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THE SQUASH VINE BORER

Melittia satyriniformis Hübner

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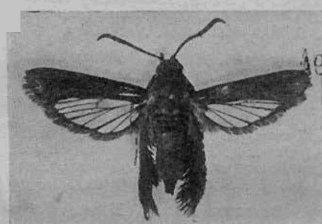

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The squash vine borer has been an important pest of cucurbits, mainly various varieties of squashes, for more than a century in the United States. T. W. Harris described the insect in 1828 in the New England Farmer, and wrote articles concerning its injury to squashes in agricultural journals during the next 23 years. The insect is also mentioned in his "Report on the Insects of Massachusetts Injurious to Vegetation," published in 1841. Previous to these accounts little was known concerning it, although Hübner first described the moth in 1825 and J. B. Smith in 1892 referred to a manuscript in the British Museum written the latter part of the eighteenth century by Abbot, in which reference is made to the life cycle in Georgia.

During that part of the nineteenth century following the accounts of Harris, reports of the injury caused by the insect to squash plantings in various parts of the United States occurred frequently, and during the last quarter of the century much attention was paid to its biology and control. Between 1866 and 1869 B. D. Walsh wrote popular articles concerning this insect in the Middle West. In 1870 Riley noted that it was present but not common in the Missouri River Valley, and in 1872 Reed published an article concerning the insect's habits, its injury to cucurbits, and the control measures available in Ontario. Lintner, in 1886, reported that the abundance of this pest had caused farmers in parts of New York to discontinue growing Hubbard squash. He advocated a number of control measures in order to minimize crop losses. In 1887 the insect is mentioned by Doran as occurring in Tennessee, and in 1885 Scudder discussed its life cycle on Cape Cod, Massachusetts. In 1892 Kellicott published the results of his investigations into the life cycle in Ohio, and in 1891 and 1892 Riley and Howard, and J. V. D. Walker advocated certain control measures against the pest. Between 1890 and 1897 the life cycle of the insect and control measures to be used against it were investigated by J. B. Smith in New Jersey. From then until the present time the insect has attracted the attention of agriculturists and entomologists in eastern United States because of its importance to the culture of cucurbitaceous crops. Britton (1919) states that with the possible exception of the striped cucumber beetle, this insect is the most serious pest of squashes and pumpkins in Connecticut. Chittenden (1899 and 1915), Worthley (1923), Spencer and Henderson (1925) and Cleveland (1927) have contributed much to the knowledge of the biology and control of the insect. The taxonomy and synonymy of the species are given by Beutenmüller (1901).

GEOGRAPHICAL DISTRIBUTION

This species, according to Chittenden (1899 b) and Beutenmüller (1901), occurs in southeastern Canada, in eastern United States south to the Gulf of Mexico and west to beyond the Missouri River, in Mexico, Guatemala, Venezuela, the lower Amazon region, and south as far as Argentina. It appears to be of tropical origin. According to Tuason (1917) this borer occurs in the Philippine Islands.

DESCRIPTION

Melittia satyriniformis was first described and named by Hübner (1825), although its larval stage was apparently known several years before this, according to Smith (1892). In 1828 Harris again described the insect as *Aegeria cucubitae,* and in 1848 Westwood named it *Trochilium ceto.* The synonymy is given by Beutenmüller (1897 and 1901). The family name Sesiidae has been abandoned in late years, and most of the species, including *M. satyriniformis,* formerly included therein are now grouped in the family Aegeriidae. A key to the adults of the family is given by Beutenmüller (1901) and by Forbes (1923). Fracker (1915) gives a key to the genera of the family according to larval characters and Forbes (1923) gives a larval key to those species of the family whose larvae are known as well as a larval key to the families of Lepidoptera. Mosher (1919) published a key to the families of lepidopterous borers found in farm crop plants and likely to be confused with the European corn borer. This includes *M. satyriniformis.* According to Beutenmüller (1901) this is the only species of the family found in North America north of Mexico whose larvae are known to bore in the stems of *herbaceous vines.* Mosher (1916) in her classification of lepidopterous pupae includes the family Aegeriidae, but not the genus *Melittia.*

Although no detailed morphological description of the various stages of this insect has been published, brief descriptions sufficing for the purpose of recognition have been given by various investigators. Much of the information that follows has been obtained from sources listed in the bibliography.

The egg is disc-shaped, depressed a little on the upper side, and bears fine reticulations on the surface. It measures 1.0 to 1.12 mm. in length and 0.76 to 0.90 mm. in width. The color is dark reddish brown.

The larva is whitish in body color, and the head is black in the early stages, becoming dark brown when full growth is attained. When first hatched the larva is about 1.8 mm. in length and about 0.66 mm. broad at the greatest diameter. The head and thoracic shield are black. The body tapers noticeably posteriorly and is much more hairy than in later instars. It is of interest to note that the young larva differs so much from the older form that Scudder (1885) thought two different species infested squash vines on Cape Cod. When half-grown the larva measures about 13 mm. in length and 2.5 mm. in width, and the head, thoracic shield, and anal process are black. The body form has lost the taper characteristic of the first instar. The fully grown larva is about 25 mm. in length and 6.0 mm. in width. The head is dark brown with a dorsal median white area, and on each side of the first thoracic segment are two oblique curved brown bands which converge posteriorly. Spencer and Henderson (1925) give the following head widths for the four larval instars: (1) 0.39-0.43 mm.; (2) 0.64-0.85 mm.; (3) 1.29-1.57 mm.; (4) 1.95-2.33 mm.

According to Dyar (Beutenmüller, 1901) this species differs from all other known Aegeriid larvae in that it lacks annulets and turbercles, and the spiracles are entirely black. The distinguishing larval characteristics of the family to which this species belongs are given by Dyar (Beutenmüller, 1901), Forbes (1923), and Fracker (1915), and these authors may be consulted for this information. Fracker also gives the larval characteristics of the genus, and Forbes' key readily distinguishes the species. According to Mosher (1919) the larva of *M. satyriniformis* is readily distinguished from other lepidopterous larvae commonly found boring in herbaceous stems, by the presence of prolegs which bear crochets of uniform length arranged in two transverse bands, one on each side of the proleg.

The larva of the striped cucumber beetle is frequently found boring in the base of the stems of squash vines, but may be very easily distinguished from the larva of the vine borer. It is a small slender larva, white in body color and with a black head. The prolegs bearing crochets and the labial spinneret characteristic of the vine borer are absent. The beetle larva is not found in those parts of the stem above ground.

The pupa of the squash vine borer is mahogany brown in color and about 16 mm. long. On the anterior end is a sharp projection sometimes called a cocoon breaker. The cocoon is usually located about two inches beneath the surface of the soil and is black in color.

The adult moth (see cover) is readily recognized by its form and color. The body length is about five-eighths of an inch and the wing spread is about one and three-sixteenths inches. The fore wings are greenish black in color and narrow. The hind wings are clear (without scales) and bear a fringe of brownish black hairs along the margins. The wing venation is pictured by Beutenmüller (1901) and need not be further discussed here. The antennae are greenish black, as is the dorsum of the head, but the face is white and the palpi are yellow. The thorax is greenish black. The abdomen is usually dull orange, somewhat clouded anteriorly, and has a median row of black spots dorsally, but in some specimens the entire abdomen is black. The legs are orange with black and white banded tarsi. The hind legs are heavily fringed with black hairs inside and orange hairs outside. The males are slightly smaller than the females, but similar in appearance.

LIFE CYCLE AND HABITS

Britton (1919) gives in brief form the life cycle in Connecticut, and Worthley has given this for Massachusetts. Observations by the writer confirm the information given by these two authors. During the latter part of June and the first part of July the pupae break through the cocoon and wriggle to the surface of the ground, where the adults emerge. The cast pupal skins are usually found projecting about half an inch from the soil. Adults are found in the field from the last of June until about the first of August, but some seasons they may be found until the middle of August (in small numbers). They fly quickly from plant to plant during the middle of the day, but during the early morning and the early evening hours they are sluggish and may be easily caught on the surface of the leaves. The females lay their eggs singly on all parts of the plant, except the upper surface of the leaves, but the majority of the eggs are placed on the basal part of the stem and on the under side. Worthley has estimated that 70.4 per cent of the eggs are placed on the stem, 26.8 per cent on the leaf stalks, and 2.8 per cent on the leaves.

The number of eggs laid by one female under normal conditions is problematical. J. B. Smith (1892) dissected females and estimated that about 212 eggs would be a maximum. Worthley states that one female will lay from 150 to 200 eggs, and on this basis it would be theoretically possible for 10 females to infest completely one acre of Hubbard squash that contained 1,500 vines. It has been the writer's experience, however, that the field infestation of squash is not uniform.

The eggs are found in the field from the last of June until the middle of August as a rule in Connecticut and in Massachusetts. Spencer and Henderson (1925) state that in Virginia the first adults of the season appear the first week in June, a peak is reached the last of June, and the last adults of the first generation disappear by the middle of August. According to Smith (1890 and 1893) in south and central New Jersey the adults appear the middle of June and in northern New Jersey about 10 days later, disappearing in the Vineland region about the middle of July. Walker (1892) states that on Long Island, New York, the eggs are laid from the middle of June until the middle of August. In

Indiana, according to Cleveland (1927), the maximum oviposition in 1926 occurred between June 22 and July 7. Osborn and Mally (1895) state that the adults fly in June in Iowa, and Drake and Fenton (1924) give the date of the first appearance of wilting of the vines in Iowa as June, which indicates the adults must be flying by the first of the month. Chittenden (1915) gives the date of the appearance of the moths at Washington, D. C., as early June. Smith(1905) states that in southern Georgia the adults of the first generation emerge during May and those of the second generation the first half of July. In North Carolina the first generation adults emerge in late April and early May (Smith, 1910).

The duration of the egg stage has been given by various authors as from about 6 to about 15 days. Spencer and Henderson (1925) state that the duration of this stage in Virginia varied from 7 to 11 days, 182 eggs averaging 8.1 days. Worthley estimates the duration of the egg stage in Massachusetts to be from 9 to 13 days, 15 eggs averaging 11.7 days. Smith (1891) gives 12 to 15 days as the duration of the egg stage in New Jersey, and Chittenden (1915) estimates this stage at 6 to 15 days, as do Britton (1919) in Connecticut and Smith (1905) in Georgia.

Some of the larvae bore into the stem immediately on hatching and others feed somewhat externally before entering the stem. Most of the larval feeding takes place in the tissue surrounding the stem cavity (Figure 46). Larvae that hatch on the leaf stalks usually bore downward toward the main stem of the plant. A large proportion of the eggs are laid close to the base of the stem, many of them at or just below the surface of the ground, so the first evidence of larval feeding is usually noted in the basal foot of the vine. Some of the frass is extruded from the burrows and indicates the presence of larvae within. The larvae can migrate from plant to plant if so inclined. The total number of larvae that occurs in one plant varies considerably. The writer has removed up to 19 borers from the basal foot of one vine. Chittenden (1899 b) cites a record of 142 borers from one vine. Most of the larvae are found in the basal four feet of the vine, and in many vines all the larvae are in the basal foot, but frequently they occur as far as 20 feet from the base. In one plot of vines in 1925, 155 borers were removed by the writer; 50 of these were found at between three and four feet from the base, 67 in the basal three feet, and 38 at a distance of from 4 to 10 feet from the base. This is an exception to the general rule, however.

The reason for the oviposition on the basal four feet of the vine in preference to the more distant sections is partly explained by the fact that the vines are young and short during the early part of the oviposition period, and hence if any eggs are laid, they must be near the base. After the vines become well grown, the leaves near the base are larger and the foliage more dense, which may

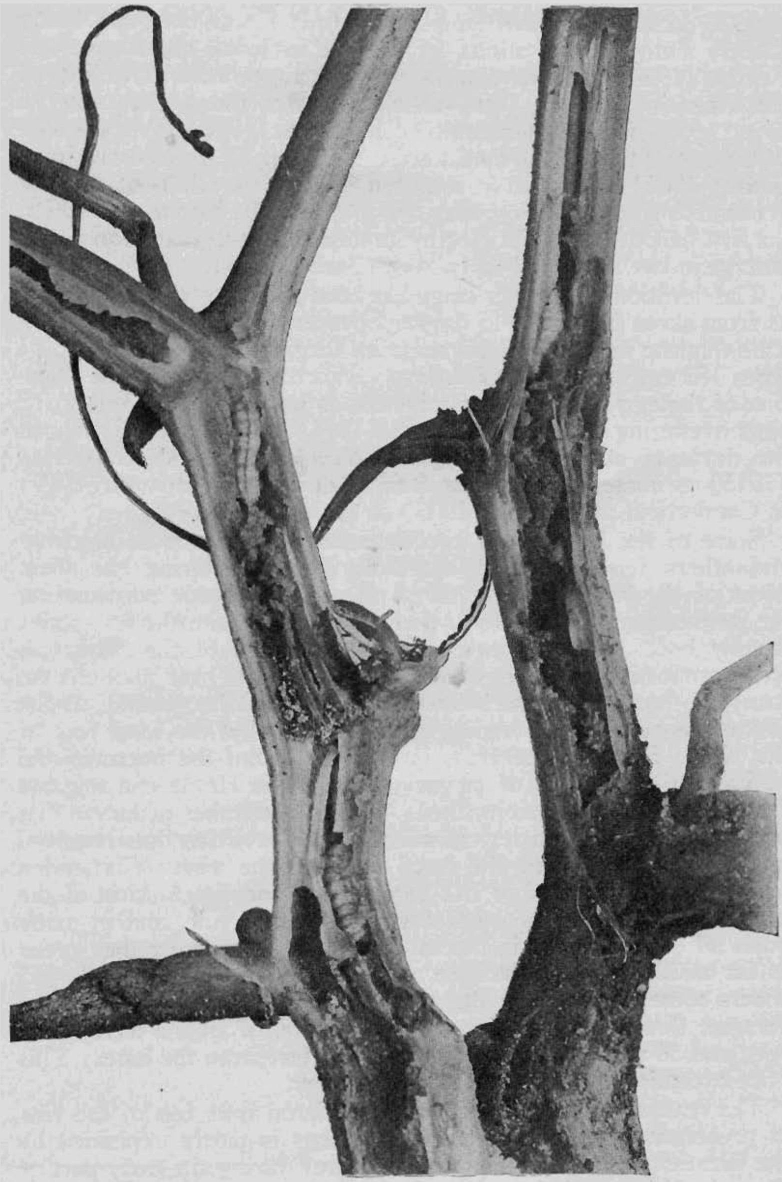

FIGURE 46. Injury to vines of Hubbard squash by the larvae of *M. satyriniformis* Hbn.

offer more attraction to the adults. In the case of summer squashes, such as crooknecks which have short thick stems, the borers may be found all along the stem.

The length of the larval period in the vines is from four to six weeks in Connecticut, and the same holds true for Massachusetts. The most careful estimates for the larval period in the vines are those of Spencer and Henderson (1925) in Virginia. They estimate the duration of the first larval instar to be from two to 10 days, 23 larvae averaging 6.0 days; for the second instar from two to 12 days, averaging 5.5 days (26 larvae); for the third instar two to 12 days, averaging 4.2 days (68 larvae); and for the fourth instar five to 43 days, averaging 14.7 days (101 larvae). Larvae occur in the vines in Connecticut, where there is only one generation a year, from the middle of July until the middle of September. Chittenden states that the larval period in the District of Columbia is four weeks or more and that fully grown larvae are found in the vines as early as July 16 and as late as the second week in November. There are two generations a year in this region.

When the larvae become fully grown, they enter the soil to a depth of about two inches and spin a cocoon. In the one-generation regions they remain in this cocoon in a prepupal stage until the following spring. Where there are two generations, the prepupal stage of the first generation may be as short as three days (Virginia) and that of the second generation as long as seven months. In any case, hibernation occurs in the prepupal stage in the north, although Smith (1905) states that the pupae hibernate in Georgia and North Carolina (1910).

Pupation occurs in the spring. The duration of this stage varies somewhat, but in New England it is probably about three weeks in length.

The number of generations per year is one in the northern part of the United States, two in the southern part, and there is a partial second generation in the intermediate regions. In New England and on Long Island there is but one generation. In southern and central New Jersey the first adults of the season occur about the middle of June and the insect is practically single-brooded, although Smith (1893) records the emergence of two adults from 250 cocoons the same season. There is thus a tendency towards two broods. Chittenden (1899 a) states that in the vicinity of Washington, D. C., there are two broods a year in a large percentage of cases. There are three periods of adult emergence in this region, the first from late in May to early in July, probably from larvae of the first brood of the previous year; the second during late July and early August, probably from larvae of the second brood of the previous year, and the third during late August and later from the first brood of the same year, this last being the normal second brood. In the Gulf states the insect is two-brooded

(Smith, 1905), and in Ohio, Kellicott (1892) has demonstrated that at least a portion of the individuals is double-brooded. Webster (1918) states that there are two generations a year in Iowa, and Smith (1910) likewise reports two generations in North Carolina.

The squash vine borer infests squashes (both early and late varieties), cymlings, pumpkins, gourds, muskmelons, cucumbers, and the wild balsam apple (*Echinocystis lobata*), but it shows a marked preference for squashes (including cymlings). Frequently the pumpkin is also heavily infested, but the other cucurbits appear

FIGURE 47. Wilting of Hubbard squash vines resulting from injury by the larvae of *M. satyriniformis* Hbn.

to be attacked only when the preferred host plants are absent, although Bentley (1914) considers the insect a serious pest of melons and cucumbers in Tennessee. The effect of the larvae on squash vines depends on the number of larvae present and the part of the vine attacked. One or two larvae in the base of the vine where the stem is thick cause a wound which usually heals, and the hypertrophied tissue which closes the wound is quite conspicuous. The same number of larvae, or only a single larva, attacking the vine some distance from the base, where the stem is thin, cause the terminal part beyond the point of attack to die. A larva which bores in a leaf stalk kills that part of the plant. Summer squashes, such as crooknecks, are frequently heavily infested but because of the thickness of the stem do not show the effects of the attack as quickly as do other varieties. A number of borers in the base of a vine completely sever it. The actual feeding of the borers may not cut completely through the stem of the vine, but the little tissue that is left soon decays. This severance of the stem at the base does not always kill the vine, for if the injury occurs after the nodal roots have entered the ground and become well developed, the plant may survive. The first noticeable effect on the vigor of an infested vine is usually a wilting of the leaves during a hot day (Figure 47). This effect is also produced by the bacterial wilt disease of cucurbits and may be caused by the larvae of the cucumber beetles. An examination of the plant will usually tell which of these factors is the real cause of the wilting.

The effect of a borer infestation on the crop of squashes harvested is often striking. A large percentage of Hubbard and cymling vines is quite frequently killed outright before the fruit has matured. Lintner (1886) mentions the fact that growing Hubbard squashes in certain parts of New York was abandoned because of the losses inflicted by the borer. Cleveland (1927) states that repeated attempts to grow Hubbard squashes at Lafayette, Ind., have failed completely. In 1929 on the Station farm near New Haven, an unsprayed plot of Hubbard squashes was completely killed by the borers. According to information gathered by Worthley from Massachusetts farmers, the borer causes an annual loss of about one-third of the crop. Britton (1919) considers this one of the most serious enemies of squash and pumpkin in Connecticut. Cymlings are quite as severely affected as the late varieties of squashes. Not only is there a loss because of the death of the vines, but infested vines, even though they survive the borer attack, do not produce as large a crop as vines that remain free from borers during the season. This is shown in the control experiments described on other pages. The borer is an insect well known to any person who has attempted to grow squashes extensively in Connecticut.

NATURAL MORTALITY

The effects of climatic and soil conditions in regard to the natural mortality of the borer have not been thoroughly investigated, and the effect of parasites has been almost equally neglected. Chittenden (1900), in discussing the effect of the severe winter of 1898-1899, when the temperature in February at Washington, D. C., was the coldest in 20 years, stated that the borer appeared so late in the season of 1899 that large crops of cymlings were obtained without difficulty, an impossibility in 1897 and 1898 owing to the abundance of the insect. Worthley (1923) in Massachusetts found that the eggs of the borer were subject to a high degree of parasitism by a wasp of the family Scelionidae identified as *Telenomus* (*Prophanurus*) sp. The extent of parasitism of small lots of eggs secured in 1920, 1922, and 1923, varied from 12.5 to 100 per cent. Cleveland (1927), on the contrary, found no egg parasites in Indiana. The larvae of the borer appear to be relatively free of enemies. The adults are sometimes caught by robber flies (Asilidae). The position of the prepupa in the soil is such that a heavy winter mortality might be expected under certain conditions, but this has not been investigated.

CONTROL

The earliest attempts to control the squash vine borer involved cutting out the larvae, catching the adult moths, and removing or crushing the eggs by hand. To these were added certain cultural methods which tended to promote the vigor of the vine and assist it in overcoming the injury. Liberal fertilization over the entire field has been advocated on the theory that the nodal roots can provide sufficient food for the maturation of a good crop. In order to assist the plant in the rapid establishment of an efficient system of nodal roots, it has been recommended that the vines be covered with earth for a few feet from the base. These cultural methods are certainly applicable at the present time, especially the general fertilization of the ground. In many instances it is customary for farmers to place fertilizer in the hills only, with the result that when the vine is cut off near the base by the borers, no good food supply is available to the nodal roots. Late fall and early spring cultivation of the ground were also advised in order to prevent the emergence of adult moths in the early summer. Fall harrowing presumably crushes many larvae in the soil and exposes others to the inclemencies of the winter, and spring plowing buries them so deeply that the adults cannot get out of the soil. Sirrine (1897) buried larvae in the soil in the fall and proved that if they are buried six inches deep, no adults emerge the following season. He therefore rcommended deep fall plowing.

Lintner (1886), summarizing the control measures developed by himself and others to date, made the following recommendations for control: (1) Plow and harrow two or three times in the fall. (2) Spread gas lime over the ground after removing the crop. (3) Sprinkle the ground with kerosene or with kerosene mixed with soap suds before a heavy rain and while the larvae are in the soil. (4) Do not re-plant squash on the same ground. (5) Plant trap crops, such as early varieties of squash, between rows of late varieties. (6) Cover the vines with netting. (7) Cut out the borers with a knife. (8) Broadcast fertilizer and cover the nodes of the vines with earth to promote the development of nodal roots. (9) Dissolve four teaspoons of saltpeter in one pail of water and apply one quart of the solution to a hill when the vines begin to wilt. (10) Use repellents, such as kerosene, tarwater, naphthalene, etc. (11) Wet the vines along the basal two feet with Paris green water after every rain. This is the first recorded information regarding the use of a stomach poison for the control of the borers. E. S. Goff of the New York Agricultural Experiment Station at Geneva, who experimented with this material and on whose report Lintner makes his recommendation, stated that no borers occurred on the parts of the vines so treated, although the vines not treated were infested. (12) Dip corn cobs in coal tar and place five in each hill, re-dipping the cobs occasionally to keep them fresh. (13) Wet the basal two feet of the vine with soap emulsion after every rain. These last two recommendation were also based on the experiments of Goff, who obtained very good results by the use of these materials. Smith (1890) recommended that the underside of the stems be rubbed to crush the eggs. He considered the Paris green to be of questionable value. It is interesting to note that others later considered the use of insecticides to be of little value.

Chittenden (1915) stated that insecticides were valueless and advocated the following methods of control: (1) Plant, before and between rows of late squashes, early crooknecks or early cymlings as trap crops and destroy the vines of the trap crops after the early squashes have been harvested. This applies to the regions where the borer is single-brooded. (2) Lightly harrow the field in the fall, and then plow to a depth of at least six inches the following spring. (3) Cover the basal parts of the vines with earth to encourage the development of nodal roots. (4) Fertilize the plot well. (5) Destroy the vines after harvest in order to kill the borers remaining therein. (6) Cut out the larvae with a knife. (7) Capture the adult moths in the early morning or early evening hours. Except for the elimination of certain measures recommended by Lintner, this indicates little improvement in control measures during about 30 years. Britton (1919) advocated similar control measures in Connecticut.

Of the control investigations carried on in late years, the work of Worthley (1923) in Massachusetts, Spencer and Henderson (1925) in Virginia, and Cleveland (1927) in Indiana are important. Worthley investigated the value of nicotine sulfate (40 per cent nicotine) as an ovicide and lead arsenate as a larvicide. The larvae feed slightly before entering the stem, or at least they must bore their way into the stem from the outside, so a stomach poison such as lead arsenate was thought to offer possibilities. As an indication of the degree of control obtained Worthley used the number of borers per thousand vines. The vines were sprayed four times weekly in July. Winter Hubbard was the variety of squash used. It was determined that nicotine sulfate at a dilution of 1-100 gave a control of 94.8 to 97.7 per cent, and that nicotine sulfate at 1-250 gave 90.5 per cent control. Lead arsenate, 2.5 pounds in 50 gallons of water, gave 57.4 per cent control and the same insecticide used at the rate of three pounds in 50 gallons gave a control of 73.5 per cent. On the basis of these experiments Worthley recommends the use of nicotine sulfate at 1-100 when a hand sprayer is used, and at 1-250 when a power sprayer is used. Four applications should be made at weekly intervals in July.

The cost of treatment was estimated. With a power sprayer it would take 275 gallons of spray to cover one acre four times, and with a hand sprayer 150 gallons would suffice. At a cost of $12.50 per gallon for nicotine sulfate, the cost of spraying one acre of 1,000 plants was estimated at $28.35 for the hand apparatus and $26.55 for the power apparatus, labor included. The increase in yield estimated to result from spraying, 59.5 per cent, or 4.5 tons, above the average yield of 7.6 tons from untreated fields, would give a net return over cost of spraying of $241.65 to $243.45 per acre, based on the average 1920-1923 wholesale market price of winter squash on the Boston market. The lead arsenate was not considered sufficiently effective to be practicable. Worthley states that the nicotine sulfate killed all eggs in laboratory experiments at both dilutions, but the egg parasites were not harmed.

Spencer and Henderson investigated the control of the squash vine borer infesting cymlings in Virginia. In 1924 the vines sprayed according to the recommendation of Worthley as above gave excellent results, but in 1925 the borer infestation was light and the results were not so definite. When cymlings were planted with the rows six feet apart the cost of spray material per acre was $31.46 with nicotine sulfate diluted 1-100 and $12.58 per acre when the dilution was 1-250. As control measures Spencer and Henderson recommend the following. (1) Early planting. Cymlings planted the first of April mature early enough to escape injury. A plot planted May 20, 1925, was only moderately injured and produced a satisfactory crop. Plots planted in June were severely injured and produced a very poor crop. (2) Cutting out the borers with a knife. This is not practicable for large areas. (3) In case of heavy infestations, the recommendations of Worthley. These give excellent results, but the cost is rather heavy for general use. (4) Fertilization. For cymlings one ounce of nitrate of soda per hill pushes the early growth. In addition to this two applications of the following formula should be made: five per cent ammonia, eight per cent phosphoric acid, and five per cent potash. This should be applied once at the time of planting and once before the vines fruit, at the rate of 300 pounds per acre per application. (5) Planting heavily and thinning out infested plants. (6) Destruction of the infested vines after harvest.

Cleveland carried out experiments in Indiana with lead arsenate as an insecticide after certain measures practiced had failed to reduce the infestation or its effect. The practice of cutting out the borers with a knife and mounding soil over the stems to encourage the development of nodal roots failed to give satisfactory results, probably because dry weather conditions prevailed and the vines failed to recover. Vines planted late, although they remained free from borers, failed to produce a crop. Cleaning up the vines after the crop was harvested gave no results. As a result of experiments carried out in 1924, 1925, and 1926 with Hubbard squash Cleveland concluded that lead arsenate offered good possibilities as an insecticide. In 1924 six applications of lead arsenate at the rate of three pounds in 100 gallons of water resulted in 46 plants out of 48 remaining free from injury, and six applications of calcium arsenate-gypsum dust (1-20) resulted in 24 plants all being kept free from injury. Of the 24 check plants, 22 were killed; and two were so badly injured no crop was obtained. The plots were planted June 6 and the vines were above ground June 16. A plot planted July 11, on which the vines were above ground July 22, remained free from injury, but no crop matured. In the 1925 experiments the results were not so conclusive, but plots treated as in 1924 showed 41 per cent of the hills infested when dusted with the calcium arsenate-gypsum, and 33.3 per cent of the hills infested when sprayed with lead arsenate in water at three pounds to 100 gallons. Late planting gave the same results as in 1924.

In 1926 various materials were tried, and the percentage of control was estimated by comparing the egg infestation with the borer infestation. Observations indicated that practically 100 per cent of the eggs hatched under normal conditions. A borer count was made August 5. The maximum oviposition occurred between June 22 and July 7. Of the materials used only lead arsenate-Bordeaux, at the rate of one and one-half pounds of the arsenate in 50 gallons of the Bordeaux (4-4-50), and calcium arsenate-gypsum dust (1-20) gave an appreciable control. With the lead arsenate-Bordeaux the egg infestation of the vines was 25 per cent, and the resulting borer infestation of the vines was six per cent. The control (number of borers found compared with number of eggs found) was estimated to be 88 per cent. With the calcium arsenate-gypsum dust, the egg infestation was 22 per cent and the borer infestation was 12 per cent. The control was estimated at 71 per cent. With the lead arsenate in water as applied in 1924 and 1925 the control was estimated at 36 per cent. The materials were applied June 29, July 8, 12, and 14. The cost per acre for four applications was estimated to be $2.77 for the lead arsenate-Bordeaux, and $3.92 for the calcium arsenate-gypsum. Late planting gave the usual results of freedom from injury, but no crop. The check vines gave no egg mortality. The more adhesive materials appeared to give better results, and of all the materials used, the Bordeaux-lead arsenate adhered to the vines best; lead arsenate in water next; and calcium arsenate-gypsum dust third. The other materials were less adhesive.

Experiments at New Haven

During the last four years the writer has conducted experiments in Connecticut for the purpose of determining the effectiveness of Worthley's recommendations under Connecticut conditions and in order to compare nicotine sulfate with lead arsenate. The life cycle of the insect in Connecticut is similar to that in Massachusetts, and the spraying dates given by Worthley were followed. Spraying was confined to the basal four feet of the vine. In all the experiments the efficiency of the treatment was based on the weight of the crop produced. From a practical standpoint this is more desirable than any estimation based directly on the mortality of the eggs and larvae, since a few surviving larvae could severely injure the vines. Moreover, it has been demonstrated that nicotine sulfate will kill the eggs. It is also true that one or two larvae in the base of a vine may not injure it to any great extent as far as the apparent vigor of the vine is concerned, but vine injury may be reflected in a reduced crop.

Three insecticides were used: (1) nicotine sulfate (40 per cent nicotine), (2) coated lead arsenate, (3) lead arsenate plus fish oil. The nicotine sulfate, plus soap to the extent of 0.5 per cent of the dilute material, was used at a dilution of 1-100 in order to compare the arsenates with the recommendations of Worthley. Coated lead arsenate was used at the rate of eight pounds in 100 gallons of water. This insecticide was developed by the Federal Bureau of Entomology for use against the Japanese beetle and consists of lead arsenate particles coated with lead oleate. It is marketed as a paste containing 50 per cent lead arsenate and 0.5 per cent lead oleate and has excellent spreading and adhesive qualities. The lead arsenate-fish oil mixture consisted of lead arsenate at the rate of three pounds to 100 gallons plus one quart of pressed fish oil. This mixture was also developed by the Federal Bureau for use in spraying shade and forest trees and possesses excellent adhesive properties. It is necessary to keep both these arsenicals vigorously agitated in a spray tank. In 1927 nicotine sulfate alone was used. In 1928 nicotine sulfate and coated lead arsenate were applied, and in 1929 and 1930 the lead arsenate-fish oil mixture was used in addition to the other two. A hand sprayer was employed for all applications.

The arrangement and treatment of the plots varied somewhat during the course of the experiments. In 1927 the seeds were planted in hills and the hills fertilized. The blocks of sprayed hills alternated with the blocks of hills not sprayed. All the vines were examined for borers, once the latter part of July and twice the first part of August; all borers found were removed. This was done in order to gather some information on the nature of the infestation, but it is not to be inferred that all borers that infested the vines were removed, for those which hatched late remained in the stems. The light infestation of this year and the removal of the borers from the vines the first part of the season made the results less striking than in other years, for this procedure favored the unsprayed vines. In 1928 the field was planted and fertilized as in 1927, and the blocks of sprayed vines alternated with the blocks of vines not sprayed. The plots were rather small because of the utilization of some of the vines for other purposes, but the results are indicative of those obtained in other years. In this and the succeeding years no borers were removed from the vines, and no record of vine infestation was kept. In 1929 the seeds were planted in rows 36 feet apart and the young plants were thinned to about 18 inches apart in the rows. In order to facilitate spraying, the vines of one row were trained towards those of the opposite row. In each row a block of sprayed plants alternated with a block of plants not sprayed, and one row duplicated that opposite. The fertilizer was applied over the whole field before planting. A record was kept of the number of vines killed in each plot.

In 1930 the procedure was similar to that in 1929, except that the rows were four feet apart and the plants of one row were trained to grow away from those of the other, and that in each row two sprayed vines alternated with two vines not sprayed. The mortality of the vines was recorded as in 1929. In all four years, all the plants were dusted before the treatment for borers in order to protect them from the ravages of the cucumber beetle. Hubbard squash was used in all experiments.

In 1929 and 1930 the vines sprayed with nicotine sulfate showed slight traces of spray burn. The edges of the leaves at the basal part of the vine were burned back about one-quarter of an inch at the most, usually much less. These leaves were otherwise uninjured and the vigor of the vines appeared unaffected. This slight injury was not considered important.

The results of the treatments are shown in Tables 1 and 2. In Table 2 the results were weighted so that the number of sprayed vines would balance the number of vines not sprayed. As previously mentioned, the infestation was light in 1927. Yet the sprayed vines well exceeded the check vines, both in total yield and in weight per squash. In 1928 the increase in yield obtained by spraying with nicotine sulfate was small, but the number of vines was too small to justify any sound conclusions. The results of the coated lead arsenate treatment were much better, but again the number of vines was small. The results of these two years show that even though the vines survive borer attack and produce mar-

TABLE 1. SQUASH VINE BORER CONTROL

	Nicotine sulfate 1-100	Check	Coated lead arsenate	Check	Lead arsenate-fish oil	Check
1927						
Vines						
planted	52	17	....	....	....	....
survived	....	....	....	....	....	....
Squashes	52	17	....	....	....	....
per vine planted	1.0	1.0	....	....	....	....
per vine survived	....	....	....	....	....	....
Pounds of squash						
total	529.1	130.6	....	....	....	....
per squash	10.2	7.7	....	....	....	....
per vine survived	....	....	....	....	....	....
1928						
Vines						
planted	8	18	12	6	....	....
survived	....	....	....	....	....	....
Squashes	6	13	12	4	....	....
per vine planted	0.8	0.7	1.0	0.7	....	....
per vine survived	....	....	....	....	....	....
Pounds of squash						
total	47.3	93.8	111.3	34.3	....	....
per squash	7.9	7.2	9.3	8.6	....	....
per vine survived	....	....	....	....	....	....
1929						
Vines						
planted	20	16	20	16	20	18
survived	20	....	14	5	14	8
Squashes	24	....	15	5	17	10
per vine planted	1.2	....	0.8	0.3	0.9	0.6
per vine survived	1.2	....	1.1	1.0	1.2	1.3
Pounds of squash						
total	136.8	....	53.3	18.8	94.8	51.0
per squash	5.7	....	3.6	3.8	5.6	5.1
per vine survived	6.8	....	3.8	3.8	4.7	2.8
1930						
Vines						
planted	28	28	28	28	28	28
survived	28	24	23	17	22	18
Squashes	31	19	25	19	25	13
per vine planted	1.1	0.7	0.9	0.7	0.9	0.5
per vine survived	1.1	0.8	1.1	1.1	1.1	0.7
Pounds of squash						
total	259.0	108.9	153.4	89.4	183.7	57.1
per squash	8.4	5.8	6.1	4.7	7.4	4.4
per vine survived	9.3	4.5	6.6	5.3	8.4	3.2

ketable fruit, spraying will certainly increase the crop. There was no mortality of vines recorded either year, the estimates being based on vines planted. In 1929 the borer infestation was heavy and the results were striking. All the vines in the nicotine sulfate plot survived, but all of those in the check plot beside it were killed by borers. The relatively low weight per squash was probably due to improper fertilization. The superiority of the coated lead arsenate was entirely due to the mortality of the unsprayed vines, and most of the increase over the checks in the lead arsenate-fish oil plot was due to the same factor. This simply reflects the lack of soil fertility and its effect on limiting the size of the squashes. In 1930 all plots showed a marked increase due to spraying, both in total yield and in weight per fruit.

Considering the results as a whole it is obvious that spraying will markedly increase the total weight of the crop produced and will increase the weight per fruit. There is also an indication that spraying will, by maintaining the vigor of the vines, tend to increase the production of marketable squashes, as is shown by the figures indicating the number of squash per vine that survived. Worthley has estimated that fields of Hubbard squash sprayed according to his recommendations should give an increase of 59.5 per cent in yield. If the results here attained are indicative of what may be expected, this estimate is none too high. The relative merits of the three sprays are difficult to determine, and little light on the question may be obtained by examining the results in 1929 and 1930 because of the great difference. The complete mortality

TABLE 2. SQUASH VINE BORER CONTROL, 1927-1930

Yield in pounds

Insecticide	1927			1928		
	Sprayed	Check	Increase	Sprayed	Check	Increase
Nicotine sulfate 1-100 ...	529.1	409.9	31%	47.3	41.6	14%
Coated lead arsenate	....	....	....	111.3	68.6	62%
Lead arsenate-fish oil	....	....	....	....	....	....
	1929			**1930**		
	Sprayed	Check	Increase	Sprayed	Check	Increase
Nicotine sulfate 1-100 ...	136.8	00.0	....	259.0	108.9	138%
Coated lead arsenate	53.3	23.5	127%	153.4	89.4	72%
Lead arsenate-fish oil	98.4	56.6	67%	183.7	57.1	222%

of the vines in the plot used as a check on the nicotine sulfate treatment eliminates any hope of comparison.

It is not proposed to go into the details of the cost of treatment here, but to indicate simply the relation between this cost and the value of the increased yield. Let us assume that the cost of harvesting and marketing per crop unit is the same for the treated and untreated areas. If the value of the increased yield is to balance the cost of treatment, then the cost of treatment per acre must be no more than the sum of the cost of raising plus the profit expected per acre multiplied by the percentage of increase in yield due to the treatment. In other words, if "c" equals cost of treatment per acre, "m" equals cost of raising plus profit expected per acre, and "i" equals increase in crop units per acre due to treatment divided by average yield of crop units per acre obtained in untreated areas, then "c" equals "mi" when the cost of treatment is balanced by the increased yield. This applies whether the increase in yield

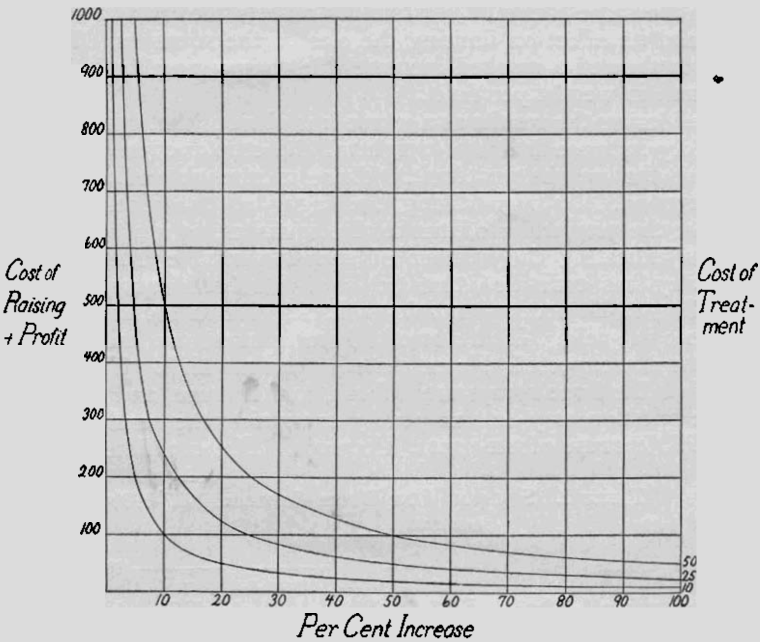

FIGURE 48. The relation between the cost of treating crops and the increase in yield necessary to balance this cost.

because of treatment is an increase in value due to improved quality or an increase in value from greater yield in crop units. When the cost of treatment is so balanced, it is probably still of considerable advantage to spray or otherwise treat the area (this formula applies, of course, to any treatment of the field tending to increase the value of the crop), because there is a slight labor advantage in having more valuable yields per acre and in eliminating the handling of many culls and because there may be a marketing advantage if the crop is improved in quality.

On this basis, the most expensive method of spraying advocated by Worthley, based on his production and values, would have to produce an increase in yield of only seven per cent to more than balance the spraying cost if the cost of marketing and harvesting were $5.26 per ton, or 10 per cent if the harvesting and marketing costs were $13.16 per ton. If lead arsenate and fish oil were used instead of nicotine sulfate, the cost of the insecticide would be about one-fourth as much. At present market prices in five-pound lots, coated lead arsenate would be almost as expensive as nicotine sulfate, but the coated lead arsenate would doubtless be cheaper in larger lots.

In order to show the relation between the cost of treatment and the increase in crop value necessary to balance this treatment, the curves in Figure 48 have been constructed. The coordinates indicate the cost of raising plus profit per acre in dollars and the per cent increase in yield or crop value per acre due to treatment. The curve indicates the cost of treatment per acre, three curves being constructed to represent a cost of $10, $25, and $50 respectively. It can be readily seen that, as the cost of raising plus profit per acre becomes higher, the percentage of increase in yield necessary to balance the cost of treatment is lowered. Conversely, as the cost of raising plus profit per acre becomes less, the percentage of increase in yield necessary to balance the cost of treatment is greater. At low crop values, as the crop value decreases, the increase in yield necessary to balance a fixed cost of treatment rises rapidly, and quite obviously the opposite is true at high crop values. By changing the coordinates so that they represent cost of raising plus profit and the cost of spraying, the percentage of increase in yield necessary to balance the cost of spraying would be represented by a rectilinear curve. The hyperbolic curve here given appears to the writer to be better illustrative of the valuations concerned. When the crop values as represented by cost of raising plus profit per acre are high, as they are in market garden sections of the country, a very slight increase in yield will balance a high cost of spraying. If the crop value as here represented is $500 per acre, an increase in spraying cost from $25 to $50 per acre is balanced by an increase in yield per acre of only five per cent.

Recommendations

In consideration of the value of the squash crop per acre and the extensive injury to the plants caused by the borer almost every year, measures which will minimize this injury should be undertaken by the grower. None of the cultural control methods advocated give as much promise as a spraying schedule. Under Connecticut conditions it is recommended that winter squash vines be sprayed at weekly intervals four times during July, beginning about July 5. Only the basal four feet of the vines need be sprayed, and care should be taken to cover thoroughly the under side of the stem of the vine as well as the upper side, the leaf stalks, and the under side of the leaves.

Lead arsenate and fish oil, coated lead arsenate, or nicotine sulfate should give good results. The lead arsenate and fish oil should be used at the rate of three pounds of lead arsenate plus one quart of fish oil in 100 gallons of water, and coated lead arsenate should be used at the rate of eight pounds to 100 gallons of water. If a hand spraying apparatus is used, nicotine sulfate should be diluted 1-100, but if a power sprayer is used, dilute the nicotine sulfate 1-250. In regards to the cost of spray materials, lead arsenate plus fish oil is the cheapest of the three. The increase in crop yield obtained by spraying will more than offset the cost of spraying, even when the most expensive of these materials is used.

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