other transplants from Texas showed no infection with downy mildew. Shortly after the transplants had been planted, characteristic pale lesions began to appear on the leaves of the onions. Eventually, these lesions became chlorotic and infected areas died, which caused many leaves to bend over and droop.

As a measure against this disease, Dithane D-14 was incorporated with every application of insecticide. The fungicide was applied at the recommended rate of 3/4 pound of zinc sulphate and 2 quarts of Dithane D-14 per 100 gallons of water. This formulation was added also to all treatments for thrips control on those plants obtained from a Texas distributor, which throughout the summer did not show symptoms of mildew whether treated or untreated.

Experiments carried out on one plot heavily infested with mildew indicated that Dithane D-14 definitely was effective against the disease. Seven applications of insecticide plus Dithane were made to certain plots, while four applications were made to others. Applications were made with a tractor-drawn potato sprayer as described under "Thrips Control." Treatments were applied every ten days. On July 26 counts of infected plants were taken to determine the effect of the fungicide treatments. One hundred plants selected at random from each plot were inspected for the presence of mildew lesions. The following table presents data obtained on the control of onion mildew.

Table 34. Average Mildew Infestation on July 26, 1953
After 4 and 7 Treatments with Dithane D-14.

Treatment	Dosage per 100 Gallons	Per Cent Infection Applications 4	7
Dithane D-14 plus Zinc sulphate 36%	2 qts.)) 3/4 lb.)	54	32
Check		87	

Since infection of the onions had taken place before fungicidal applications were made, it is obvious that treated plots could not be expected to be free of lesions at the time counts were taken. Therefore, as indicated in Table 34, Dithane treatments were effective against the mildew. Seven treatments appear to have been more effective than four treatments, as a 22 per cent increase of infection was noted for the four treatments over the seven treatment infection. In comparison to treated plots, the untreated plots were severely damaged by the mildew, 87 per cent of the plants having been infected.

Observation of the above experiments has led the author to believe that if treatment of onions with Dithane takes place before the inoculum is established, complete or nearly complete control of mildew can be obtained. Since the data that have been obtained are not conclusive regarding the effectiveness of Dithane for mildew control on onions, it is obvious that no definite conclusions can be drawn. If, however, the continued culture of Spanish onions is to take place in the Connecticut Valley, growers should be aware of the hazards involved with importation of transplants and should be ready to cope with problems which arise.

White Rot

An infection of white rot, caused by the pathogen *Sclerotium cepivorum* Berk., was detected during the summer of 1953 on a plot of seed sets. The particular plot of seed sets was under treatment and experiment for the control of onion maggot, *Hylemya antiqua* Meig., when the infection was observed.

The plot had taken on a typical maggot infested appearance during the middle of June. That is, the tops of the onions began to turn yellow and die back toward the stem. Others had completely wilted and collapsed, giving the field a yellow-brown color instead of the deep green indicative of healthy seed sets. Upon inspection of the bulbs and the anticipation of finding a heavy maggot infestation, it was discovered that the onions were heavily covered with a fine mycelium and the roots were decayed. Two such onions are pictured in Plate XV. In addition, some of the bulbs were covered with a layer of bead-like sclerotia, each about the size of the head of a pin. About 30 per cent of the crop was destroyed.

It was obvious that the onion maggot had nothing to do with the condition of the onions. Identification of fungus indicated that the pathogen responsible for the unhealthy appearance of the seed sets was *Sclerotium cepivorum* Berk., a fungus injurious to onions, shallot and garlic. The above-ground symptoms described earlier are identical for both onion maggot and white rot damage.

As the summer progressed, a field of set onions which appeared unhealthy was brought to the attention of the author. Upon inspection, it was noticed that the yellowish appearance and dying of the tips of the leaves was confined to a definite number of rows, which were uniform in their appearance. Closer examination revealed the presence of sclerotia and mycelium, both characteristic of white rot on the bulbs. It was obvious that bulbs infected with *Sclerotium cepivorum* had been planted only in the rows showing the symptoms.

Further investigation relating to the history of the infected bulbs revealed the fact that they were purchased from the owner of set onions which were so heavily infected with white rot, reported previously. It was also learned that the bulbs from which the infected set onions had been grown had come, the previous year, from the same piece of land upon which highly infected seed sets were being grown.

It was apparent that an infection had started and was spreading by means of infected bulbs. The situation appeared rather unique since the disease had not been reported from this area previously. As late as 1948, Tims (1948) recorded white rot from Oregon, Virginia, Kentucky and Louisiana. No reports have been made of the disease from northeastern United States.

Whether or not this pest will persist in this area is yet to be seen. Reports by Booer (1945) and Walker (1926) indicate that the fungus requires a cool climate and relatively dry soil (40-60 per cent water holding capacity). These conditions regularly are found in the Connecticut Valley growing region and it appears that the disease could readily become established in this area.

An effective control for the white rot disease has not yet been found. In Louisiana, Tims (1948) reported that liming of the soil to bring the pH up to about 7.0 reduced the disease but did not give complete control. Booer (1945) investigated the disease in England and found that 1 pound of 4 per cent mercurous chloride dust per 25 yards of row, applied with the seed, increased crops significantly. Such a procedure, however, is economically unsatisfactory. The only alternative as far as control is concerned, is to rotate crops so that onions, or other species of the genus Allium are not planted in infested soil for several years. It is also recommended that onion bulbs grown on infested soils should be destroyed and not planted, especially in soil never having been infected. Such a procedure would tend to spread the pathogen to uninfected soil.

Smut

Onion smut has not been a problem in the Connecticut Valley since the advent of the newer organic fungicides. Arasan, 50 per cent tetramethyl thiuram disulphide, used at the rate of 1/4 to 1/8 pound per pound of seed has given excellent control of smut, and the disease has become almost non-existent.

During the three years of work in the field, the author was able to find a single field of seed onions showing signs of smut infestation. This particular field was sown with seed treated with Arasan at the rate of 1/12 pound of Arasan per pound of seed. Even at this low rate of fungicide application, smut infected plants were rare. Less than one per cent of the plants showed symptoms of smut.

With such exceptional control it is doubtful that smut, once a very dreaded disease, will ever again become an important disease to the onion industry. Two onion seedlings infected with the smut pathogen, *Urocystis cepulae* Frost are pictured in Plate XVI.

CONCLUSION

Experiments and observations concerning onion pests in the Connecticut Valley were carried on in onion growing areas adjacent to Amherst, Massachusetts. Biology and control of both the oninn thrips and onion maggot, as well as observations on certain diseases affecting onions, were studied. The principal conclusions of these studies were:

1. Onion thrips pass the winter as adults and enter onion fields during the second and third weeks of May. Four generations were found to develop on commercial onions.

2. Onions grown from transplants (Spanish type) should be sprayed for thrips at ten-day intervals. Applications should begin when thrips populations average nine thrips per plant.

3. Dieldrin, parathion, malathion and chlordane were all found to be very effective against the onion thrips. Most effective results were obtained when insecticides were applied with high pressure sprayers such as potato sprayers.

4. The onion maggot passes the winter in the pupal stage in refuse piles and discarded onions. Adults begin to emerge during the first week of May, or when dandelions are in full bloom. Two complete generations occur in this area.

5. Seed onions and "Seed Sets" should be treated for

onion maggot control. DDT or dieldrin dust mixed with seed during planting gave excellent control.

6. Cost studies indicated that sprays of parathion, malathion and chlordane were more economical than dieldrin for thrips control. DDT dust for maggot control was more economical than dieldrin dust.

7. The fungicide, Dithane, gave good control of downy mildew of onions. White rot of onions was identified from the Connecticut Valley, and no positive control of the organism has yet been proposed.

SUMMARY

This presentation includes both biological studies and control investigations of the onion maggot, *Hylemya antiqua* Meigen and the onion thrips, *Thrips tabaci* Lindeman, as well as observations on certain onion diseases. The text is divided into three sections corresponding to the above three topics.

The investigations on the biology of both the onion thrips and the onion maggot made it possible to observe the habits of these pests in regard to the application of control measures. It was determined that the onion thrips passes the winter as an adult in debris around fields, where it finds protection, as well as on stored onions. It was also found that thrips enter the onion fields during the second and third weeks of May and become abundant about the middle of June. Four principal generations were observed to infest commercial onions, while as many as five or six are possible on late maturing varieties or other vegetation.

The onion maggot was observed to overwinter in the pupal stage, especially abundant in onion refuse piles and onions discarded on fields. Adults of the onion maggot emerged from overwintering puparia during the first week of May and continued

for approximately three weeks. Two distinct generations of the onion maggot were observed, with indications of a partial third. Egg deposition of the first generation was more readily observed than that of the second generation in which case the eggs were deposited deeply in crevices near the onion plants.

Control measures for the onion thrips were based upon observations of the biological studies, especially population studies. It was determined that there was no apparent advantage to start spray applications before an average of nine thrips per plant existed. Applications at ten-day intervals were found most effective. Insecticides most effective for control of the onion thrips were parathion used at the rate of 0.25 pounds per acre, dieldrin at the rate of 0.5 pounds per acre and malathion at 0.25 pounds per acre. Chlordane as well as Metacide and EPN-300 were insecticides which also gave outstanding results. In all cases, high pressure applications using a potato sprayer proved the most effective method.

The control of the onion maggot presented a somewhat different problem than did thrips. This insect produces damage to onions below the surface of the soil, thus necessitating the application of insecticides below the soil for larvae or above the soil level for adults and eggs. In order to kill larvae, insecticides were mixed with seed before planting. Larvae were killed as they crawled through the soil to attack the seedlings. The two most outstanding insecticides for this type of control were DDT and dieldrin. Ten per cent DDT dust used at the rate of 0.5 pounds per pound of seed and one per cent dieldrin used at the rate of 0.5 pounds per pound of seed both gave excellent control of the onion maggot.

In order to obtain control of onion maggot stages above ground, a spray was used which would kill adults migrating to onion fields for the purpose of oviposition. A potato sprayer delivering 100 gallons per acre at a pressure of 400 pounds gave good control of maggot with the use of dieldrin at 0.5 pounds per acre.

Studies of costs indicated that parathion, malathion and chlordane were more economical for use against thrips than was dieldrin. For onion maggot control, seed treatment was much more economical and more effective than spraying, and DDT was more economical than dieldrin.

Studies on the control of diseases of onions indicated that Dithane, D-14 plus zinc sulphate gave substantial control of downy mildew. Smut no longer exists as a primary disease in the Connecticut Valley. Arasan used at the rate of 1/8 to 1/5 pounds per pound of seed gives effective control. The disease, white rot of onions, has been identified from infected fields. This disease has never been previously reported from this area and if it continues to spread, may become a very serious factor in onion production. No positive control of the organism causing this disease has been proposed.

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A P P E N D I X

The method of Analysis of Variance used in these analyses was taken from Livermore (1952). His presentation in "Laboratory Exercises in Statistical Analysis" provided a simplified pattern of approach.

The determination of the Least Significant Difference between Means (LSD) was also patterned after Livermore (1952). The formula and symbols for determining the least significant difference are as follows:

$$LSD = t_{.05} \sqrt{2MSr/n}$$

where;

$t_{.05}$, is equal to the value of 't' found in the t-table of Snedecor (1950) at the 5 per cent level, for the number of degrees of freedom (D.f.) of the Error, in the Analysis of Variance of the particular problem.

MSr, is equal to the Mean Square of the Error

and n, is equal to the number of replicates.

Table 2A. Analysis of the Effectiveness of Insecticides Applied with a Potato Sprayer for the Control of Onion Maggot.

Insecticide		Inches Destroyed/50 Feet of Row				
		Blocks				
		1	2	3	4	Sums
Dieldrin		8.4	12.0	4.8	15.6	40.8
DDT		9.9	10.8	14.4	14.4	49.5
Chlordane		9.6	18.0	6.0	20.4	54.0
Heptachlor		15.6	16.8	12.7	16.8	61.9
Aldrin		24.7	14.2	19.1	17.4	75.4
Parathion		16.8	26.4	19.2	18.0	80.4
Check		37.2	27.6	21.6	31.2	117.6
	Sums	122.2	125.8	97.8	133.8	479.6
	SX^2	9674.9				
	C	8175.0				

Analysis of Variance

Source of Variation	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	27	1499.9				
Treatments	6	1026.0	171	9.24	2.66	4.01
Blocks	3	141.0	47	2.54	3.16	5.09
Error	18	333.0	18.5			

LSD = 6.3

Table 3A. Analysis of the Effect of Pelleted Seed for the Control of Onion Maggot.

Insecticide	Lbs. per Lb. of Seed	Inches Destroyed per 50 Ft. of Row — Blocks 1	2	3	4	Sums
1% Heptachlor	0.5	14.4	30.0	16.8	18.0	79.2
5% DDT	0.5	18.0	13.2	26.4	6.0	63.6
10% DDT	0.5	1.2	1.2	0	2.4	4.8
1% Dieldrin	0.5	1.2	0	2.4	1.2	4.8
Check		36.0	30.0	24.0	60.0	150.0
	Sums	70.8	74.4	69.6	87.6	302.4
	SX^2	9332.0				
	C	4572.0				

Analysis of Variance

Source of Variation	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	19	4760				
Treatments	4	3639	909.7	10.03	3.26	5.41
Blocks	3	32	10.7	0.11	3.49	5.95
Error	12	1089	90.7			

LSD = 14.6

Table 4A. Analysis of the Effectiveness of Dry Seed Treatments Against Maggot Damage.

Insecticide	Lbs. per Lb. of Seed	Inches Destroyed/50 Ft. of Row Blocks 1	2	3	4	Sums
1% Aldrin	0.25	24.3	22.4	25.2	21.2	93.1
1% Heptachlor	0.25	21.0	22.7	24.0	23.0	90.7
Calomel	0.25	23.0	22.1	18.0	24.6	87.7
5% Chlordane	0.125	18.1	22.8	19.2	19.5	79.6
1% Heptachlor	0.50	10.6	16.5	15.6	14.9	57.6
5% DDT	0.25	9.2	8.1	7.4	7.3	32.0
5% DDT	0.50	4.1	3.2	2.4	3.1	12.8
10% DDT	0.25	1.4	2.4	1.8	1.3	6.9
1% Dieldrin	0.25	1.3	1.2	1.6	2.0	6.1
1% Dieldrin	0.50	1.2	0.7	0.6	0.8	3.3
10% DDT	0.50	0.3	0.3	0.8	0.7	2.1
Check		34.8	36.2	30.9	32.6	134.5
	Sums	149.3	158.6	147.5	151.0	606.4
	SX^2	13494.4				
	C	7661.0				

Analysis of Variance

Source of Variance	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	47	5833.4				
Treatments	11	5735.6	521.5	186.2	2.09	2.84
Blocks	3	5.0	1.7	0.6	2.89	4.44
Error	33	93.0	2.8			

LSD = 2.4

Table 5A. Analysis of the Effect of Several Insecticides as Dry Seed Treatments for the Control of Onion Maggot in Seed Onions.

Insecticides	Lbs./Lb. Seed	Number of Infested Onions/50' of Row — Block 1	2	3	4	Sums
Dieldrin	0.50	1	2	2	1	6
DDT	0.50	2	2	4	4	12
Dieldrin	0.25	2	5	3	4	14
Heptachlor	0.50	8	7	7	6	28
Check	---	14	17	16	17	64
	Sums	27	33	32	32	124
	SX^2	1332				
	C	769				

Analysis of Variance

Source of Variation	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	19	563				
Treatments	4	545	136.20	117.30	3.26	5.41
Blocks	3	4	1.30	1.12	3.49	5.95
Error	12	14	1.26			

LSD = 1.66

Table 6A. Analysis of the Effect of Several Insecticides Applied as a Low Gallonage Spray for Control of Onion Maggot on Seed Onions.

Treatment		Number of Infested Onions/50 Ft. of Row			
		Blocks			
		1	2	3	Sums
Dieldrin		5	7	6	18
Chlordane		8	8	8	24
DDT		9	6	15	30
Malathion		12	15	12	39
Check		16	19	16	51
	Sums	50	55	57	162
	SX^2	2030.0			
	C	1749.6			

Analysis of Variance

Source of Variation	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	14	280.4				
Treatments	4	225.0	56.2	9.2	3.84	7.01
Blocks	2	6.0	3.0	0.4	4.46	8.65
Error	8	49.4	6.1			

LSD = 4.7

Table 7A. Analysis of the Effectiveness of Four Insecticides Applied with High Pressure Equipment for the Control of Maggot on Seed Onions.

Treatment	Number of Damaged Onions/50 Feet of Row			
	Blocks			
	1	2	3	Sums
Dieldrin	2	4	3	9
Chlordane	5	6	4	15
DDT	9	5	7	21
Malathion	9	7	11	27
Check	14	15	19	48
Sums	39	37	44	120
SX^2	1294			
C	960			

Analysis of Variance

Source of Variation	D.f.	Sums of Squares	Mean Squares	F	5%	1%
Total	14	334.0				
Treatments	4	300.0	75.0	20.8	3.84	7.01
Blocks	2	5.0	2.5	0.7	4.46	8.65
Error	8	29.0	3.6			

LSD = 3.57

Table 8A. Analysis of a Dust, Furrow Treatment for the Control of Onion Maggot on Set Onions.

Treatment		Number of Onions Infested/100 Ft. of Row			
		Blocks			
		1	2	3	Sums
DDT		6	7	8	21
Dieldrin		10	8	9	27
Lindane		12	12	6	30
Chlordane		10	13	10	33
Heptachlor		14	9	16	39
Check		17	14	14	45
	Sums	69	63	63	195
	SX^2	2301			
	C	2112			

Analysis of Variance

Source of Variance	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	17	189				
Treatments	5	123	24.6	3.96	3.33	5.64
Blocks	2	4	2.0	0.32	4.10	7.56
Error	10	62	6.2			

LSD = 4.7

Table 9A. Analysis of the Effectiveness of Several Insecticides Applied with Weed Killer Machinery for the Control of Maggot on Set Onions.

Treatment		Number of Infested Onions/100 Ft. of Row			
		Blocks			
		1	2	3	Sums
Dieldrin		4	5	4	13
Chlordane		6	5	6	17
DDT		6	6	6	18
Aldrin		8	7	9	24
Lindane		9	10	8	27
Heptachlor		11	11	9	31
Check		16	14	16	46
	Sums	60	58	46	176
	SX^2	1732			
	C	1475			

Analysis of Variance

Source of Variance	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	20	257.0				
Treatments	6	246.0	41.0	45.4	3.00	4.82
Blocks	2	0.4	0.2	0.22	3.88	6.93
Error	12	10.6	0.88			

LSD = 1.5

Table 10A. Analysis of Effectiveness of Several Insecticides Applied with High Pressure for the Control of Maggot on Set Onions.

Treatment		Number of Infested Onions/100 Ft. of Row Blocks 1	2	3	Sums
Dieldrin		2	1	1	4
Chlordane		2	3	4	9
DDT		4	4	3	11
Heptachlor		5	4	5	14
Check		18	20	17	55
	Sums	31	32	30	93
	SX^2	1155			
	C	577			

Analysis of Variance

Source of Variation	D.f.	Sum of Squares	Mean Square	F	5%	1%
Total	14	578.0				
Treatments	4	569.0	142.2	129.2	3.84	7.01
Blocks	2	0.4	0.2	0.18	4.46	8.65
Error	8	8.6	1.1			

LSD = 1.9

Table 18A. Analysis of the Effectiveness of Insecticides for Thrips Control Applied with a Hand Sprayer Two Days After Treatment.

Insecticide	Lbs. of Toxicant per Acre	No. of Thrips/20 Plants Blocks 1	2	3	4	Sums
Dieldrin	0.5	6	9	9	8	32
Chlordane	1.0	14	11	9	14	48
DDT	0.6	28	31	34	35	128
Lindane	0.2	15	19	11	11	56
Toxaphene	1.5	26	28	22	24	100
Check		455	477	690	518	2180
	Sums	544	575	775	610	2504
	SX^2	1,187,308.0				
	C	261,250.7				

Analysis of Variance

Source of Variation	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	23	926057.3				
Treatments	5	891861.9	178372.4	95.2	2.90	4.56
Blocks	3	5296.9	1765.6	0.91	3.29	5.42
Error	15	28899.5	1926.6			

LSD = 66.0

Table 18A (cont.). Analysis of the Effectiveness of Insecticides for Thrips Control Applied with a Hand Sprayer One Week After Treatment.

Insecticide	Lbs. of Toxicant per Acre	No. of Thrips/20 Plants Blocks 1	2	3	4	Sums
Dieldrin	0.5	12	9	11	8	40
Chlordane	1.0	17	15	14	18	64
DDT	0.6	42	30	44	36	152
Lindane	0.2	79	98	100	103	380
Toxaphene	1.5	71	60	61	60	252
Check		500	415	430	527	1872
	Sums	721	627	660	752	2760
	SX^2	944610				
	C	317400				

Analysis of Variance

Source of Variation	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	23	627210				
Treatments	5	617872	123574.4	239.9	2.90	4.56
Blocks	3	1612	537.3	1.04	3.29	5.42
Error	15	7726	515			

LSD = 34.1

Table 18A (cont.). Analysis of the Effectiveness of Insecticides for Thrips Control Applied with a Hand Sprayer One Week After Treatment.

Insecticide	Lbs. Toxicant per Acre	No. of Thrips/20 Plants Blocks 1	2	3	4	Sums
Dieldrin	0.5	21	32	25	26	104
Chlordane	1.0	43	49	40	52	184
DDT	0.6	129	121	116	114	480
Lindane	0.2	290	281	278	287	1136
Toxaphene	1.5	260	495	301	328	1384
Check		690	545	621	656	2512
	Sums	1433	1523	1381	1463	5800
	SX^2	2491680				
	C	1401666.6				

Analysis of Variance

Source of Variation	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	23	1,090,013.4				
Treatments	5	1,046,125.4	209225.0	74.4	2.90	4.56
Blocks	3	1,758.1	586.0	0.21	3.29	5.42
Error	15	42,129.8	2808.6			

LSD = 79.7

Table 19A. Analysis of the Effectiveness of Several Insecticides Applied with a Hand Sprayer for the Control of Thrips, One Week After Treatment.

Insecticide	Lbs. Toxicant per Acre	No. of Thrips/Plant Block 1	2	3	4	Sums
Dieldrin	0.5	5	4.2	4.8	4.4	18.4
Chlordane	2.0	5.3	6.1	4.4	5.0	20.8
Heptachlor	0.5	9.5	8.9	11.6	12.0	42.0
Malathion	0.25	13.4	11.6	12.7	13.5	51.2
Aldrin	0.75	17.0	16.0	14.5	18.5	66.0
DDT	0.6	16.0	15.0	17.8	17.6	66.4
Lindane	0.2	21.4	22.1	20.6	20.7	84.8
Toxaphene	1.5	29.0	25.1	26.2	29.7	110.0
Check		63.1	56.7	58.5	53.7	232.0
	Sums	179.7	167.7	171.1	175.1	683.6
	SX^2	21884.6				
	C	13363.0				

Analysis of Variance

Source of Variation	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	35	8521.6				
Treatments	8	8396.0	1049.5	218.6	2.36	3.36
Blocks	3	9.3	3.1	0.64	3.01	4.72
Error	24	116.3	4.8			

LSD = 2.99

Table 19A (cont.). Two Weeks After Treatment.

Insecticide	Lbs. Toxicant per Acre	No. Thrips/Plant Blocks 1	2	3	4	Sums
Dieldrin	0.5	12.5	13.0	12.1	12.8	50.4
Chlordane	2.0	20.1	16.5	18.6	20.4	75.6
Heptachlor	0.5	22.3	25.0	26.2	25.5	99.0
Malathion	0.25	38.0	36.4	41.0	37.8	153.2
Aldrin	0.75	40.1	35.4	42.1	38.4	156.0
DDT	0.6	27.0	28.4	25.2	25.4	106.0
Lindane	0.2	46.0	47.2	50.1	48.7	192.0
Toxaphene	1.5	52.4	55.6	49.8	57.4	215.2
Check		67.2	65.3	66.5	65.8	246.8
	Sums	325.6	322.8	331.6	332.2	1312.2
	SX^2	57704				
	C	47829				

Analysis of Variance

Source of Variance	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	35	9875				
Treatments	8	9769	1221.0	297.8	2.36	3.36
Blocks	3	7.6	2.5	0.61	3.01	4.72
Error	24	98.4				

LSD = 2.95

Table 19A (cont.). Three Weeks After Treatment

Insecticide	Lbs. Toxicant per Acre	No. of Thrips/Plant Blocks 1	2	3	4	Sums
Dieldrin	0.5	29.3	26.8	28.7	29.2	114.0
Chlordane	2.0	30.4	36.7	33.6	32.1	132.8
Heptachlor	0.5	42.4	39.7	36.5	37.0	155.6
Malathion	0.25	49.1	50.3	53.0	51.6	204.0
Aldrin	0.75	47.5	51.0	45.6	45.9	190.0
DDT	0.6	46.0	44.8	47.0	45.4	183.2
Lindane	0.2	56.4	58.6	58.5	59.3	232.8
Toxaphene	1.5	53.4	54.5	54.0	54.1	216.0
Check		60.0	62.3	58.7	61.0	242.0
	Sums	414.5	424.7	415.6	415.6	1670.4
	SX^2	81473				
	C	77461				

Analysis of Variance

Source of Variation	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	35	4012				
Treatments	8	3895	487	115.9	2.36	3.36
Blocks	3	17	5.7	1.36	3.01	4.72
Error	24	100	4.2			

LSD = 3.05

Table 20A. Effectiveness of Various Dusts for the Control of Onion Thrips, Two Days After Treatment.

Insecticide	Lbs. of Dust per Acre	No. of Thrips/Plant Blocks 1	2	3	Sums
Dieldrin 1%	20	4.1	3.4	3.0	10.5
Heptachlor 2½%	20	7.8	8.4	8.4	24.6
Chlordane 5%	20	9.3	8.2	9.2	26.7
Aldrin 1%	20	10.2	9.0	11.7	30.9
Lindane 1%	20	7.8	9.3	8.4	25.5
DDT 5%	20	18.0	19.3	17.3	54.6
Check		55.1	50.3	54.2	159.6
	Sums	112.3	107.9	112.2	332.4
	SX^2	10634			
	C	5261			

Analysis of Variance

Source of Variance	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	20	5373				
Treatments	6	5234	872.3	76.5	3.00	4.82
Blocks	2	2	1	0.08	3.88	6.93
Error	12	137	11.4			

LSD = 5.99

Table 20A (cont.). One Week After Treatment.

Insecticide	Lbs. Dust per Acre	No. Thrips per Plant Blocks 1	2	3	Sums
Dieldrin	20	7.9	10.6	10.9	29.4
Heptachlor	20	19.1	18.0	18.1	55.2
Chlordane	20	13.5	13.9	16.4	43.8
Aldrin	20	23.0	21.2	23.3	67.5
Lindane	20	29.2	33.4	30.4	93.0
DDT	20	37.1	37.9	37.5	112.5
Check		45.0	46.8	46.2	138.0
	Sums	174.8	181.8	182.8	539.4
	SX^2	16937			
	C	13855			

Analysis of Variance

Source of Variance	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	20	3082				
Treatments	6	3057	509.5	592.4	3.00	4.82
Blocks	2	15	7.5	8.72	3.88	6.93
Error	12	10	0.86			

LSD = 1.63

Table 20A (cont.). Two Weeks After Treatment.

Insecticide	Lbs. Dust per Acre	No. Thrips per Plant Blocks 1	2	3	Sums
Dieldrin	20	26.4	29.8	29.3	85.5
Heptachlor	20	34.1	31.2	35.5	100.8
Chlordane	20	32.0	31.1	34.5	97.6
Aldrin	20	38.6	42.4	42.2	123.2
Lindane	20	44.2	48.0	49.7	141.9
DDT	20	44.0	41.6	42.8	128.4
Check		58.0	53.0	57.0	168.0
	Sums	277.3	277.1	291.0	845.4
	SX^2	36162			
	C	34033			

Analysis of Variance

Source of Variance	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	20	2129				
Treatments	6	1640	273	6.9	3.00	4.82
Blocks	2	18	9	0.22	3.88	6.93
Error	12	471	39.2			

LSD = 11.1

Table 21A. Analysis of the Effect of Insecticides on Thrips Control with a Potato Sprayer.

Insecticide	Lbs. of Toxicant per Acre	No. Thrips/Plant Blocks 1	2	3	Sums
Dieldrin	0.5	3.8	4.1	4.7	12.6
Chlordane	2.0	7.1	6.9	6.4	20.4
Heptachlor	1.0	12.0	13.8	11.8	37.6
Aldrin	0.75	14.1	12.4	12.8	39.3
Check		60.0	51.8	55.7	167.5
	Sums	97.0	89.0	91.4	277.4
	SX^2	10568			
	C	5130			

Analysis of Variance

Source of Variation	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	14	5438				
Treatments	4	5400	1350	337.5	3.84	7.01
Blocks	2	6	3	0.75	4.46	8.75
Error	8	32	4			

LSD = 3.76

Table 21A (cont.). Effect on 100 Lb. Bags/Acre

Insecticide	Lbs. Toxicant per Acre	No. of 100 Lb. Bags/Acre Blocks 1	2	3	Sums
Dieldrin	0.5	321	330	321	972
Chlordane	2.0	334	332	329	985
Heptachlor	1.0	299	304	314	917
Aldrin	0.75	298	206	291	885
Check		278	281	299	858
	Sums	1530	1533	1554	4617
	SX^2	1,425,623			
	C	1,421,113			

Analysis of Variance

Source of Variance	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	14	4510				
Treatments	4	3982	995	17.3	3.84	7.01
Blocks	2	68	32	0.55	4.46	8.65
Error	8	460	57.5			

LSD = 14.25

Table 22A. Analysis of the Effectiveness of Insecticides Applied with a Weed Control Applicator.

Insecticide	Lbs. Toxicant perAcre	No. Thrips per Plant Blocks 1	2	3	Sums
Dieldrin	0.5	17.3	19.1	19.2	55.6
Chlordane	2.0	22.7	26.8	22.5	72.0
DDT	0.6	33.8	34.0	31.5	99.3
Check		40.9	32.3	43.8	117.0
	Sums	114.7	112.2	117.0	343.9
	SX^2	10,697			
	C	9,856			

Analysis of Variance

Source of Variation	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	11	841				
Treatments	3	752	250.7	17.3	4.76	9.78
Blocks	2	2	1.0	0.07	5.14	10.92
Error	6	87	14.5			

LSD = 7.6

Table 23A. Analysis of the Effectiveness of Wettable Powders Versus Emulsions for Thrips Control Two Days After Treatment.

Insecticide	Lbs. Toxicant per Acre	No. Thrips/Plant Blocks 1	2	3	Sums
Dieldrin	0.5	1.0	1.6	1.6	4.2
Dieldrin W.P.	0.5	3.1	2.2	2.5	7.8
Chlordane	2.0	1.4	1.5	2.2	5.1
Chlordane W.P.	2.0	4.0	3.4	4.3	11.7
DDT	0.6	1.7	2.0	3.0	6.7
DDT W.P.	0.6	3.6	3.9	4.8	12.3
Heptachlor	0.5	2.9	2.8	1.2	6.9
Heptachlor W.P.	0.5	4.2	4.3	4.1	12.6
Lindane	0.2	1.3	1.8	3.2	6.3
Lindane W.P.	0.2	6.5	5.1	4.3	15.9
Check		44.0	48.1	36.9	129.0
	Sums	73.7	76.7	68.1	218.5
	SX^2	5932.8			
	C	1446.7			

Analysis of Variance

Source of Variance	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	32	4486.1				
Treatments	10	4412.3	441.2	126.0	2.35	3.37
Blocks	2	3.4	1.7	0.48	3.49	5.85
Error	20	70.4	3.5			

LSD = 3.15

Table 23A (cont.). One Week After Treatment

Insecticide	Lbs. Toxicant per Acre	No. Thrips/Plant Blocks 1	2	3	Sums
Dieldrin	0.5	5.0	4.2	4.9	14.1
Dieldrin W.P.	0.5	5.5	7.0	7.2	20.7
Chlordane	2.0	6.0	6.0	6.3	18.3
Chlordane W.P.	2.0	11.1	10.3	9.2	30.6
DDT	0.6	3.8	4.1	4.7	12.6
DDT W.P.	0.6	7.3	7.0	7.6	21.9
Heptachlor	0.5	5.6	7.9	5.8	18.9
Heptachlor W.P.	0.5	12.0	11.0	13.3	36.3
Lindane	0.2	9.0	8.1	8.4	25.5
Lindane W.P.	0.2	17.6	18.0	14.0	49.6
Check		58.0	52.0	53.5	163.5
	Sums	141.5	135.6	134.9	412.0
	SX^2	11390.9			
	C	5143.4			

Analysis of Variance

Source of Variation	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	32	6246.6				
Treatments	10	6207.6	620.7	341.0	2.35	3.37
Blocks	2	2.6	1.3	0.7	3.49	5.85
Error	20	36.4	1.8			

LSD = 2.3

Table 23A (cont.). Two Weeks After Treatment

Insecticide	Lbs. Toxicant per Acre	No. Thrips/Plant Blocks 1	2	3	Sums
Dieldrin	0.5	12.0	12.9	10.0	34.9
Dieldrin W.P.	0.5	18.0	19.5	16.7	54.2
Chlordane	2.0	14.1	13.9	15.7	43.7
Chlordane W.P.	2.0	19.2	18.4	18.8	56.4
DDT	0.6	9.6	12.0	9.0	30.6
DDT W.P.	0.6	18.3	21.0	19.9	59.2
Heptachlor	0.5	17.5	17.0	18.0	52.5
Heptachlor W.P.	0.5	17.2	19.0	18.1	54.3
Lindane	0.2	21.0	23.5	21.8	66.3
Lindane W.P.	0.2	34.1	21.0	26.2	81.3
Check		62.0	45.0	46.2	153.0
	Sums	243.0	223.2	220.2	686.4
	SX^2	18,229			
	C	14,277			

Analysis of Variance

Source of Variation	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	32	3952				
Treatments	10	3658	365.8	27.5	2.35	3.37
Blocks	2	2.8	14.0	1.05	3.49	5.85
Error	20	2.66	13.3			

LSD = 6.19

Table 24A. Analysis of the Relative Effectiveness of Several Insecticides Applied with a Hand Sprayer Two Days After Treatment.

Insecticide	Lbs. Toxicant per Acre	No. Thrips/Plant Blocks 1	2	3	Sums
Parathion	0.25	0	0	0	0
Metacide	0.20	0.1	0.2	0	0.3
Malathion	0.25	0	0.1	0.2	0.3
TEPP	0.25	0.5	1.3	0.9	2.7
Dieldrin	0.5	0.7	0.3	0.1	1.1
DDT	0.6	0.2	0.9	0.1	1.2
EPN	0.25	0.7	0	0.2	0.9
Chlordane	2.0	0.9	0.6	1.0	2.5
Heptachlor	0.75	0.7	0.2	0.6	1.5
Toxaphene	1.0	0.4	0.5	2.1	3.0
Lindane	0.2	0.7	0.8	0.9	2.4
Check		78.8	65.0	88.7	232.5
	Sums	83.7	69.9	94.8	248.4

SX^2 18,316

C 1,714

Analysis of Variance

Source of Variation	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	35	16602				
Treatments	11	16316	1483.2	125.7	2.26	3.18
Blocks	2	25.8	12.9	1.09	3.44	5.72
Error	22	260.2	11.8			

LSD = 5.8

Table 24A (cont.). One Week After Treatment.

Insecticide	Lbs. Toxicant per Acre	No. Thrips/Plant Blocks 1	2	3	Sums
Parathion	0.25	0.5	0.6	0.5	1.6
Metacide	0.20	0.3	1.5	0.6	2.4
Malathion	0.25	3.6	2.4	0.7	6.7
TEPP	0.25	4.6	2.5	2.3	9.4
Dieldrin	0.5	7.3	3.0	5.5	15.8
DDT	0.6	2.4	2.8	2.4	7.6
EPN	0.25	4.1	2.2	2.8	9.1
Chlordane	2.0	7.9	8.8	12.4	29.1
Heptachlor	0.75	15.4	8.7	11.3	35.4
Toxaphene	1.0	5.9	4.1	4.8	14.8
Lindane	0.2	9.0	7.3	20.2	36.5
Check		38.2	41.0	51.0	130.2
	Sums	99.2	84.9	114.5	298.6

SX^2 7289.0

C 2476.7

Analysis of Variance

Source of Variation	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	35	4812.3				
Treatments	11	4568.3	415.0	45.14	2.26	3.18
Blocks	2	40.0	20.0	2.17	3.44	5.72
Error	22	204.0	9.2			

LSD = 5.1

Table 24A (cont.). Two Weeks After Treatment.

Insecticide	Lbs. Toxicant per Acre	No. Thrips/Plant Blocks 1	2	3	Sums
Parathion	0.25	2.2	1.0	1.3	4.5
Metacide	0.20	3.8	1.6	1.5	6.9
Malathion	0.25	7.1	6.0	8.2	21.3
TEPP	0.25	6.3	4.5	6.6	17.4
Dieldrin	0.5	6.1	8.3	6.0	20.4
DDT	0.6	7.3	7.8	7.4	22.5
EPN	0.25	3.4	12.1	5.2	20.7
Chlordane	2.0	20.3	8.6	14.6	43.5
Heptachlor	0.75	16.4	19.8	18.6	54.8
Toxaphene	1.0	23.4	21.9	12.0	57.3
Lindane	0.2	20.3	21.6	37.6	79.5
Check		61.0	54.0	60.2	175.2
	Sums	177.6	167.3	179.2	524.0

SX^2 16,210

C 7,625

Analysis of Variance

Source of Variance	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	35	8585				
Treatments	11	8164	742.1	39.6	2.26	3.18
Blocks	2	9	4.5	0.24	3.44	5.72
Error	22	412	18.7			

LSD = 7.3

Table 25A. Analysis of the Effectiveness of Several Insecticides Applied with a Three-Gallon Garden Sprayer Two Days After Treatment.

Insecticide	Lbs. Toxicant per Acre	No. Thrips/Plant Blocks 1	2	3	Sums
Parathion	0.25	0.1	0.3	0.1	0.5
Metacide	0.20	0.2	0.4	0	0.6
EPN	0.25	1.1	0.7	0.6	2.4
Dieldrin	0.5	1.0	1.1	2.1	4.2
Chlordane	2.0	2.3	1.0	2.4	5.7
Lindane	0.2	0.8	3.3	2.2	6.3
Heptachlor	0.75	5.0	4.0	6.0	15.0
Check		53.0	58.0	51.0	162.0
	Sums	63.5	68.8	64.4	196.7

Analysis of Variance

Source of Variance	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	23	7276.4				
Treatments	7	7243.0	1034.7	461.9	3.77	4.28
Blocks	2	2.0	1.0	0.44	3.74	6.51
Error	14	31.4	2.2			

LSD = 2.6

Table 25A (cont.). Ten Days After Treatment

Insecticide	Lbs. Toxicant per Acre	No. Thrips/Plant Blocks 1	2	3	Sums
Parathion	0.25	0.6	0.3	0.3	1.2
Metacide	0.20	1.3	1.6	1.0	3.9
EPN	0.25	2.0	4.0	2.9	8.9
Dieldrin	0.5	4.2	6.4	3.6	14.2
Chlordane	2.0	6.0	6.0	6.4	18.4
Lindane	0.2	11.7	10.2	6.0	27.9
Heptachlor	0.75	8.6	11.2	15.8	35.6
Check		38.4	43.6	51.0	133.0
	Sums	72.8	83.3	87.0	243.1
	SX^2	6921.2			
	C	2462.4			

Analysis of Variance

Source of Variation	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	23	4458.8				
Treatments	7	4327.8	618.2	65.4	2.77	4.28
Blocks	2	1.0	0.5	0.05	3.74	6.51
Error	14	130.0	9.28			

LSD = 5.3

Table 26A. Analysis of the Effectiveness of Low Volume Equipment for the Control of Thrips on Seed Onions.

Insecticide	Lbs. Toxicant per Acre	Ave. No. Thrips/Plant Blocks 1	2	3	Sums
Dieldrin	0.5	9.7	7.7	8.4	25.8
Malathion	0.25	15.2	14.1	15.4	44.7
Chlordane	2.0	16.1	20.3	15.2	51.6
Check		25.6	27.3	29.6	82.5
	Sums	66.6	69.4	82.5	204.6
	SX^2	4070.1			
	C	3488.4			

Analysis of Variance

Source of Variation	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	11	581.7				
Treatments	3	555.6	185.2	43.5	4.76	9.87
Blocks	2	0.6	0.3	0.07	5.14	10.92
Error	6	25.5	4.25			

LSD = 4.2

Table 27A. Analysis of Effectiveness of Five Treatments of Insecticide by a Potato Sprayer for the Control of Thrips.

Insecticide	Lbs. Toxicant per Acre	No. of Thrips/Plant Blocks 1	2	3	Sums
Parathion	0.25	2.0	2.3	2.0	6.3
Dieldrin	0.50	3.8	3.5	3.5	10.8
Malathion	0.25	3.6	3.7	4.5	11.8
Chlordane	2.0	7.3	6.4	6.8	20.5
Check		46.1	43.2	42.7	132.0
	Sums	62.8	59.1	59.5	181.4
	SX^2	6054.3			
	C	2193.6			

Analysis of Variance

Source of Variation	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	14	3860.7				
Treatments	4	3852.7	963.2	1204.0	3.84	7.01
Blocks	2	1.6	0.8	1.0	4.46	8.65
Error	8	6.4	0.8			

LSD = 1.8

Table 28A. Analysis of the Effect of Varying the Time of the First Application for the Control of Thrips.

Date of First Spray		No. Thrips/Plant Blocks 1	2	3	Sums
May 12		4.3	2.1	3.5	9.9
June 3		3.2	4.3	4.5	12.0
June 15		10.8	11.6	6.7	29.1
Unsprayed		84.0	81.5	70.1	235.6
	Sums	102.3	99.5	84.8	286.6
	SX^2	18992.5			
	C	6844.9			

Analysis of Variance

Source of Variation	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	11	12147.6				
Treatments	3	12020.4	3673.4	259.8	4.76	9.78
Blocks	2	44.1	22.0	1.46	5.14	10.78
Error	6	83.1	13.9			

LSD = 5.3

Table 29A. Analysis of the Effect of the Time Interval Between Sprays for the Control of the Onion Thrips.

Interval		No. Thrips/Plant Blocks 1	2	3	Sums
7 Days		3.1	1.8	2.0	6.9
10 Days		5.0	6.0	6.1	17.1
14 Days		12.5	12.6	12.0	38.1
Untreated		67.1	65.4	76.2	208.7
	Sums	88.7	85.8	96.3	270.8
	SX^2	15186			
	C	6111			

Analysis of Variance

Source of Variation	D.f.	Sums of Squares	Mean Square	F	5%	1%
Total	11	9075.2				
Treatments	3	9004.7	3001.5	1250.0	4.53	9.15
Blocks	2	14.7	7.3	0.78	5.14	10.92
Error	6	55.8	9.3			

LSD = 6.1

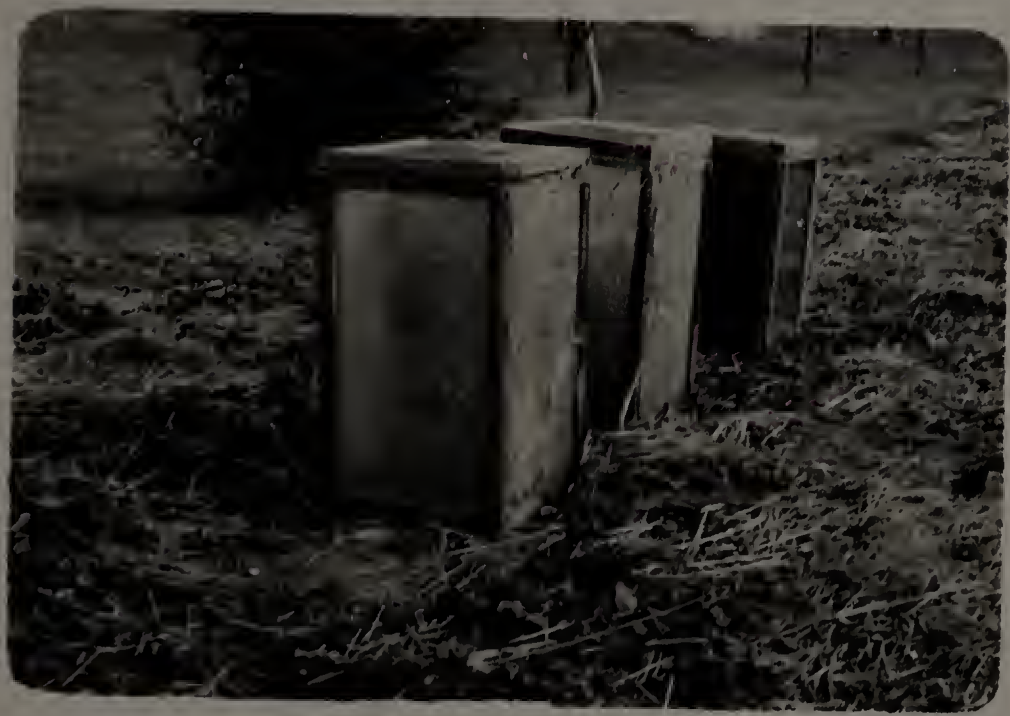

Plate I. Cages used for the life cycle study of the onion maggot.

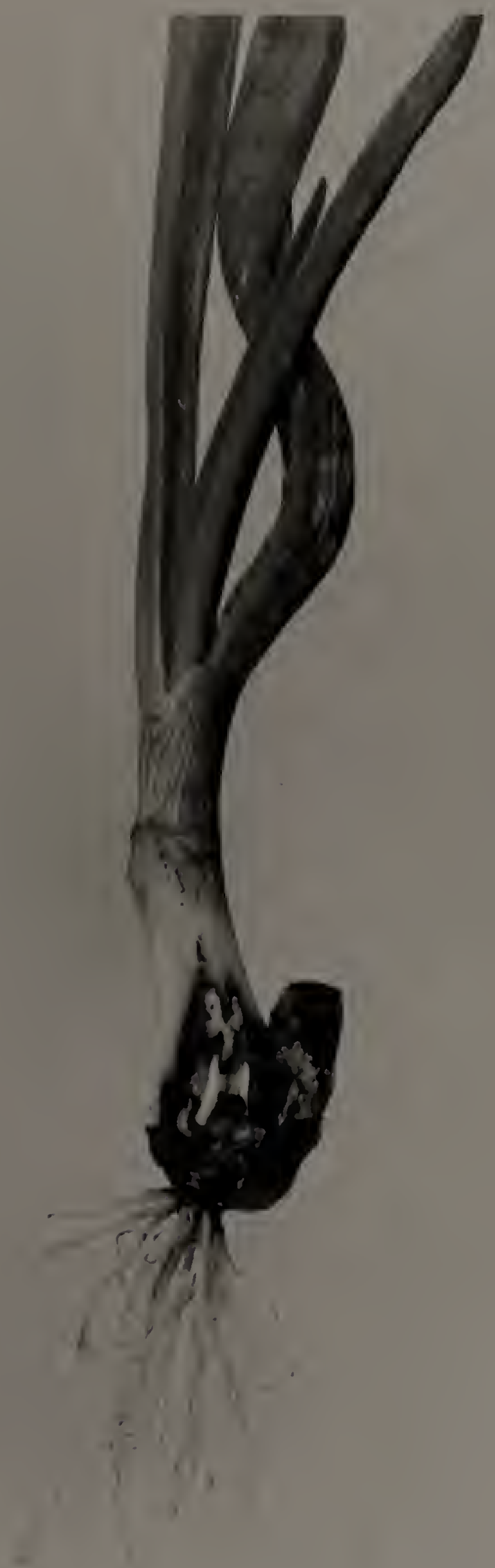

Plate II. Type of injury produced by onion maggot to young seed onions.

Plate III. Malformation and destruction of an onion bulb by onion maggot.

Plate IV. Complete destruction of an onion by a combination of onion maggot and secondary organisms.

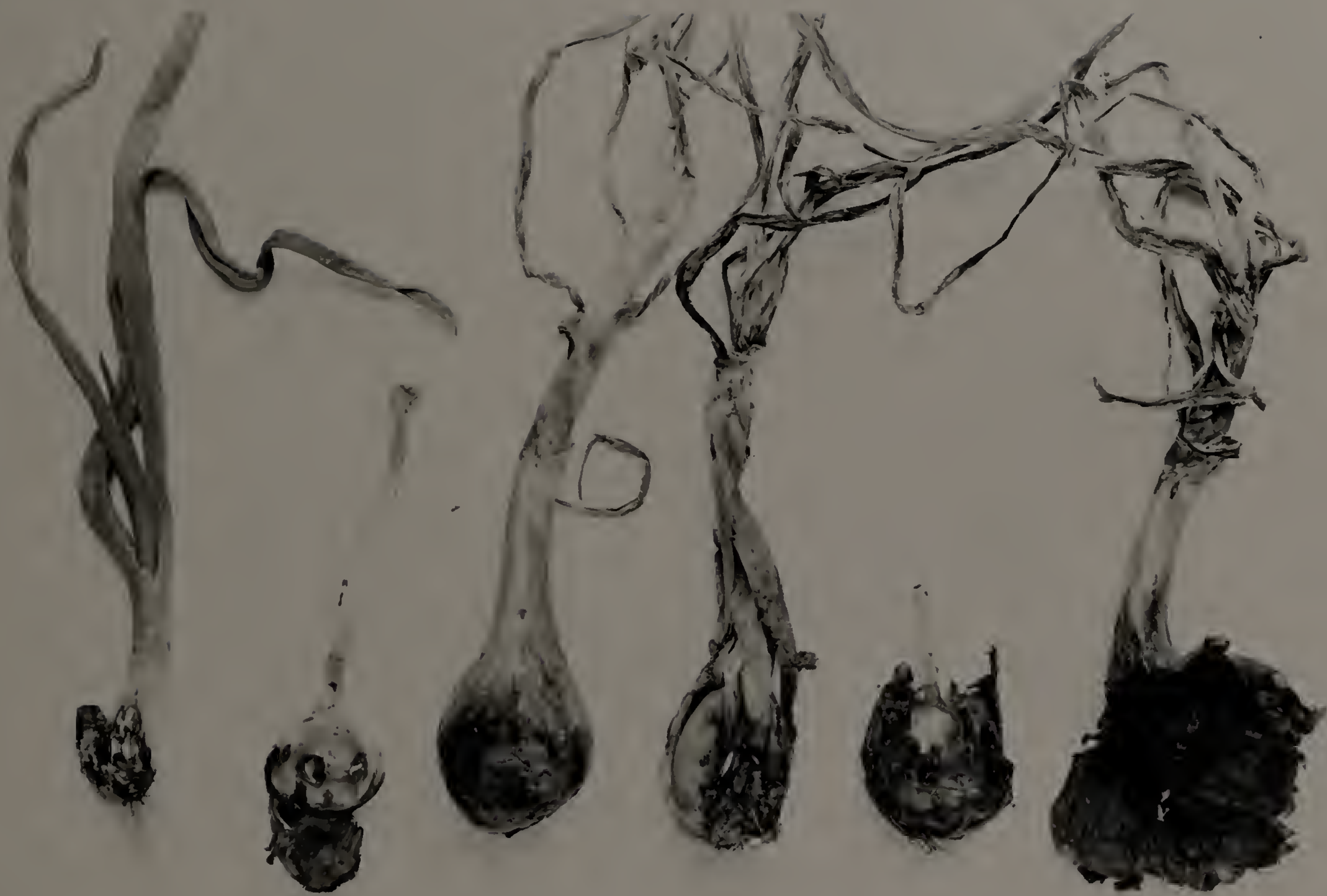

Plate V. A series of onions which have been attacked by onion maggot for various lengths of time.

Plate VI. Type of onion seed planter used in the Connecticut Valley. The attached rotary duster was used to blow insecticide into the furrow for maggot control.

Plate VII. The middle row in the above photo portrays the type of damage to seed sets by maggots. Spaces and thinning are the result of maggot infestation.

Plate VIII. An onion plant showing the typical blotched and dried areas caused by thrips feeding. Compare with Plate IX.

Plate IX. A plant free from thrips injury. Compare with Plate VIII.

Plate X. Close-up of the Iron Age potato sprayer used for thrips and maggot control.

Plate XI. The Iron Age potato sprayer used for thrips control, showing thorough coverage.

Plate XII. Thinned appearance of these seed sets was caused by the deleterious effects of lindane on seedlings.

Plate XIII. This photo shows the manner in which insecticides were tested for their phytotoxic effects to onion seedlings.

Plate XIV. The greenhouse flat on the left contains onions grown from untreated seed while those on the right were treated with lindane. Both flats were planted at the same time.

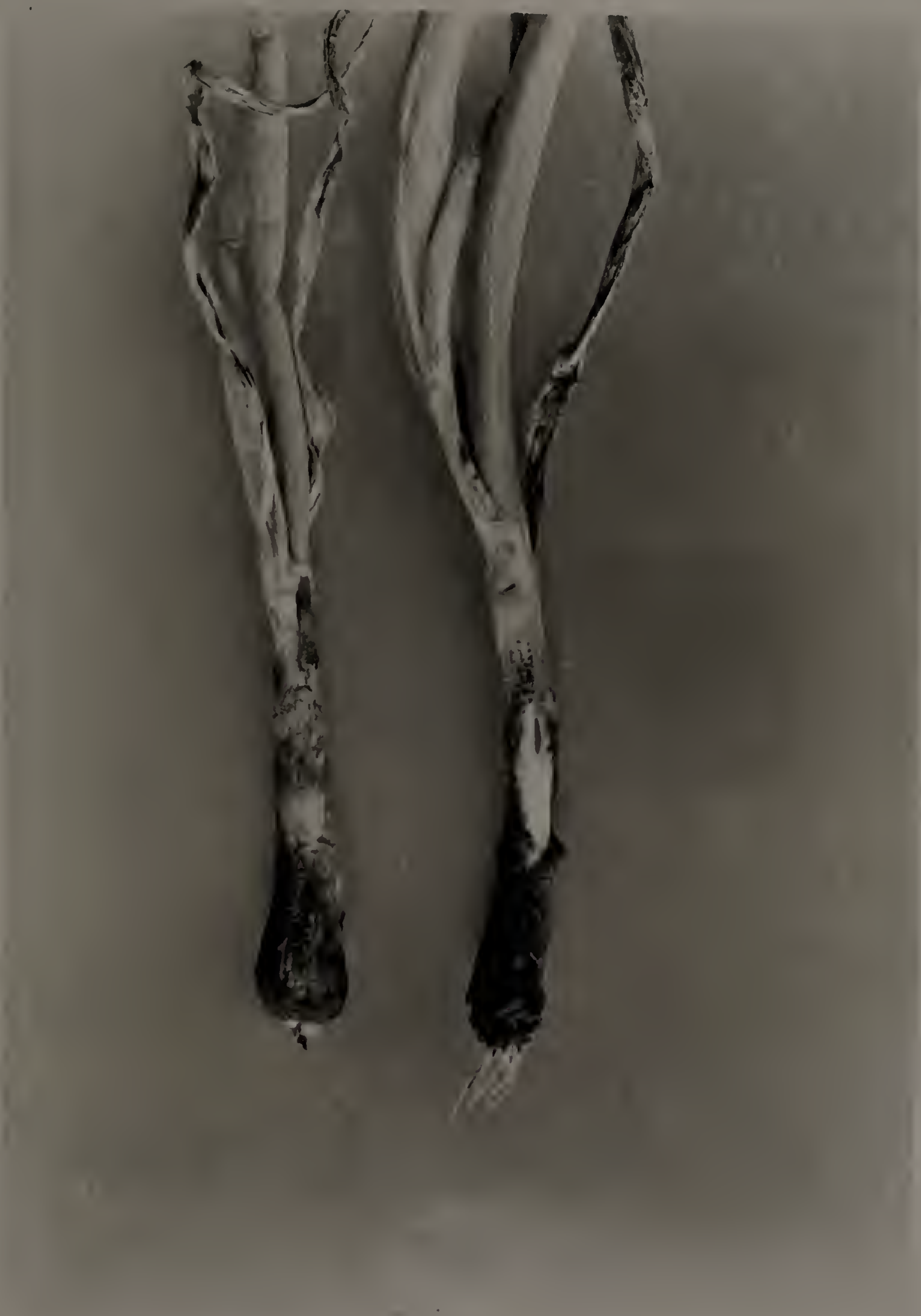

Plate XV. Typical appearance of onions infected with white rot.

Plate XVI. Onions infected with smut.

Plate XVII. A close-up of onions heavily infested with thrips.

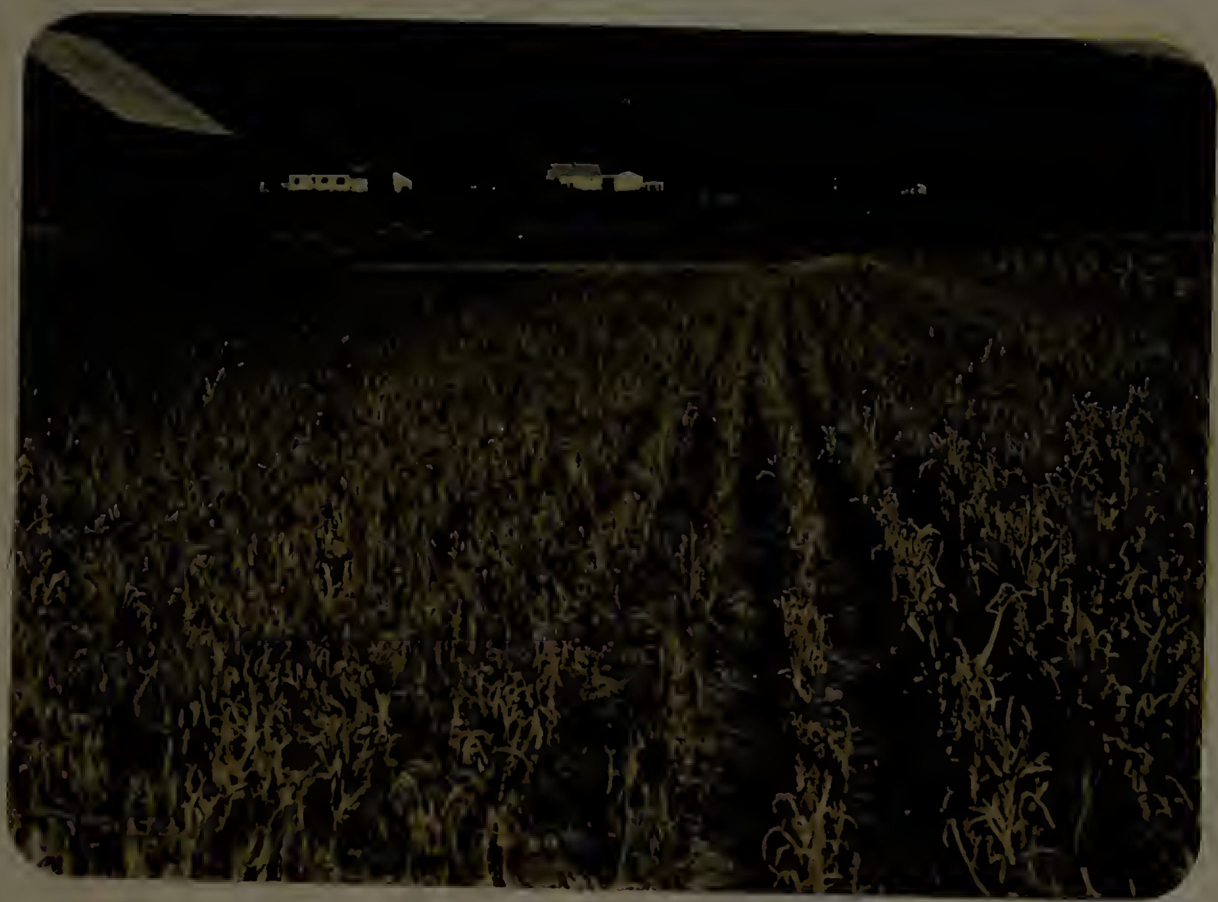

Plate XVIII. A plot of onions which was unsprayed. Note the dead and dry foliage of the four rows in the middle of the photo caused by thrips.

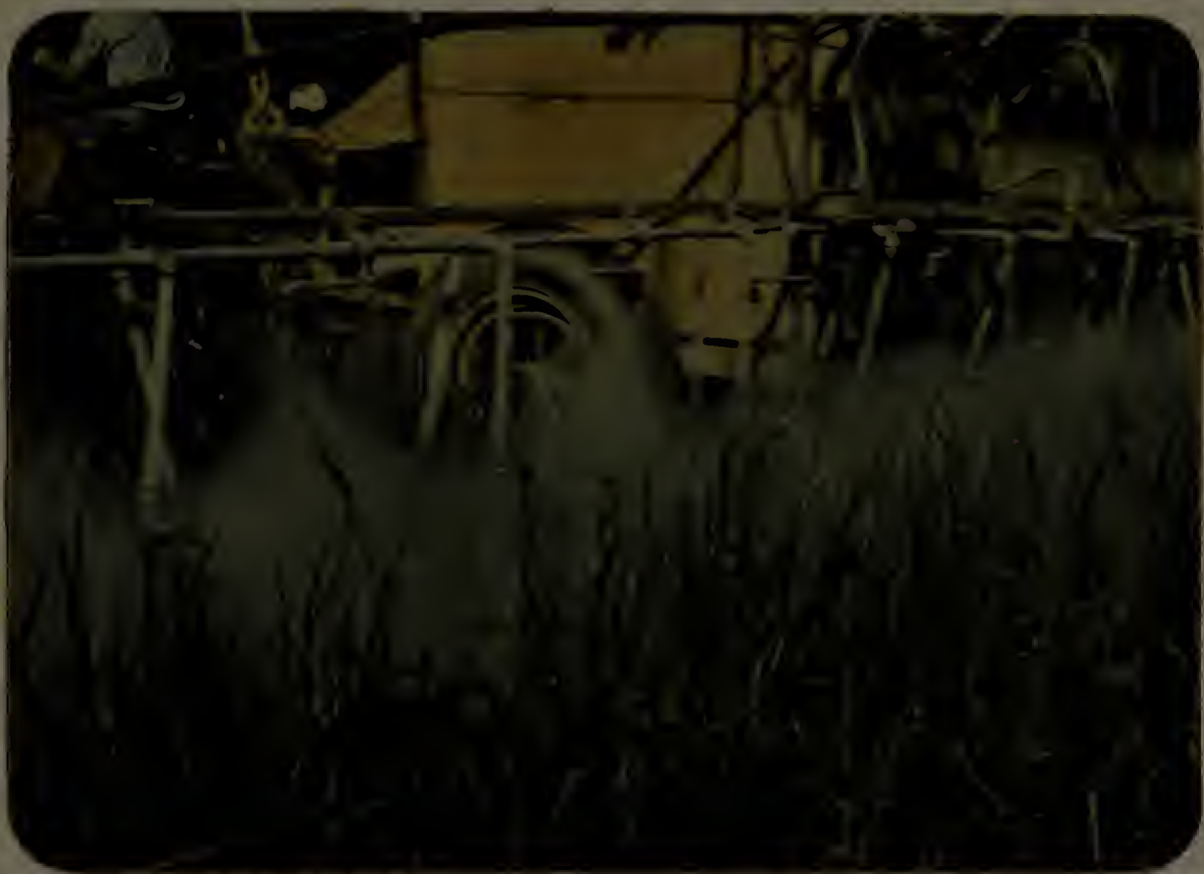

Plate XIX. Close-up of the Iron Age sprayer in use showing the spray pattern.

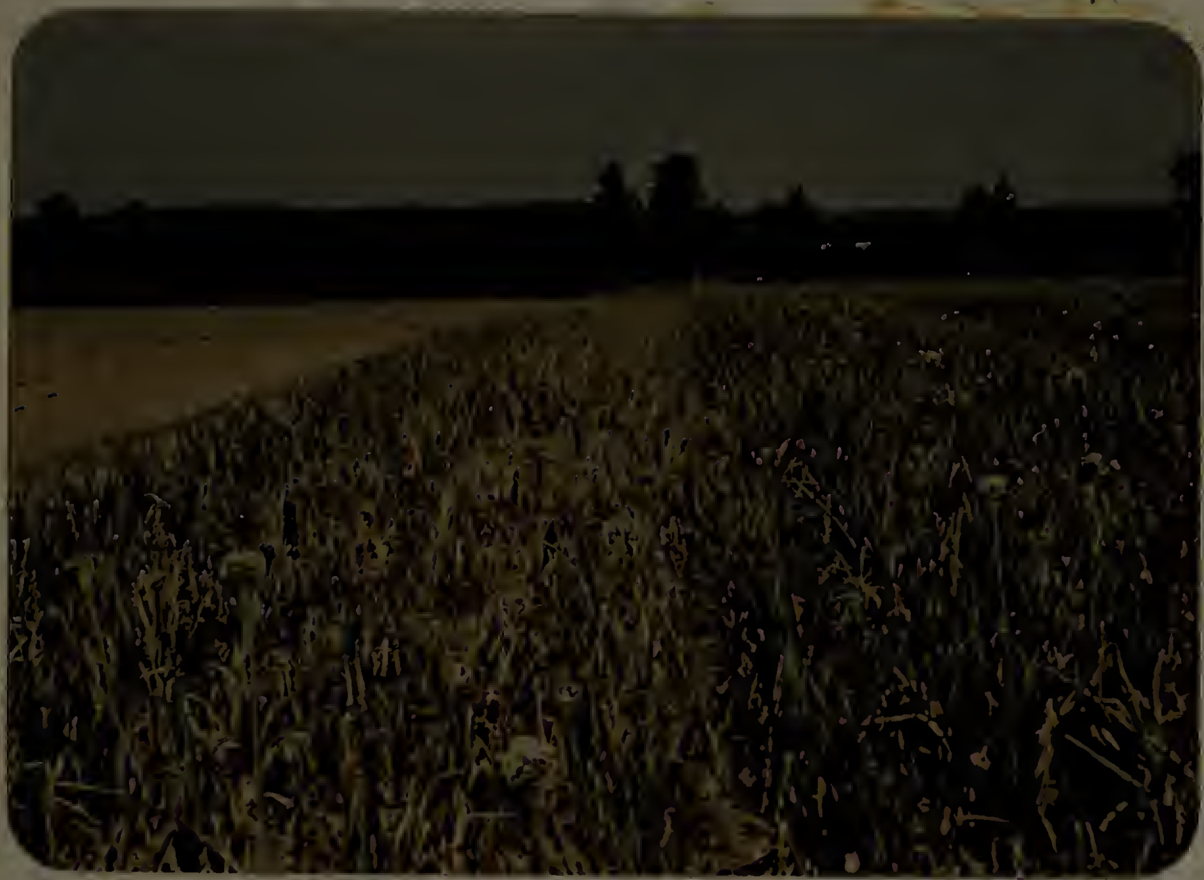

Plate XX. A clear demarkation between sprayed onions on the right and unsprayed onions on the left is evident.

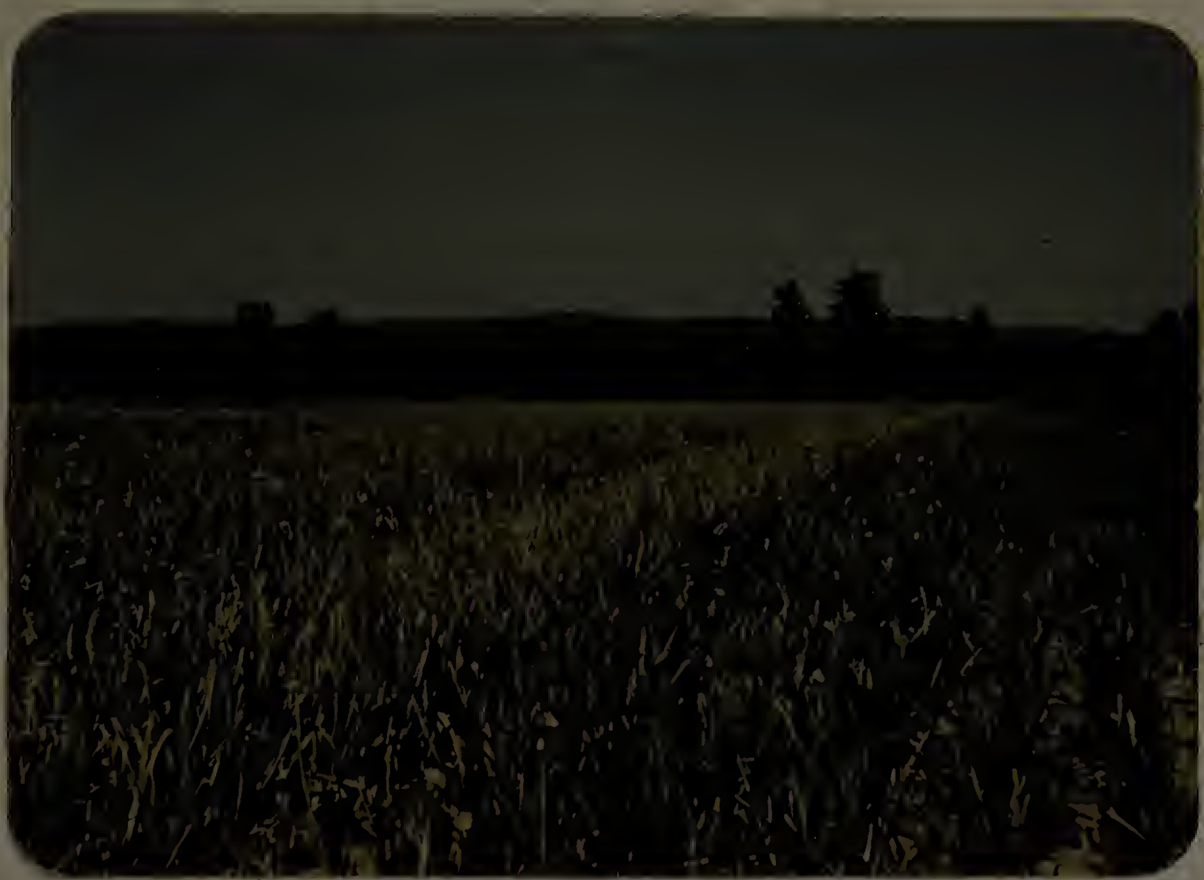

Plate XXI. Unsprayed onions appear lighter because of the dried areas on leaves caused by thrips. Treated onions on the right appear deeper green.

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