
New York Agricultural Experiment Station.

GENEVA, N. Y.

THE CABBAGE MAGGOT: ITS BIOLOGY AND CONTROL.

W. J. SCHOENE.



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*Absent on leave. †Connected with Grape Culture Investigations.

THE CABBAGE MAGGOT: ITS BIOLOGY AND CONTROL.

W. J. SCHOENE.*

SUMMARY.

The cabbage maggot (*Phorbia brassicae* Bouché) has been known in America and in northern Europe for more than eighty years. During this long period it has been regarded as the most important injurious pest of such cruciferous vegetables as cabbage, radish, cauliflower and turnip. The insect is widely distributed and ever present, but it resembles certain native species in that the damage it causes fluctuates from year to year. Some seasons entire crops are destroyed, while at other times the insects are difficult to find and are of little importance.

The insect in America is an introduced species. It has been reported many times as injurious in Norway, Sweden, Denmark, Holland and the British Islands, but the species seems not to have attracted attention in France or Italy. In North America the cabbage maggot ranks as an important insect in Canada and the northern tier of states of the United States, but has only occasionally been reported in sections further south. The cabbage maggot is a northern insect and, like its host, attains maximum development in a cool, moist climate. Serious injury has rarely been reported south of latitude 45° in North America and latitude 40° in Europe.

The known host plants of this insect in North America have been naturalized from Europe. It is supposed that the maggots were introduced at an early date by turnips used on ships or by the importation of infested roots for food. It is even more likely that the pupa stage of the insect was imported by the use as ship ballast of soil that contained puparia. The latter assumption is made because a number of cruciferous weeds have evidently been imported by the same means.

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The white egg, 1.1 mm. long, marked with longitudinal furrows, is deposited on or near succulent cruciferous plants. Three to five days later the larva appears and attacks the sound tissue of the root or that part of the plant devoid of chlorophyl. Eighteen to twenty days are required for the larva to mature. It has an average length of about 7 mm. When mature the larva enters the soil to pupate. The pupal stage may last from twelve to eighteen days, or may be prolonged for an indefinite period of several months. The females begin to oviposit soon after emerging, probably within three to five days. Adults may live for five or six weeks.

The insect hibernates in the pupa stage. The over-wintering pupæ finish their development in the spring and the adults begin to emerge about the time the Windsor cherry blossoms. The flies continue to emerge over a period of four or five weeks, and those that appear in the spring are largely the adults of the fall brood of larvæ, though a few originate from the first and second broods of larvæ of the previous summer.

When conditions are favorable there are at least three broods and perhaps a partial fourth brood. However, the summer temperatures that frequently occur during July and August in western New York are unfavorable to the normal development of the insect, and seem to cause a retardation which may last until the weather becomes cool. High temperatures affect the insect both directly and indirectly. The roots of cabbage and other cruciferous plants become tough and woody at the appearance of hot weather, so that the larvæ grow very slowly. Also, it appears that the weather may directly influence the pupal stage and that this period may be lengthened or shortened so that the insect may be one-, two- or three-brooded. This situation has been interpreted in the same way as that outlined by various writers for the Hessian fly, which is, namely, that high temperature or severe drought causes a retardation of the developing larvæ and pupæ. It is probable that the optimum temperature for the development of the pupæ is around 80° F. for the average maximum temperature and 55° for the minimum.

The cabbage maggot derives its reputation as an injurious insect largely from its attacks in the spring of the year on cabbage seedlings, radishes and early cabbage. The activities of the insect during the autumn, when feeding upon turnips and sprouted cabbage, have been largely overlooked. Our studies show that the presence

both in spring and fall of large acreages of succulent cruciferous roots is a condition necessary for the cabbage maggot to occur in great numbers.

The insect has a number of natural enemies, some of which have a wide distribution in North America and have probably been imported in soil used as ship ballast. The principal enemies are certain staphylinids of the genus *Aleochara*, a cynipid parasite, *Pseudoeucoila gillettei*, and perhaps several species of mites of the genus *Trombidium*.

The cabbage maggot is amenable to treatment. Cabbage growers have been able to secure cabbage seedlings free from injury at a very small cost by the use of cheesecloth screens. Truck gardeners have been successful in preventing serious losses to their fields of early cabbage by employing tar-paper disks. The removal of all crop remnants when the cruciferous crops are harvested and the destruction of cruciferous weeds will lessen the numbers of the insect in any community.

INTRODUCTION.

The root-inhabiting maggots that affect cruciferous crops have for more than eighty years ranked as injurious insects in those sections of the northern states and Canada and northern Europe devoted to the culture of cabbage and related crops. The insects are ever present and widely distributed but the injuries vary in different localities and from year to year. Some communities suffer more than others, the attacks being both more frequent and more severe. During the periods when the insects are present in unusual numbers, crops are often largely if not entirely destroyed. Because of these injuries some gardeners have abandoned the growing of radishes, except perhaps the very earliest varieties. Also, to secure a satisfactory stand of early cabbage two or three times as many plants are set as are needed, and even then the toll required by the insects is such that the crop is often a failure. For, in addition to the death of some of the plants, there is, besides, a certain amount of root injury that dwarfs and retards the remainder of the crop. Growers of late cabbage in some localities have, in years when the insect was numerous, been unable to grow sufficient seedlings on their own premises to set the desired acreage. Under such circumstances

farmers are forced to plant fewer acres than intended or to meet the deficiency they are compelled to purchase plants which are frequently only obtainable from other states. This practice not only adds to the cost of production but increases the danger from introduced pests.

This bulletin is a report on observations covering the active period of the insect for eight seasons, the effects of weather and of different crops on their numbers, and the susceptibility of the fly to certain control measures. The present investigation was initiated in 1906 and has been continued, with interruptions, until the autumn of 1913. The control work during the early part of the study was directed mainly to perfecting the method of growing cabbage seedlings under cheesecloth, for the protection of young plants in districts devoted to the cultivation of late varieties of cabbage.¹ More recently the various remedies applicable to the protection of truck crops were investigated² and a brief announcement³ was made regarding some points in the life history of the pest. This bulletin gives the progress of the investigation up to the present time.

HISTORICAL NOTES AND SYNONYMY.

HABITS AND GENERAL CHARACTERS OF THE ANTHOMYIDÆ.

The Anthomyidæ (*Anthos* flower and *muia* fly) have been so named from their habit of frequenting flowers of various plants, conspicuous among which are the *Umbellifera* and *Compositæ*. They are small to moderately large flies, often resembling the common house fly, and usually are non-metallic in color. The group is closely allied to the typical species of the family Muscidæ from which it was separated by Meigen in 1838. The Anthomyidæ are characterized by having the first posterior cell of the wing broadly open, the squamæ usually of considerable size, and the eyes of the male contiguous. In the larval stage the great majority of the species are vegetable feeders, either in living or decaying material. According to Williston⁴ the larvæ of species of such genera as *Spilogaster*, *Hydrotæa*, *Hylemyia* and *Cænosi*a have been found in dung or manure; those of *Hydrotæa*, *Ophyra*, *Anthomyia*, *Homalomyia* and others in decaying vegetable material; those of *Hylemyia*, *Anthomyia*, *Homalomyia* in the

¹ N. Y. Exp. Sta. Buls. 301 and 334.

² N. Y. Exp. Sta. Bul. 382.

³ *Jour. Econ. Ent.* 4:210-216, 1911.

⁴ Williston, S. W. *Manual of North American Diptera*, p. 333, 1908.

nests of various hymenoptera, while the larvæ of various species of *Phorbia* (*Pegomyia*) feed upon the sound roots of onions, radishes and related crops.

SYNONYMY.

The adult of the cabbage maggot was described as *brassicæ* by Bouché¹ in 1833 and again more fully in 1834 and placed in the genus *Anthomyia*. Meigen² had described the species in 1826 under the name of *Anthomyia floralis* Fallen. Thus Meigen's description antedates that of Bouché's *brassicæ* several years, but as *floralis* is occupied in the same genus by *floralis* Fallen, Bouché's name has been accepted.

The insect was again described by Macquart³ in 1835 under the name *Chortophila floccosa*. Zetterstedt⁴ gave a description of the fly under the name of *Aricia floralis* Meig. non Fallen. In 1835 Harris⁵ named the insect which he had reared from maggots working in radishes as *Anthomyia raphani* and published a description in 1841. Curtis⁶ in 1843 determined the larvæ he found in cabbage roots as *Anthomyia radicum* L. Schiner,⁷ in 1862, examined a Zetterstedt specimen of *Aricia floralis* Meig. non Fallen and placed it in the genus *Anthomyia*. Fitch,⁸ although unable to separate the flies bred from different sources, treated them separately and retained the names *raphani* for the species infesting radish and *brassicæ* for the one attacking cabbage.

For many years the insect was recorded in literature under several names without much question as to the identity of the species. But in 1883 Meade⁹ stated in his description of *floccosa* Macq. that it was probably a synonym of the *floralis* of Fallen and Meigen. In 1888 Stein¹⁰ records *floccosa* Macq. as common in Saxony and also says it is synonymous with *floralis* Fall.; but in 1892 after an

¹ Naturgesch. d. Garten-Insekten, p. 131, 1833. Same 1834, p. 73.

² Syst. Besch., V: 165, 1826.

³ Hist. Nat. Dipt., II: 326, 1835.

⁴ Dipt. Scand., IV, 1536.

⁵ Harris, T. W. Cat. Animals of Mass., p. 80, 1835.

Harris, T. W. Ins. Inj. to Vegetation, p. 494, 1841.

⁶ Jour. Roy. Agr. Soc. of Eng., 4: 127-131.

Curtis, John. Farm Insects, p. 141, 1860.

⁷ Fauna. Austr., 1: 646.

⁸ Fitch, Asa, 11th N. Y. Rept., pp. 59-61 and pp. 40-43.

⁹ R. H. Meade. Ent. Mo. Mag. 19: 214, 1883.

¹⁰ Cornell Agr. Exp. Sta., Bul. 78, p. 575, 1894.

examination of type specimens concludes that *floralis* Fall. is distinct from *floccosa* Macq. This situation was interpreted by Slingerland to mean that *floccosa* Macq. was synonymous with the *floralis* of Meigen but not with the original types used by Fallen. The problem of identity was further simplified when both Meade and Stein, in reply to Slingerland, stated that *brassicæ* Bouché and *floccosa* Macquart were synonymous.

The cabbage maggot was for a long time known in Europe as *Phorbia floralis* and by systematic writers as *floccosa*, although a few writers recognized the name *brassicæ*. In this country the species found on cabbage was commonly regarded as *brassicæ*, and those attacking turnips and radishes as *radicum* and *raphani*. Economic workers in America noticed the similarity of the insects from these different sources and Fitch, Lintner, Cook and Fletcher all questioned the prevailing notions as to the distinction of the species; but to Slingerland is due the credit of clearing up the synonymy. By examination of type specimens and the literature of the species, he concluded that *brassicæ* and *raphani* were synonymous and that *radicum*¹ does not occur in this country.

Stein,² in his revision of the Anthomyidæ, placed *brassicæ* in the genus *Chortophila*, which name has been adopted by many economic writers in Europe. In the United States, *brassicæ* has been assigned by entomologists generally to either *Phorbia* or *Pegomyia* (*Pegomya*), but since *Phorbia* is synonymous with *Chortophila* and has the merit of priority, we have, at the suggestion of Aldrich,³ discussed the species under the appellation of *Phorbia brassicæ*.

ECONOMIC IMPORTANCE.

The insect has been known on the Continent of Europe since it was described by Bouché⁴ in 1833. There are a few accounts of injury by the species in Germany, Switzerland and the Netherlands, but it has received most attention by the economic writers of Norway and Sweden and of Finland. In 1899 Sven Lampa⁵ reported that fourteen acres of turnips near Orbyhus in Uppland (Sweden), were

¹ Since the publication of Slingerland's account, *radicum* has been reported by various writers to occur in the United States.

² Bezzi and Stein, Katalog der Paläarktischen Dipteren, 3:710, 1907.

³ Letter from Dr. J. M. Aldrich, dated Feb. 28, 1916.

⁴ Bouché, P. F., Naturgesch. d. Garten-Insekten, p. 74, 1834.

⁵ Uppsatser Praktisk Entomologi, pp. 47-49, 1899.

practically destroyed. Schöyen¹ of Christiana, Norway, has mentioned the injury of the insect in a number of his annual reports, particularly those of 1899, 1900, 1902 and 1904. Reuter² of Helsingfors, Finland, has referred to the destructive work of the insect almost every year during the period of 1897 to 1909. In 1897³ he records injury to rape in the Island of Gotland, that amounted to many thousands of dollars. He states that rape is not grown in Finland but that the insects attack other plants and that they are very detrimental to the seed-growing industry. One of Reuter's correspondents, Dr. Grotenfelt⁴ of Mustiala, reports serious injury to young cabbage plants. He noticed that the destruction was greatest on light or sandy soil. Reuter⁵ received reports in 1900 of injury to cabbage and cauliflower in the vicinity of Esbo, and states that in 1904⁶ the insect attracted less attention than in previous years.

In England the species has long been regarded as of much importance. According to Slingerland⁷ the insect was mentioned by Major in 1829 as the cauliflower fly. Curtis stated in 1841 that it often destroyed whole fields of cabbage. The insect is discussed many times by Miss Ormerod⁸ in her annual reports, and more recently by Whitehead and Theobald.⁹ Judging by their accounts and that of Carpenter¹⁰ of Ireland, the insect probably occurs in the British Islands wherever these vegetables are extensively grown.

The entomological literature of the Dominion of Canada is especially rich in references to this species. Fletcher has mentioned the insect in his annual reports almost every year from 1885 to 1906 and more recently it has been a subject for discussion by Bethune and Hewitt. As early as 1885 Fletcher¹¹ reports serious injury in all parts of Canada, from Nova Scotia to Vancouver Island. Mr. R. Brodie¹² of Montreal, one of Fletcher's correspondents, says, "The cabbage

¹ Beretning om Skadeinsekter og Plantesygdommen.

² Skad. Upp. i Finland, 1897-1909.

³ Skad. Upp. i Finland, p. 51, 1897.

⁴ Skad. Upp. i Finland, p. 35, 1899.

⁵ Skad. Upp. i Finland, p. 29, 1900.

⁶ Skad. Upp. i Finland, p. 5, 1904.

⁷ Cornell Exp. Sta. Bul. 78, p. 482, 1894.

⁸ Ormerod, E. A., Rept., p. 8, 1881; p. 10, 1882; p. 146, 1893.

⁹ Economic Zoology, 1st Rept., p. 34; 2nd Rept., p. 67.

¹⁰ Jour. Dept. Agr., 3:109, 1902.

¹¹ Rept. Exp. Farms, Ottawa, p. 6, 1885.

¹² Rept. Exp. Farms, Ottawa, p. 22, 1887.

maggot has been very destructive to our cabbages and cauliflowers in this neighborhood these past few years, but especially last season. In 1885 I planted two acres of early cabbage and lost about half of them by the maggots." Mr. Lang of Barrie, Ontario, makes a similar complaint. In his report for 1890 Fletcher¹ says the insect was particularly injurious during that season, and during the following year records it as the most destructive species. In 1898 outbreaks are mentioned near Olds, Alberta, and along the St. Lawrence in the Province of Quebec. He further states that "root maggots did much harm throughout the season". In 1900² the insects were unusually scarce at Nappan, Nova Scotia, but at other points in Nova Scotia, New Brunswick and Prince Edward Island they were very destructive. In his report for the same year³ it is stated that, "The root maggots caused great havoc in many places among cauliflowers and early cabbages." P. B. Gregson⁴ in 1901 mentions injury from the maggots that occurred at many points in Alberta, particularly at Edmonton, while Fletcher⁵ in his report states that they were decidedly more abundant than usual in some places in western Assiniboia and around Calgary, in Alberta, and also on the coast of British Columbia. The latter again stated in 1903,⁶ "The cabbage or radish maggot did much injury to turnips as well as cabbage and cauliflowers in gardens. It was, however, irregular in its occurrence, doing much harm in one place, while in another very close to it, it hardly appeared at all." The insect was mentioned by Blair⁷ in 1904 and by Fletcher⁸ in 1905. This latter report is especially interesting. "The onion and cabbage maggots which for the last few years have been so excessively destructive, during the past season were hardly noticeable in many localities where in previous years they had made a clean sweep of almost everything." The following season he states that they had been less destructive than has been the case for some years. Bethune⁹ reported in 1906 a serious infestation at Markdale, Ontario. The insect was reported

¹ Rept. Exp. Farms, Ottawa, pp. 161-165, 1890.

² Rept. Exp. Farms, Ottawa, p. 238, 1900.

³ 31st Ann. Rept. Ent. Soc. of Ont., p. 70, 1900.

⁴ 32nd Ann. Rept. Ent. Soc. of Ont., p. 119, 1901.

⁵ Rept. Exp. Farms, Ottawa, p. 230, 1901.

⁶ 34th Ann. Rept. of Ent. Soc. Ont., p. 65, 1903.

⁷ Rept. Exp. Farms Ottawa, p. 362, 1904.

⁸ 36th Ann. Rept. Ent. Soc. Ont., p. 86, 1905.

⁹ 37th Ann. Rept. Ent. Soc. Ont., p. 49, 1906.

again by Hewitt¹ as injurious during 1910 and 1911. In the former report he says, "From year to year the attacks of these insects appear to assume greater proportions."

The insect was first recorded in Massachusetts in 1835 by Dr. Harris² and since has been frequently reported as occurring in destructive numbers. In the trucking regions near Boston it has been very difficult in some seasons to grow early cabbage. Packard³ mentions, in his report for 1877, that he had known the insect in Maine more than twenty years. It is again listed by Miss Patch⁴ in 1907. Weed⁵ describes a serious outbreak in New Hampshire as follows: "During the season of 1903 there was a very extraordinary attack throughout New England of the various root maggots of the genus *Anthomyia*. Cabbages, cauliflowers and onions were infested to an extent that completely ruined the crop for hundreds of growers." Waugh⁶ mentions the occurrence of the pest in Vermont in 1897 and says that the insect had been known ten years before. Britton⁷ mentions a case of serious injury to three acres of cabbage in Orange county, Conn., in May, 1895. In describing the injury by cabbage and onion maggots Smith⁸ of New Jersey says that these plants are more or less damaged every year. "The injury may not be equally severe two successive years . . . or there may be a series of bad seasons. During the past few years, however, the injury has been serious in many sections of the State, the loss on one farm alone in Cumberland county amounting, in 1906, to \$1,000 or over, while in many other places from one-half to one-fourth of the crop was destroyed." The insect is evidently of much importance in Minnesota, for Washburn⁹ in his *Diptera of Minnesota* remarks, "The larvæ of this fly caused a loss of thousands of dollars to market gardeners in this state alone."

The insect has been known in New York State for many years. Its injuries are especially noticeable in the trucking regions about the large cities and in localities that are devoted to the production

¹ Rept. Exp. Farms, Ottawa, p. 229, 1910; p. 229, 1911

² Cat. of Animals and Plants of Mass., p. 80, 1835

³ U. S. Geological Survey Rept. for 1877, p. 762

⁴ Maine Exp. Sta., Bul. 148, p. 282.

⁵ N. H. Exp. Sta., Bul. 115, p. 174.

⁶ Vt. Exp. Sta. Rept., pp. 116-9, 1896-1897

⁷ Conn. St. Exp. Sta. Rept. 1895, p. 207

⁸ N. J. Exp. Sta. Bul. 200, pp. 3-27.

⁹ Minn. Exp. Sta. Bul., 93, p. 122.

of late cabbage. In some communities the gardeners have found that it does not pay to grow radishes, except some early varieties. Early cabbage, cauliflower, and seedlings grown for late cabbage are also very susceptible. The insect is a constant source of annoyance to persons desiring to grow these vegetables in kitchen gardens as well as a great handicap to the market gardener and cabbage grower.

In conclusion, the insect varies in numbers from year to year, much the same as many native pests. There are often periods covering several seasons when the injuries are marked, which may be followed by a number of years during which the insects are difficult to find or the numbers are so small as to be unimportant. Not only do the injuries vary during a period of years, but frequently damages by the pest are unequally distributed in the same community.

DISTRIBUTION.

As indicated in the previous chapter, the insect is widely distributed throughout the British Isles and northern Europe, including the Scandinavian peninsula, Holland, Switzerland, Germany and Austria. It apparently has not attracted attention in France and Italy. Chittenden¹ gives, as the distribution in North America, Canada and the northern tier of states in the United States. The insect is also known to be injurious in Pennsylvania, Ohio and northern Illinois. It has been reported in Maryland, Virginia, Mississippi, Florida, South Carolina, Georgia, Alabama and Colorado.

An examination of the map shows that injurious outbreaks of this insect have not been reported south of parallel 40° N. in North America nor south of parallel 50° in Europe.

HOST PLANTS OF INSECT.

The cultivated plants, cabbage, cauliflower (*Brassica oleracea*), radish (*Raphanus sativus*), turnip (*Brassica rapa*), rutabaga or swedes (*Brassica campestris*), and stock (*Matthiola*) are mentioned by Slingerland as food plants listed in European literature. The two mustard-like weeds, common winter cress (*Barbarea vulgaris*) and the hedge mustard (*Sisymbrium officinale*) are also recorded as susceptible to attack. In our work we have found maggots attacking

¹ Chittenden, F. H., *Insects Injurious to Vegetables*, p. 132, 1907.

all cruciferous crops cultivated in the region about Geneva as well as wild mustard. In the early summer the larvæ have often been collected from the roots of wild or hedge mustard, which occurs in great abundance in this region while on Long Island the creatures have been observed in the roots of white mustard (*Brassica alba*, Plate V, fig. 2). Shepherd's purse (*Capsella bursa-pastoris*) and winter cress, both very common weeds in this area of the State, have appeared so far to be immune to attacks by the insect.

ORIGIN.

Slingerland¹ states, "Like its food plants, this insect is doubtless of European origin." Then after giving a full account of the early history of the insect in North America, he concludes, "Thus the pest was introduced into this country from Europe early in the present century, perhaps first appearing in Massachusetts, from whence it gradually spread north, west, and south into the neighboring states." Slingerland seems to have arrived at the conclusion that the insect had been introduced from Europe, because its food plants were of European origin, and that the insect had been reported first at Boston from whence it spread westward.

It has been more than twenty years since this statement was made, and the insect has not yet been found injurious to any plant not of European or Asiatic origin. The wild cabbage, *Brassica oleracea* var. *sylvestris*, which is looked upon as the prototype of the large group of plants to which the term cabbage is now applied, can be found growing wild on the western shores of Europe and in England. According to Britton and Brown² the various weeds of the mustard family upon which the insect is known to feed and many others upon which the insect has not been reported, have been naturalized from Europe. Also the statement is made that many of these mustard-like weeds have been found about our principal seaports growing in soil that has been used as ballast. The suggestion is that the transportation of earth in the form of ballast has been the means of introducing the seeds of certain foreign plants into this country. The danger from this source would depend upon where the soil was taken. But it is safe to conclude that if the seeds of

¹ Cornell Exp. Sta. Bul. 78, p. 482, 1894.

² Britton and Brown, Illustrated Flora of the Northern States and Canada, 2:116, 1897.

many varieties of mustards have been imported in ballast as Britton and Brown assert, large numbers of puparia of the cabbage maggot have been brought to our shores in the same way.

If we take into consideration the number of weeks required for ships to cross the Atlantic about 1830 it would not seem possible for the insect to have been brought over in the egg or adult stages. Although infested turnips used for food on the ship-board might have carried larvæ, the probability of the species having been transported in the larval stage is rather remote. On the other hand if ballast were taken from soil at almost any point in Holland, Denmark or Sweden in which these mustard-like weeds were growing, it would be very likely to contain puparia and the conditions for introducing the insect would be ideal.

BIOLOGY OF THE INSECT.

DESCRIPTIONS OF LIFE STAGES.

Egg.—(Plate II, fig. 1). The chorion is white, glistening and marked with irregular longitudinal furrows. The egg is .34 mm. in diameter and 1.1 mm. long. The outer end, that first extruded from the ovipositor, is bluntly rounded, while the opposite end is more conical and flattened at the apex. Extending along the dorsum from this flattened area is a depression that is formed by two sutures reaching about two-thirds the length of the egg. The chorion breaks along these sutures when the larva emerges.

Larva, First instar.—The larva is .35 mm. in diameter by 1.5 mm. long. It is cylindrical and tapers anteriorly. The tubercles adorning the caudal segment are similar to those later described for the other stages, though in some specimens the bifid tubercle appears as two tubercles. There are no anterior spiracles present, which differentiates this from the later stages.

Second instar.—The size varies slightly, but the individuals average about .8 mm. in diameter and 3.75 mm. in length. The anterior spiracular process contains from eight to twelve divisions. The posterior spiracular process has only two slits which easily distinguish this from the third instar.

Third instar.—(Plate II, fig. 2). The size varies from 1 mm. to 2 mm. in diameter and from 2.5 to 8 mm. in length. It is white, fleshy, at first cylindrical and tapering anteriorly, but toward the

end of the feeding period the middle segments become much enlarged. The rear of the caudal segment is flat or slightly concave and obliquely truncate. This segment is ornamented with seven pairs of fleshy tubercles, one pair of which protrudes in the region of the anus, the others are arranged on or near the rear margin of the posterior segment. The two pairs of tubercles that protrude from the lower margin are the most conspicuous, both because of their position and larger size. Each tubercle of the central pair is slightly notched, so that it is two-pointed. This character distinguishes *brassicæ* from other species found about cruciferous plants. The rear spiracles, which are extensions of the longitudinal tracheal trunks, protrude from the center of the flattened area. They are yellow in color and slightly knob-shaped, and each contains three slit-like openings. These openings are guarded by irregular dendritic processes. In the head region a pair of black, opaque hooks protrude from the buccal opening. In close proximity to this opening on the surface of the cheek are two pairs of tubercles. The anterior spiracular processes protrude laterally from the sutures of the first and second anterior segment. This process is fan-shaped and contains ten to fourteen papilliform tubules. Before the transformation of the larva to the pupa the bifid tubercles mentioned above shrink in size and change to an opaque black. This change may occur either several days or only a few hours before pupation.

Puparium.—(Plate II, fig. 4). Elongate-ovate, bluntly rounded at the ends. The outer protective covering of the pupa is formed by the hardening and contraction of the integument of the third instar, and contains some of the characteristic structures of the larva. The two pairs of posterior tubercles, one pair of which is bifid, and which serve to distinguish the larva, are usually evident, though smaller than in the larva, due to the shrinking and hardening of the chitin. The anterior spiracular process which in the larva protrudes posterior to the first segment is located at the anterior end of the puparium. The large individuals measure 2.3 mm. in diameter by 6.5 mm. long and the small specimens 1.05 mm. in diameter by 3.52 mm. long. These are the measurements of the puparia of the overfed and the underfed larvæ. The normal individuals measure about 2 mm. by 5.5 mm.

Adult, male.—(Plate I, fig. 1). Very bristly, color generally dark with gray markings. The compound eyes occupy most of the surface

of the head and are contiguous. Face silvery gray. Antennæ black, and three-jointed. Basal segment small; third segment largest and bears a two-jointed pubescent bristle. Thorax ash gray in color with three distinct longitudinal lines on dorsum. Squamæ large. The hind body shining dark gray, rather small, elliptical, tapering and bluntly rounded at the apex when viewed from above and slightly clavate as seen from a lateral view. Abdomen ornamented with bristles which are of two sizes. The large bristles occur in rows near the rear margin of the segments, while the others, which are more numerous, are irregularly distributed. Wing veins brownish and second posterior cell broadly open. Legs black and bristly, with a tuft of short bristles at the base of the posterior femur. This tuft of bristles serves to separate the males of this species from males of closely allied forms.

Adult, female.—(Plate I, fig. 2). The female is much lighter in color than the male. The body and legs are ash gray with a tinge of brown. Eyes dichoptic. Dorsum of thorax striped as in the male, but less distinct. Abdomen slightly top-shaped, conical toward the apex, and less bristled than the male. The tuft of bristles at the base of the posterior femur, which serves to distinguish the male, is absent in the female.

The adults average about 6 mm. in length, though they vary to the same degree as the puparia.

LIFE HISTORY AND HABITS.

DURATION OF LARVAL PERIOD.

Until recently, data bearing on the length of the larval period have been meager. Bouché stated that the larval stage lasts three to four weeks, and a number of later writers have expressed similar views. Washburn gives twenty to twenty-one days as the length of the larval period.¹ As shown previously,² this time was found to be eighteen to twenty days when the larvæ were reared in the laboratory. Of more interest and of considerable more importance is the time actually required for the larva to mature in the field. During the years of 1908, '09, and '10, the eggs were being deposited about cabbage plants in large numbers, from about May 20th to

¹ Minn. Exp. Sta. Bul. 100, p. 6. 1906

² Jour. Econ. Ent., 4:214. 1911.

June 4th. During these years first brood larvæ were found in large numbers from June 10th to June 25th. It is thus seen that in the field the larvæ of the first brood require about twenty-one days to mature.

While both laboratory and field observations indicate that under normal conditions the larval stage lasts about three weeks, a large amount of data has been accumulated to show that the extent of this period may be materially altered. When disturbed or in the absence of food, larvæ have been known to pupate when they had reached only half size. It is thought that lack of sufficient moisture will also stimulate the larva to pupate. Several laboratory tests planned to determine the effect of moisture failed to yield results, because the larvæ would either die or pupate when the food became dry. It is a common experience on removing infested radishes from the soil to have the larvæ quit the plants and pupate as soon as the bulbs become shriveled. Under such circumstances there is usually much variation in the sizes of the puparia.

SELECTION OF HOST PLANTS.

There seems to be a general impression among writers on this subject that some plants are more liable to attack than others. Cook observed in 1888 that radishes were more attractive to the insect for purpose of oviposition than cabbage, and suggested the use of radishes as a trap crop. Hulst also states that cauliflower is preferred to either cabbage or radish. We have frequently noticed that where rows of cauliflower alternated with rows of cabbage, the former plants sustained greater damage. A number of cabbage growers in this community have, for several years, mixed radish seed with cabbage seed in growing their seedlings. Some of these beds have been very carefully examined and it appears that radishes generally contain more maggots than cabbages, though cabbage seedlings have always shown evidence of maggot injury and in one instance practically all of the cabbage seedlings were ruined. During three seasons cruciferous plants grown especially to determine their relative susceptibilities have been systematically examined at various times during the growing period. Also numerous inspections have been made of all the wild and cultivated cruciferæ in this locality. The general conclusion of these studies is that, while in some instances more eggs have been deposited about one variety than another,

tenderness of growth or succulency has much more to do with the degree of infestation than the variety or species of plant. In the early part of the summer maggots can be found about the roots of all varieties of cabbage seedlings and about wild mustard, while later in the summer when adults are present in considerable numbers it has been difficult to find the larvæ about either cabbage or mustard.

SEASONAL SUSCEPTIBILITY OF CABBAGE TO INJURY.

In the locality about Geneva, N. Y., where late varieties of cabbage are extensively grown, we have never been able to find during the summer any fields that were being injured by root-maggots. As just stated, these insects are always present in the spring, injuring cabbage seedlings, cauliflower, radish and other cruciferous plants and also in the fall attacking turnips, cabbage stumps, etc. Not only are injuries absent during July and August, but it is difficult to find the work of the insects on roots of the different varieties of cabbages grown in this region at the time the crop is harvested.

There are two classes of varieties of cabbage grown in this community, one locally called late cabbage, including such varieties as Holland Danish, Red Danish and Danish Ball-head, the sets being planted during early July and the crops harvested about the first of November. The other, commonly known as early cabbage, including such varieties as All Head Early and All Seasons, is planted from the first to the fifteenth of June and matures during the first part of September. The early varieties are grown for immediate consumption and for sale to kraut factories, while the late kinds are stored for winter use.

During the autumns of 1910, 1911 and 1912 numerous inspections of the fields in the vicinity of Geneva, N. Y., were made to learn particularly the extent to which cabbage stumps serve as breeding places for the pest. After cabbages are cut it is a common practice in New York to allow the stumps to remain undisturbed until the following spring. With the removal of the crop in the autumn these stumps put forth numerous shoots which continue to grow till the appearance of very cold weather. The adventitious buds or sprouts (Plate VI) are very attractive to the adults of this insect, and numerous eggs are deposited on the stalk at the bases of the buds, so that before the appearance of cold weather the sprouted stumps may be thoroughly infested with maggots. Since the late cabbage

is not taken from the fields until cold weather and after the period of oviposition has past it is practically free from injury during the autumn.

It is thus seen that during ordinary years the cabbage crop is only subject to injury by root-maggots during the spring months. The observations indicate also that the crop remnants of the varieties of cabbage that mature in September constitute the chief breeding places for the cabbage maggot in this locality during the autumn.

INJURIES BY MAGGOTS TO CABBAGE ROOTS.

When the root of the seedling cabbage or cauliflower is attacked, the young larva directs its activities at first to the cortex of the stem just below the surface of the soil. Later the entire stalk may be consumed or the larva may confine its work to a more or less irregular groove. When the seed bed is badly injured it is usual to find seedlings in which only a few withered leaves and the outer epidermal structures of the stalk remain, the larvæ having mined the interior of the stalk and the largest petioles after exhausting the food at the root (Plate IV). The laceration of the root by the larva is often accompanied by decay of the injured parts. When the body of a radish or turnip is attacked, the larvæ are most often found in hidden tunnels in the cortex, though the tunnels frequently penetrate more deeply (Plate V). Sometimes these channels are mere grooves, the epidermis having been destroyed. The channels made by the larvæ in the aerial part of a cabbage stalk are nearly always found in the cortex and are hidden by the thin outer bark (Plate VI).

The size of the channels is about the same as the girth of the maggot. They extend in no definite direction, occasionally being straight, but more often winding or zigzag. The newly made tunnels are clean, but later they frequently become browned and discolored, due to the decay of the exposed tissues.

PUPARIUM.

As shown later, the length of the pupal period depends upon the conditions surrounding the puparium. The pupa stage lasts, ordinarily, from twelve to eighteen days for most individuals, while a few pupæ require two to three months. The brood that hibernates remains in this stage for five to eight months, and an occasional

pupa of the hibernating brood may require eight or ten months to develop.

The puparium of the cabbage maggot is found in the soil in close proximity to the roots of cruciferous plants. In examining infested cabbage seed-beds during June for first brood puparia, the observation has frequently been made that at least ninety per ct. of the individuals are found within three inches of the injured plant and in the first three inches of soil. A great many specimens can be found within an inch of the plant and rarely a puparium may be found in the injured seedling. This is more likely to occur in plants having a tuber-like root, such as turnips and radishes. In autumn the hibernating brood occurs at a slightly greater distance from the injured root than the spring brood. At this season the puparia are frequently found at a depth of four inches and at a distance of five or six inches from the plant. When the aerial parts of the plant become infested, such as sprouted cabbage stumps and cabbages that have put forth second growth, a small percentage of the larvæ pupate in the upper part of the plant.

The tendency of the larva to migrate from the infested plant has a very important bearing on the numbers that would reach maturity. This is especially true when the insect infests root crops grown for stock feed. If the larvæ were to pupate in the turnips or Swedes grown to be used as succulent feed during the winter, they would largely be destroyed.

PERIOD OF EMERGENCE OF ADULTS OF THE SPRING BROOD.

There are many observations on record as to the time the first adults of *P. brassicæ* appear in the spring, but apparently no data have been collected as to the number of days required for the entire brood to emerge. To secure information on this point an arrangement was made with Mr. O. W. Winburn, Geneva, to place cloth screens over an infested stump field to entrap the flies as they emerged from the soil. The field selected for this purpose was one that had been planted to early cabbage the year previous, the crop having been taken during September and the stumps permitted to sprout. Some of these stumps had become badly infested with maggots before cold weather stopped their growth. The ground for the experiment was divided into three plats, one of which was not cultivated, the other two being plowed six and nine

inches respectively. Tight cheesecloth frames six by eighteen feet were erected over each plat and the flies collected as shown in Table I.

TABLE I.—A RECORD OF THE EMERGENCE OF CABBAGE MAGGOT FLIES AT SENECA CASTLE DURING 1911.

DATE OF COLLECTION.	Plowed 6 inches.	Plowed 9 inches.	Not plowed.	Total.
April 29.....	Screened.....			
May 4.....	.....	Screened.....	Screened.....	
May 9.....	5.....	.....	7.....	12
May 15.....	6.....	.....	2.....	8
May 19.....	1.....	14.....	3.....	18
May 27.....	21.....	.....	1.....	22
June 2.....	14.....	.....	.....	14
June 7.....	3.....	.....	.....	3
June 14.....	2.....	.....	2.....	4
June 14.....	Screens removed.....	.....	Total.....	81

Attention is directed to the fact that the adults continued to emerge over a considerable period; in this case, from May 9th to June 14th or thirty-six days. The number collected from each of these plats is too small to indicate the effect of cultivation upon their emergence.

DEPTH OF SOIL THROUGH WHICH ADULTS EMERGE.

Washburn¹ reports an experiment in which pupæ of *P. brassicæ* were buried out of doors at depths of 1, 2, 3, 4, 5 and 6 inches. No adults emerged from the lots buried one and six inches respectively in the soil and he states, "It would seem that the flies were not able to penetrate through six inches of soil under conditions as nearly like outside conditions as possible," Card and Stene² found *Rhagoletis pomonella* able to emerge from a depth of six inches, though normally larvæ of this species pupate in the first inch of the soil. Stiles and Gardner,³ while working with *Musca domestica*, had thirty-seven flies emerge from puparia buried in sand to a depth of forty-eight inches. These experiments show that some diptera are adapted to pushing their way through a considerable depth of soil.

¹ Minn. Exp. Sta. Bul., 112, p. 204.

² Md. Exp. Sta. Ann. Rpt. 1904, p. 192.

³ U. S. Pub. Health & Mar. Hosp. Serv. *Public Health Repts.* 15:1829. 1910

On June 23, 1906, several pots were prepared and fourteen puparia of *P. brassicae* were planted in each, ranging in depths from two to twelve inches. By August 16th adults had emerged as follows:

Depth of Puparia in Soil.	Number of Adults Emerging.
2 inches	1
4 inches	1
6 inches	0
8 inches	2
10 inches	5
12 inches	3

The soil used in this case was a clay loam, which was only slightly compacted. The pots were kept in the laboratory. The fact that some flies were able to emerge from such depths, even under the most favorable circumstances, would certainly discourage any efforts to control the insect by cultivation which had as its object deep burial of the puparia in the soil.

DISPERSION OF ADULTS.

Winds play an important part in the distribution of insects. Popenoe¹ in his work with the potato beetle along the east shore of Virginia observed that an off-shore wind carried great numbers of the hibernating individuals out to sea where they perished, the beach often being covered with windrows of the dead beetles. Hartzell² reports that large numbers of rose chafers were washed up on the shore of Lake Erie, near Westfield; and in the summer of 1906, we found dead May beetles along the northeast beach of Seneca Lake. Similar observations on other species of insects have been recorded in literature.

In our studies about Geneva and Seneca Castle, N. Y., it appears that cabbage is the chief breeding place of the root maggot and that a majority of the insects hibernate in fields where the stumps are left standing, but in most seasons the injury, when present, is so general that it is not possible to learn whether or not the injury to the seed-bed is influenced by being located near a stump field. Here cabbage is extensively grown and our observations indicate that the insect, especially when abundant, becomes pretty thoroughly distributed. Frequently the space between cabbage fields is often not much greater than the fields themselves, so that only a small

¹ U. S. D. A. Ent. Bul. 82, p. 1.

² From records of the N. Y. Agricultural Experiment Station.

amount of dispersion is necessary. In years when the adults are not so numerous or in other localities that are not so exclusively devoted to this crop, the insects are likely to be more abundant in close proximity to the fields than elsewhere. Also, it has been observed in some years that seedlings in cabbage-growing localities have been pretty generally destroyed, while on farms a few miles distant the seed-beds were in excellent condition.

FEEDING AND OTHER HABITS OF ADULTS.

The difficulty of breeding *P. brassicæ* and other diptera has been mentioned by several workers. Slingerland¹ in his study of this species was unable to obtain eggs, though his cages contained hundreds of adults. Washburn,² however, finds that adults which have matured in the field will oviposit in cages, but he does not state their egg-laying capacity. Hewitt³ in his investigation of *Musca domestica* speaks of certain difficulties in rearing this insect.

The adults used in our efforts to breed *P. brassicæ* were mostly those that had emerged in cages in the laboratory, and some fresh-looking individuals captured at large. In addition to supplying them with water and some cruciferous plants for purposes of feeding there were also furnished banana, sugar water and blossoms of the common weeds in this community, including wild mustard (*Sisymbrium officinale*), wild carrot (*Daucus carota*) and the milk-weed (*Asclepias* sp.). The adults were seen to visit the blossoms and to feed greedily upon the sweetened mixture and half decayed banana. Usually they were quick to detect the presence of dilute molasses or sugar syrup when a drop was placed in the cage, often locating the food in a few seconds. When adults were put in cages in the laboratory without food they lived only two or at the most, three days, while with food and water regularly supplied, the length of life ranged from two to four weeks; and in one instance a female lived forty-eight days in a lantern globe. This individual emerged in the laboratory and was first observed April 18th. For the last two weeks of its life the fly was not very active, and for three or four days before it died was hardly able to crawl. The posterior third of both wings had been worn away and one of the tibiæ was lost. In the abdomen were found thirteen full-sized eggs, the chorion of which

¹ Cornell Exp. Sta., Bul. 78, p. 513.

² Minn. Exp. Sta. Bul. 100, p. 5.

³ Hewitt, C. Gordon. The House Fly, p. 64. 1910.

appeared mucilaginous and somewhat smooth in contrast to the usual clean-furrowed ova.

The facts brought out by the cage work has been the fondness of the adult for sweetened water and the necessity for food and moisture for its sustenance.

In the field various species of *Anthomyidæ* are present in this latitude from May until October. They are conspicuous during the latter part of May and June, and the species affecting cabbage can be found about fruit blossoms and flowers of certain weeds. Frequently while apples are in bloom adults have been taken with pollen clinging to the legs and chætæ. After the period of fruit blossoming the flies are found in abundance about wild mustard blossoms. Later in the season the adults become scarce and usually during August are difficult to find, though they reappear in September. Observations on the relative abundance of adults during the different summer months are presented in chronological order in Table IV. The activities of the flies during the day are influenced to a marked degree by the weather. During early morning and on cool or windy days, the adults remain in hiding and may usually be taken by sweeping mustard or cabbage. At such times they have been frequently seen on the under side of the plants. During the warmest part of a cool day adults of this and other species have been collected along warm, sunny paths and about protected situations.

Low temperatures, of course, reduce the number of eggs deposited;¹ but windy weather, during which the adults remain in hiding, does not act upon the insects in the same manner. During the occurrence of strong winds, adult females have been found in chinks in the soil, and in crevices about cabbage plants. The swaying of the seedling after a rain pushes back the earth at the surface, forming a small pocket by the stalk. This seems to be a favorite retreat during a strong wind, and large numbers of eggs have been found at the lower extremity of this pocket in the afternoons of windy days. Freshly plowed or cultivated soil attracts the flies. They have been observed many times in recently turned furrows where they appear to feed.

Our observations indicate that during periods favorable for oviposition the females are found on the soil and near cruciferous plants, while the males confine themselves largely to the foliage of weeds and shrubs. On May 24, 1909, while inspecting some

¹ *Jour. Econ. Ent.* 4:211.

cabbage seedlings in a truck garden near Waterloo, N. Y., a number of males were noticed on onion tops, and nearby, on freshly stirred soil from which onions had recently been taken, a number of females. Although the flies were closely observed for some time, they were seen only to walk over the moist soil, occasionally stopping as if to lap moisture. The males appeared to bask in the sun, and remained quiet except for rubbing together the hind tarsi. This habit of the males of resting on shrubbery while the females are on the ground feeding or ovipositing has since been observed many times. Apparently they choose no special kind or size of plant, and in addition to weeds they have been taken on leaves of young elm, wild blackberry, strawberry, grape, aster and wild mustard.

APPEARANCE OF ADULTS IN RELATION TO THE BLOSSOMING OF FRUITS.

During eight seasons this insect has been under our observation, the first of the adults to emerge in the spring have appeared during the first two weeks of May, the actual time of appearance depending somewhat on the weather. The period of the first appearance of the flies as compared with the blossoming of our common fruits is shown in Table II.

TABLE II.—THE APPEARANCE OF ADULTS OF *P. brassicae* AS COMPARED WITH THE BLOOMING TIME¹ OF CHERRY, APPLE AND PEAR.
(Data for Geneva, N. Y., for six years.)

	1907.	1908.	1909.	1910.	1911.	1913.
Adults appearing	May 16.	May 12.	May 13.	May 12 ²	May 6.	May 1.
FRUIT BLOOMING:						
Cherry, Windsor....	May 15	May 12	May 13	Apr. 18	May 5	Apr. 26
Cherry, Montmorency.....	May 18	May 18	May 18	May 1	May 11	May 2
Apple, R. I. Greening.....	May 31	May 23	May 27	May 9	May 18	May 4
Pear, Bartlett.....	May 24	May 19	May 19	Apr. 30	May 13	May 1

¹ The blossoming time of fruits was kindly supplied by O. M. Taylor of this Station.

² During April of 1910 the weather was unusually warm. This is indicated by date at which the Windsor cherry bloomed that year. On April 29th flies were present about cabbage seed beds at Geneva, and some anthomyids were taken. Although these individuals could not be definitely identified as *P. brassicae*, it is very probable that this species was present in small numbers. The weather turned cool immediately following April 29th and no more collections were made until May 12th when the identity of the insect was established.

Two interesting facts are suggested by this table: First, abnormal seasons affect the emergence of the adults and the blooming of tree fruits in much the same way; and second, the flies appear about the same time that the Windsor cherry is in bloom.

INTERVAL AFTER EMERGENCE OF ADULT BEFORE EGG DEPOSITION.

Our field observations have yielded no definite information on the extent of the preoviposition period except that eggs have been found either the first day adults were observed in the spring, or within the next two or three days. Since adults that emerged in captivity have not been induced to oviposit in cages any data secured in breeding-cage work is open to question. Notwithstanding this fact, numerous dissections were made both of females that emerged in cages and of individuals captured at large. In Table III are shown the measurements of the ova of adults that emerged in cages. These adults had been fed upon sugar water and egg albumen. The data show that the eggs attained full size in about seven days, even when the insects were in captivity. It is believed that during favorable weather the adults would mature even sooner in the open and would normally oviposit in from three to five days after emergence.

TABLE III.—MEASUREMENTS OF OVA IN THE OVIDUCTS OF ADULTS OF *P. brassicæ*.

POSITION OF EGGS IN IN OVIDUCT.	Adult just emerged.	Adult emerged 3 days.	Adult emerged 7 days.	Adult emerged 14 days.
Largest ova (1)	190 x 240 microns	180 x 270 microns.	220 x 960 microns eggs apparently mature.	Ova mature.
Ova next to above (2) . .	90 x 100 microns.	. . . . .	190 x 240 microns	210 x 360 microns.
Ova next to above (3) . .	. . . . .	. . . . .	110 x 110 microns.	120 x 120 microns.
Ova next to above (4) . .	. . . . .	. . . . .	100 x 100 microns.	80 x 80 microns.
Ova next to above (5) . .	. . . . .	. . . . .	. . . . .	60 x 60 microns.

DETAILS OF OVIPOSITION HABITS.

Selecting location for egg-laying.—Generally the female alights on the outer margin of a leaf, which is examined in several places, the adult always running quickly from one place of inspection to another. After spending several seconds on the upper margin of the leaf the insect passes down the petiole and stalk to the ground. The plant may be encircled several times at a distance of one-fourth to three-fourths of an inch from the stalk, the female dragging the extended ovipositor over the soil. When, in walking about, the female detects a crevice, she backs into it, and apparently examines its character with the extended ovipositor. Frequently the female has been seen to make several trips from the soil to the tip of the leaf before ovipositing. In the observed cases only one egg was deposited, but the fact that eggs may be found in batches indicates that a number of them may be deposited at one time.

Number of eggs deposited by one female.—Numerous females were dissected to ascertain the number of eggs that they normally carry. Those with medium-sized abdomens averaged about twenty eggs, while individuals with heavy abdomens contained fifty or more fully developed ova. The following examination of a collection made August 15, 1910, is typical. The abdomens of six females contained, respectively, 21, 24, 27, 30, 39, and 54 mature eggs. Each ovarian follicle contained three immature ova that showed some development, the largest being about one-fourth the size of those mature. This suggests that under favorable circumstances three or four batches of eggs might be deposited, especially since the adults are probably active four or five weeks. In this case, as with other insects, the number of eggs found in the abdomen may bear very little relation to the number oviposited. Hewitt, in speaking of the house fly, which is a closely related species, says that "A single fly lays from one hundred and twenty to one hundred and fifty eggs at one time and may deposit five or six batches of eggs during its life." If the period of oviposition of the cabbage fly extended several weeks, as in the case of *Musca domestica*, some individuals might deposit two hundred or more eggs, while those flies that mature only one batch will average forty to fifty eggs.

NUMBER OF BROODS.

The number of broods of the cabbage maggot has been a mooted question. Bouché and Taschenberg made only general statements regarding the number of broods. These have been repeated by later workers or the number of broods has been estimated on the basis of the time required for the first brood. Thus Cook ¹ in 1874 concluded that there were two or more broods, while Riley ² in 1884 thought there were not less than three. The students of this insect have, with few exceptions, confined their attention largely to the first brood. Slingerland ³ traced two broods and stated that the life history becomes complicated in July and August. Washburn ⁴ has constructed a diagram showing the life history from April 30th to Sept. 26th. This includes two complete broods and the adults of the third. Smith ⁵ states that, "There are three or more broods in a season, and the maggots may infest chiefly the wild, cruciferous weeds rather than the cultivated plants. There is, however, a brood that becomes noticeable late in the season, part of which reaches maturity the same year and part of which passes the winter in the puparium stage and changes to adult flies in the spring. It seems probable that not all the puparia found about the plants in the winter are from the late brood of maggots, but that some are from those of earlier maggots, so that the puparia in hibernation may be from all of the broods."

Our observations indicate that *as a rule the insect is three-brooded in this latitude*, though it is quite probable that in favorable seasons a portion of the insects are four-brooded, and in many summers they are mostly two-brooded. The following notes, bearing on the number of generations of the insect are based on field observations and breeding records.

Broods observed during 1909: First brood.—The flies began to emerge about May 15th and were present in considerable numbers from May 20th to June 1st, as shown by the oviposition records.⁶ It is probable that the bulk of the first brood emerged during the ten days of May 16th to 25th.

¹ Rept. Mich. Bd. Agr., p. 119, 1874.

² U. S. D. A. Rept., pp. 319-331, 1884.

³ Cornell Exp. Sta., Bul. 78, p. 515.

⁴ Minn. Exp. Sta., Bul., 100, p. 17.

⁵ N. J. Exp. Sta., Bul. 200, p. 9.

⁶ Jour. Econ. Ent. 4:211.

Second brood.—The emergence of the second brood during the same season was well defined by our collections from a plowing experiment.¹ These data show that the majority of the adults appeared between June 25th and July 3rd, though they continued to emerge during the rest of the month.

Third brood.—The adults were collected as in the previous brood, as they emerged from a bed planted to turnips and cabbage. In this case the collections indicate that the majority emerged between August 26th and Sept. 4th, though, as in the second brood, the total period of emergence lasted four or five weeks.

Broods observed during 1910: First brood.—A few anthomyids were collected in the latter part of April and though not definitely identified, adults of *P. brassicæ* were undoubtedly present at that

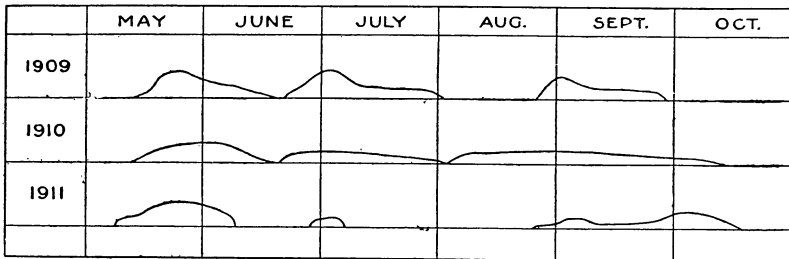


FIG. 1.—DIAGRAM SHOWING NUMBER OF BROODS AND PERIODS OF APPEARANCE ABOUT GENEVA, N. Y., DURING 1909, 1910 AND 1911.

time. Specimens of this species were abundant in the field from May 16th to June 9th.

Second brood.—Adults emerged almost daily from June 21st to August 2nd in outside breeding cages. Our records show that the numbers were greater between June 30th and July 8th than at any other time during this period. As the flies were all reared from eggs and pupæ of the first brood there is no doubt as to which brood these particular adults belong.

Third brood.—During this season adults were abundant in the field from August 3rd to October 3rd. A few were observed until October 14th. Certainly these were mostly third-brood flies, though the possibility of a partial fourth brood during this period is evident.

¹ Jour. Econ. Ent. 4:211.

Broods observed during 1911: First brood.—Adults were collected as they emerged from a cabbage-stump field, the period lasting from May 9th to June 14th. Adults were observed in the field three days prior to the first date and they were numerous in the field about June 6th.

Second brood.—Puparia secured from a sandy soil near Rochester produced flies in large numbers from June 9th to 16th. A small percentage of the puparia from this locality produced flies during the period of June 30th to July 6th. No adults emerged in the laboratory after this date until the first of September and during this time adults were very scarce in the field.

Third brood.—A few first-brood pupæ transformed to adults early in September, and these made their appearance during the period of Aug. 31st to Sept. 9th. At these dates adults were still very scarce in the field and continued so until the 23rd of September. They were conspicuous in several fields from the above date until October 8th.

TABLE IV.—OBSERVATIONS ON *P. brassicae* FOR THE YEARS 1909–10–11.

(Arranged in chronological order.)

Date.	1909.	1910.	1911.
May 8	.....	.....	Adults abundant.
May 12	.....	Few adults in sunny places.	.....
May 13	Two adults.....	.....	Adults numerous.
May 14	Adults on chickweed blossoms.	.....	.....
May 16	Few flies close to ground	Flies scarce.	.....
May 19	Adults numerous.....	Few adults on shrubs and mustard.	Adults numerous.
May 22	A few hiding in cracks in soil in pea field.	.....	.....
May 24	Adults ovipositing.....	.....	Adults abundant about radish roots.
May 27	.....	Adults hiding in soil...	Not so numerous.
May 28	Adults ovipositing.	.....	.....
June 2	Males numerous on weeds at 7 A. M. No females.	Flies numerous on vegetation.	.....
June 6	.....	Eggs still being deposited.	Adults more numerous than for several days.

TABLE IV (continued).

Date.	1909.	1910.	1911.
June 8	Mustard in bloom. Flies about blossoms and roots.	No eggs deposited. Adults taken by sweeping mustard.	
June 10	Few adults collected		Few adults in the field.
June 17	.....	Adults not numerous. . .	Adults emerging in abundance in laboratory 10th to 17th.
June 20	June 20th to July 8th. Adults emerging in considerable numbers.	June 20th to Aug. 2nd. Adults emerging in sparing numbers both in cages and out side.	
June 25			
June 29			
July 8			
July 15			
July 20			
July 25			
July 30	.....	Flies very abundant about tops of cabbage plants.	June 20th to Aug. 20th adults very hard to find in field. None emerging in laboratory.
Aug. 1			
Aug. 3	.....	
Aug. 8	.....	Females numerous about cabbage and peas.	
Aug. 11	.....	Females observed at droplets of dew on cabbage.	
Aug. 15	.....	Females heavy with eggs.	
Aug. 24	.....	Adults collected by sweeping turnips.	Adults very scarce.
Aug. 25	Aug. 25th to Sept. 5th. Adults emerging in considerable numbers.	Adults numerous.	Aug. 30th to Sept. 10th very few adults emerging in laboratory.
Aug. 30			
Sept. 5			
Sept. 10	Sept. 5th to 22nd few adults emerging.	Adults numerous.	Males very scarce. Males very scarce.
Sept. 16			
Sept. 18			
Sept. 20			
Sept. 23			
Sept. 29	.....	Few adults.	Adults observed.
	.....	Few adults on cabbage and turnips.	Adults very scarce.
Sept. 30	.....	Adults collected on mustard.	

TABLE V.—AVERAGE MONTHLY TEMPERATURE READINGS AND PRECIPITATION DURING CABBAGE MAGGOT ACTIVITY.

(Precipitation in *Italic*.)

	May. Max. Min.	June. Max. Min.	July. Max. Min.	Aug. Max. Min.	Sept. Max. Min.
1909.....	69.8 40 <i>2.83</i>	79.2 55.3 <i>2.17</i>	81.6 57.6 <i>2.04</i>	83 56.9 <i>2.21</i>	76.2 50.8 <i>2.22</i>
1910.....	65.8 44 <i>3.45</i>	76.9 53.5 <i>1.55</i>	85 61.3 <i>2.39</i>	80.8 57.2 <i>5.47</i>	74.1 52.4 <i>3.29</i>
1911.....	79.3 50.5 <i>1.36</i>	79.1 55.9 <i>2.51</i>	88.2 60.7 <i>4.49</i>	82.2 59.6 <i>3.36</i>	73.8 51.8 <i>3.21</i>
Average precipitation for previous 20 years.....	<i>2.94</i>	<i>3.33</i>	<i>3.71</i>	<i>3.30</i>	<i>2.40</i>

SUMMARY OF DATA BEARING ON NUMBER OF BROODS.

The statements presented in the previous paragraphs are based on data resulting from the collection of adults as they emerged from infested cabbage seed beds supplemented by numerous field collections. These data show first that adults are always present in large numbers during the latter half of May. This has not only been true during the eight seasons covering these observations, but the fact has been noted by all persons who have studied this insect. However, the most important fact that has been brought out by the life history studies is that the number of adults present during July and August varies from year to year. In some seasons the adults are comparatively numerous during this period and during other seasons there are practically none. Some effort has been made to correlate the numbers of adults with certain conditions of summer weather. It appears that varying percentages of the adults of the second brood are delayed in emerging and that these delayed insects may remain in the pupa stage for six or eight weeks and emerge about September first.

In this connection, attention is called to Table V. The average of the daily maximum temperatures during May, 1910, was 65.8° F. with a precipitation of 3.45 inches. As compared with these records the weather of May, 1911, was as follows: Average of maximum

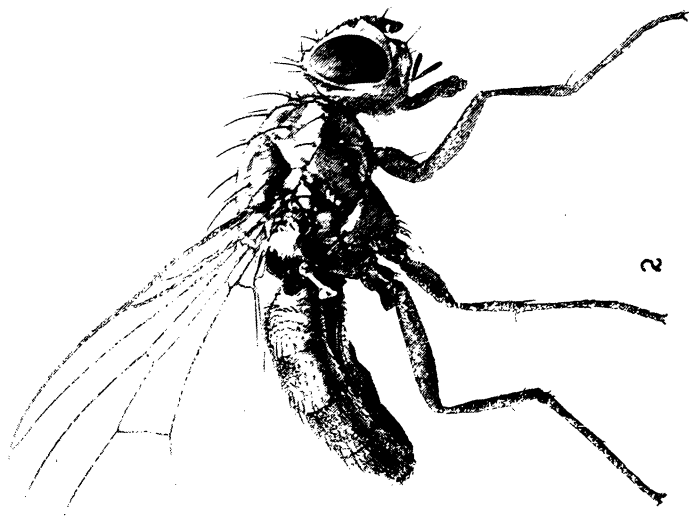
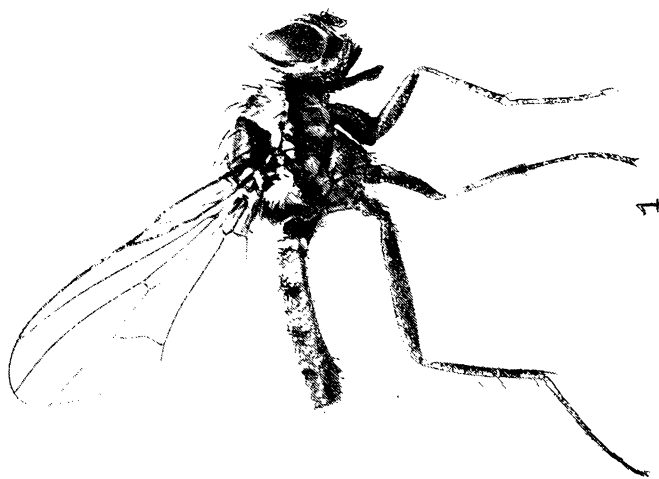


PLATE I.—ADULTS OF CABBAGE MAGGOT: 1, MALE; 2, FEMALE.

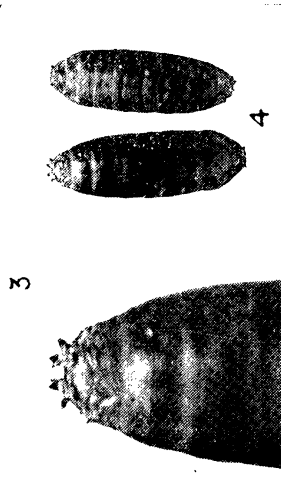
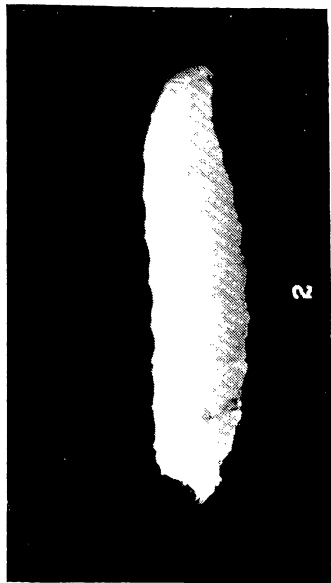
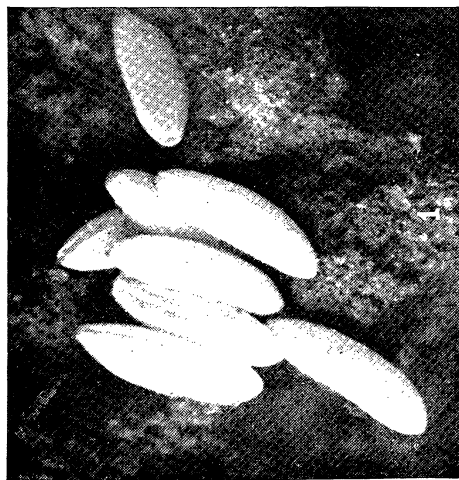


PLATE II.—LIFE STAGES OF CABBAGE MAGGOT.

1, Eggs, much enlarged; 2, lateral view of larva; 3, bifid tubercles of anal segment of puparium, greatly enlarged; 4, puparia; 5, channels in sand by emerging flies and staphylinid beetles.

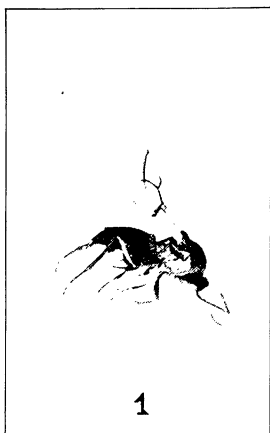


PLATE III.—PARASITIC AND PREDACEOUS ENEMIES OF CABBAGE MAGGOT.
Cynipid adult (1) and pupa (2); staphylinid pupæ (3) and adult (4).

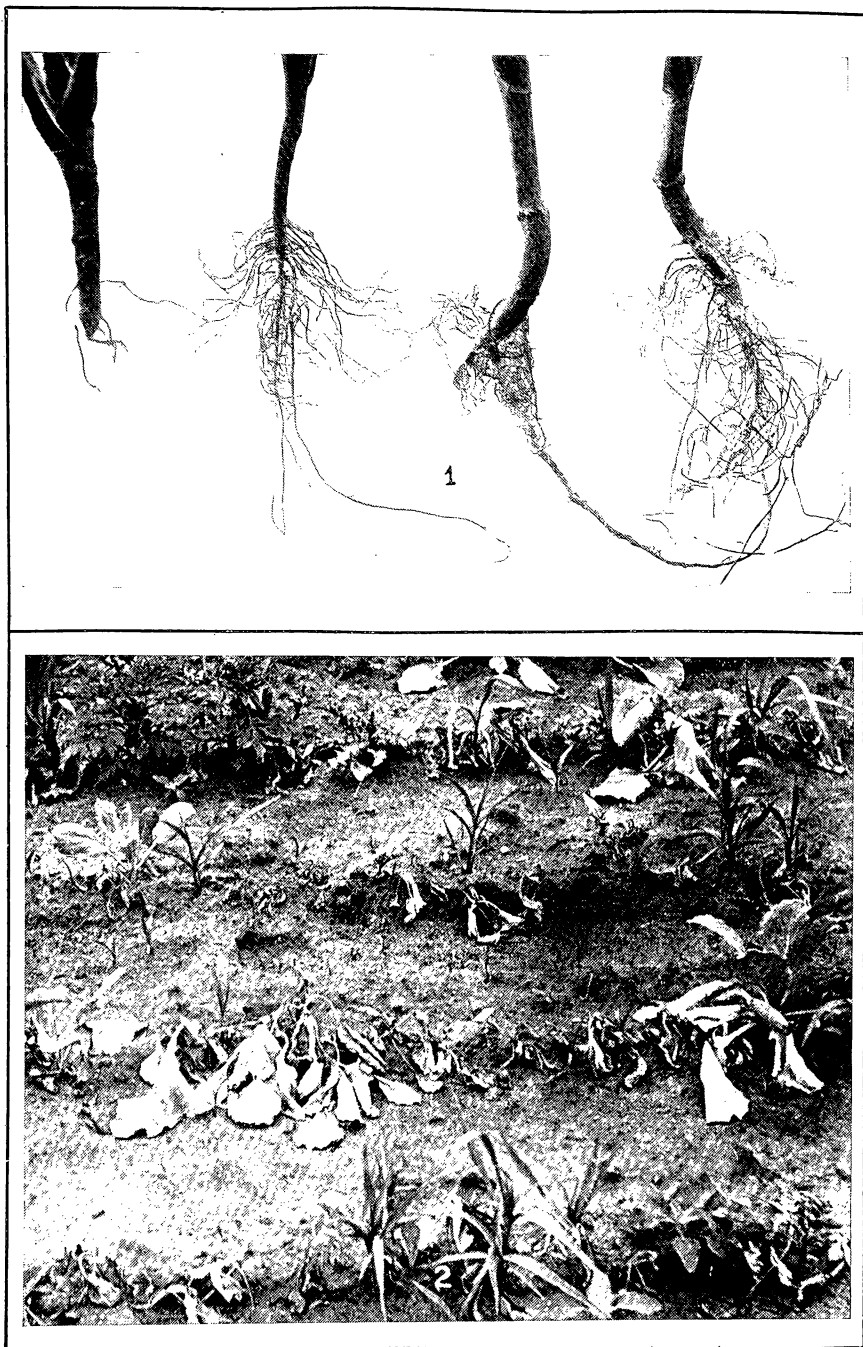


PLATE IV.—INJURIOUS WORK OF CABBAGE MAGGOT.
1, Different degrees of root injury; 2, damages to seed bed.

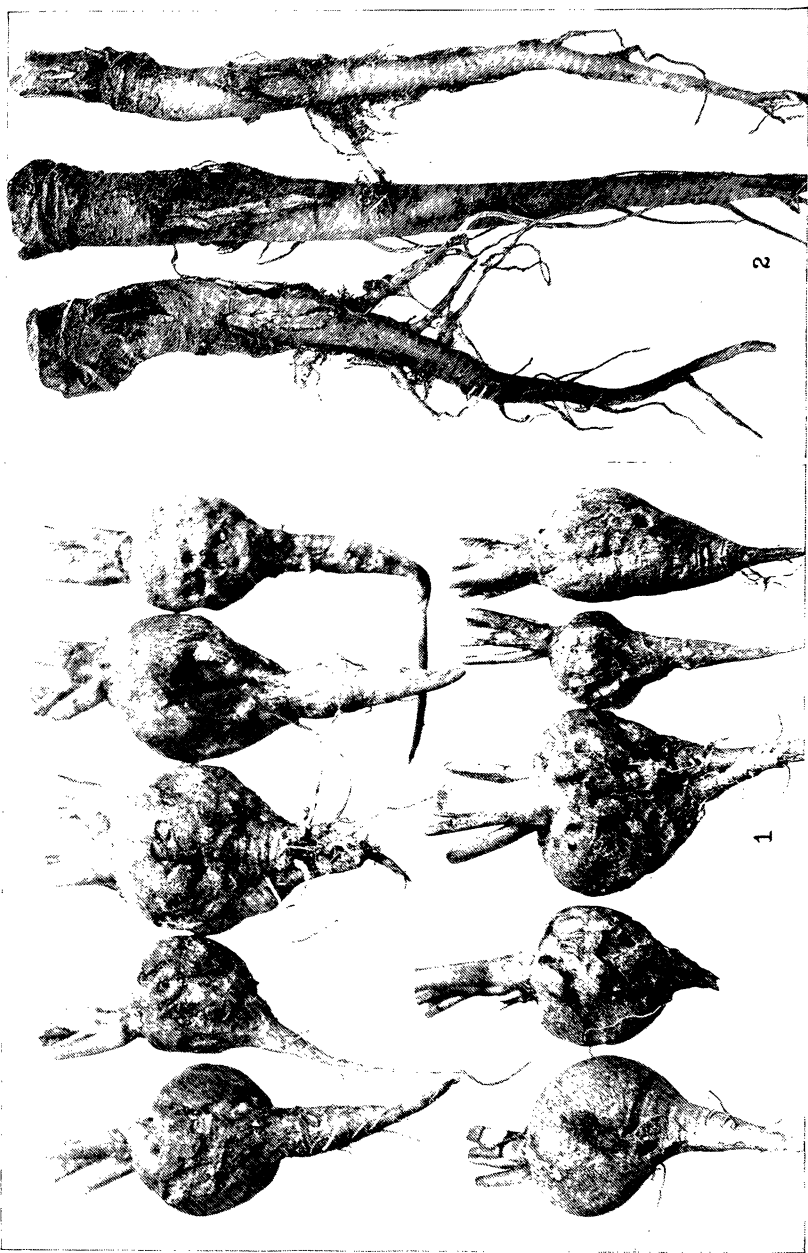


PLATE V.—INJURIOUS WORK OF CABBAGE MAGGOT ON RADISHES (1) AND WHITE MUSTARD (2).

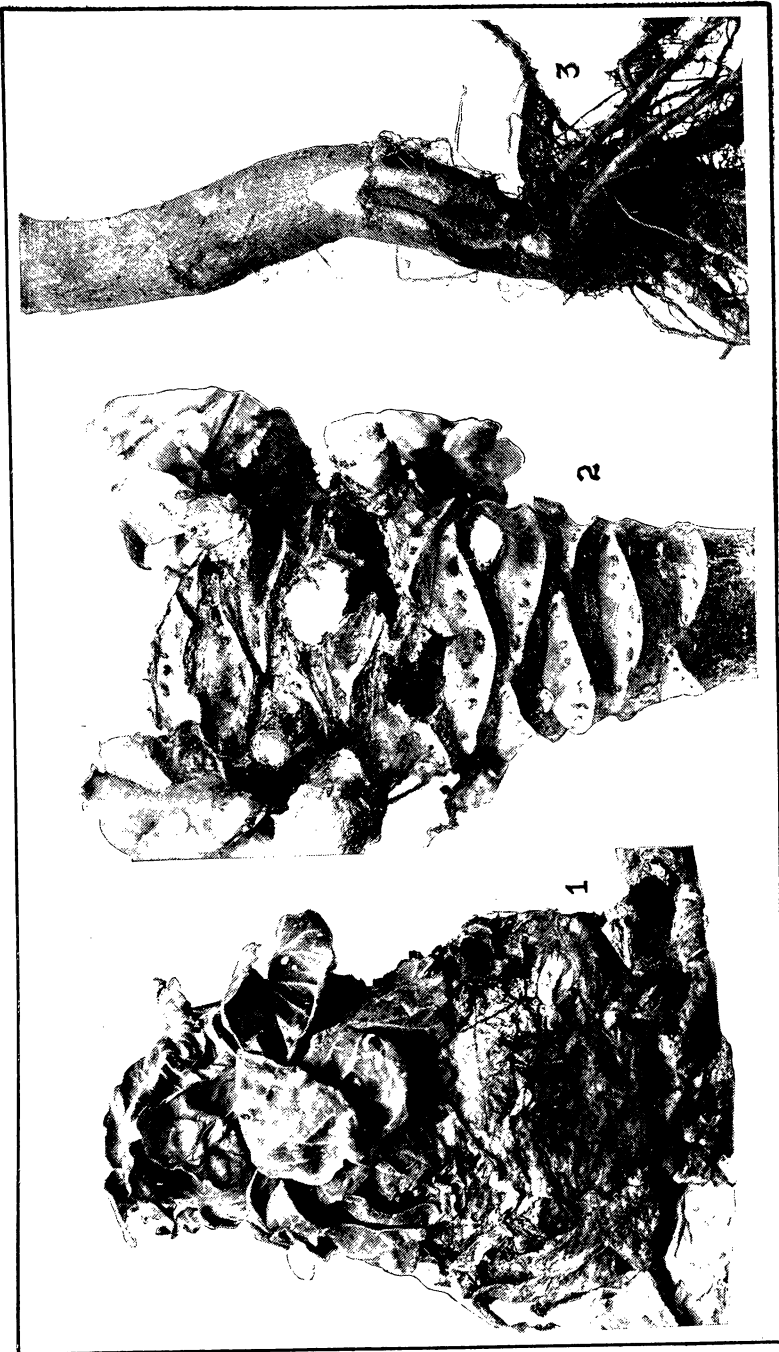


PLATE VI.—DAMAGES BY FALL BROOD OF CABBAGE MAGGOT ON SPROUTED CABBAGE (1), CABBAGE STALK (2) AND CABBAGE ROOTS (3).

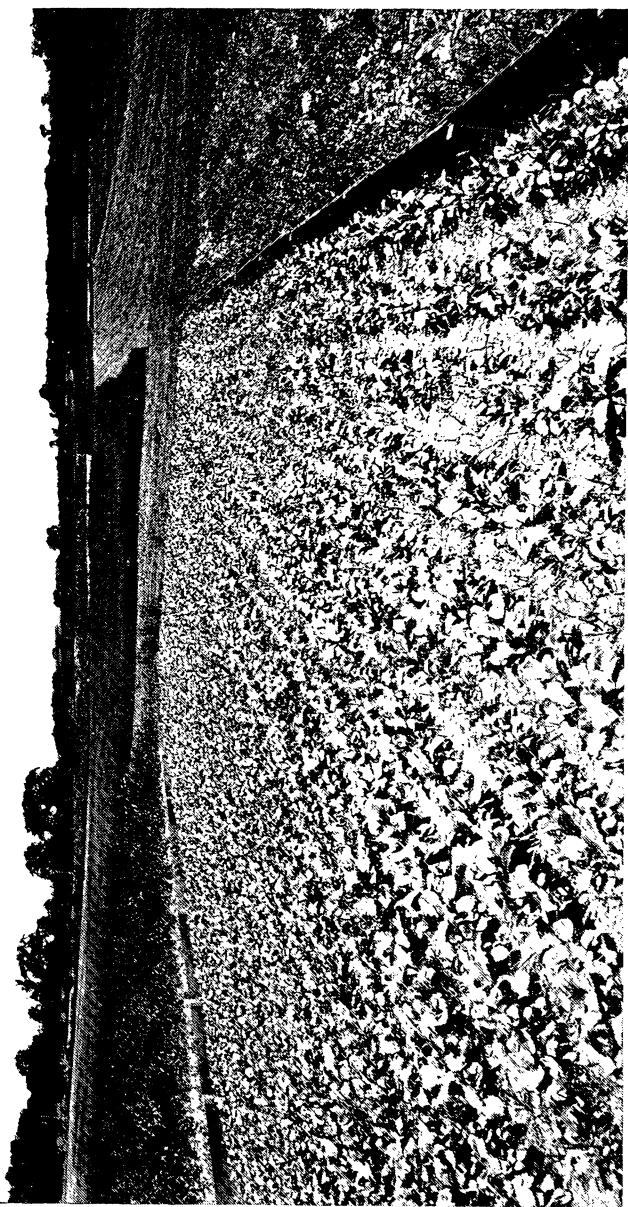


PLATE VII.—CABBAGE SEED BED PROTECTED DURING EARLY GROWTH BY CHEESECLOTH SCREEN.

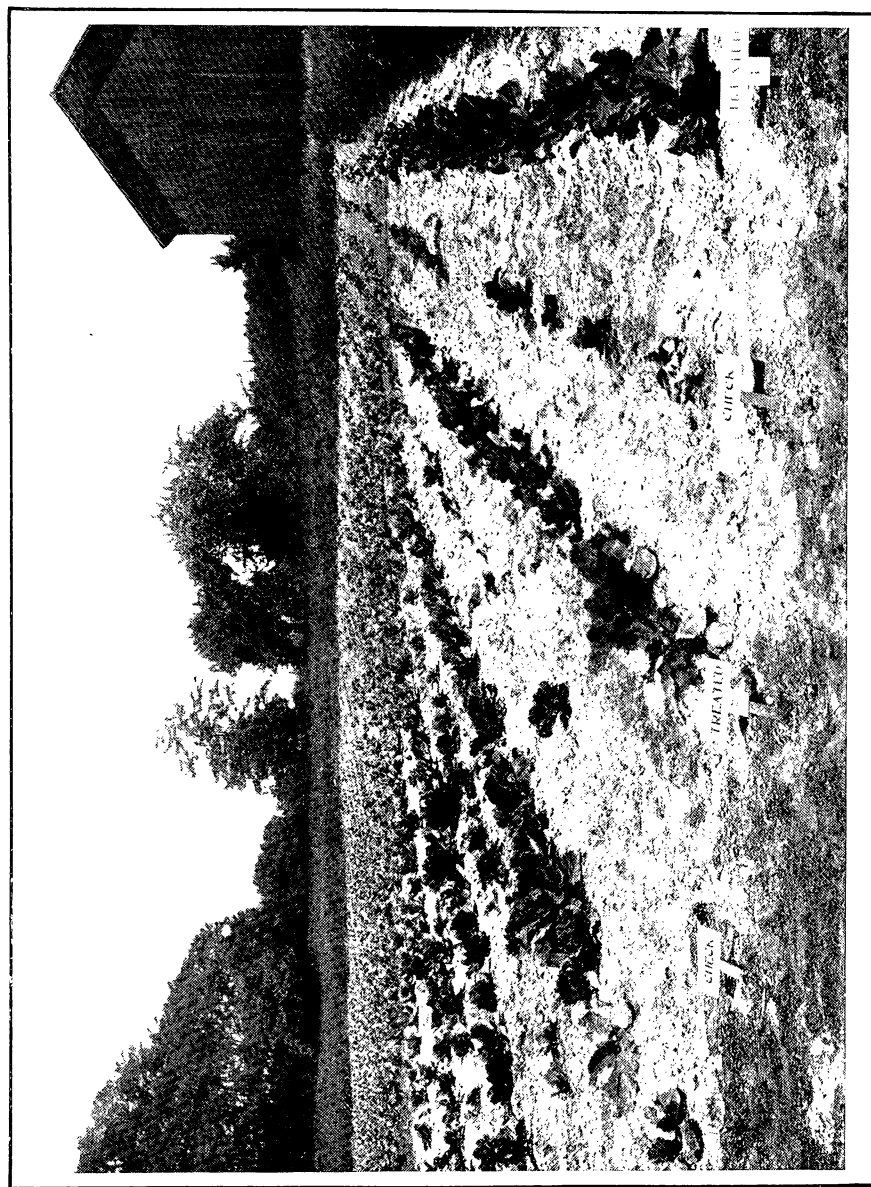


PLATE VII.—PROTECTING EARLY CABBAGE BY TAR-PAPER DISKS.

temperature 79.3° F., precipitation 1.36 inches. It will be observed that there is a difference of 13.5° F. in the averages for this month during these two years.

The experimental data presented in a later chapter suggest that these differences in temperature may, in part, account for the retardation in the time of appearance of some individuals.

In addition to any direct influence meteorological conditions may have on the development of the insect and the numbers that mature, there is always an indirect effect due to the influence of the weather upon the growth of the plants. It seems very logical to assume that the numbers of larvæ that reach maturity would depend somewhat upon the rate of growth and the succulence of the host. If a number of young larvæ infested a small plant that was making a slow growth, all individuals might fail to mature, whereas, if the seedling were growing rapidly it would support a number of larvæ without being seriously affected. During July and August both wild and cultivated cruciferous plants make a hard woody growth and this is unfavorable to the younger stages of the insect.

In conclusion, it is apparent from the foregoing data that there have been differences in the time of the appearances of the later broods, and that these have been coincident with abnormal precipitation and temperature. This situation has been interpreted in the same way as that outlined by Osborne¹ and Webster² for the Hessian fly, which is that high temperature or severe drouth causes a retardation of developing larvæ and pupæ.

The weather in this climate varies considerably from year to year. Some summers are characterized as wet, others as dry and hot. These differences have an important influence on the growth of cabbage, and it follows that the insects feeding upon this crop are to some extent affected. Abundant moisture makes an abundance of succulent growth which is very favorable to root-infesting insects; dry, hot weather produces a stunted woody growth upon which maggots feed very little or not at all. In addition to this indirect effect, all stages of the insect are influenced directly by weather conditions. The activity of the adult is probably shortened for want of moisture in dry, hot weather, and there occurs in the juvenile stages a retarda-

¹ U. S. D. A. Ent. Bul. 16, N. S., p. 24.

² U. S. D. A. Ent. Cir. 70, p. 11.

tion in development during which the insect remains dormant until the return of suitable conditions.

HIBERNATION.

Peter Friedrich Bouché, in his *Naturgeschichte der Insekten*, 1834,¹ says, "Spätlinge überwintern theils als Fleige, . . . theils als Puppe in der Erde." Curtis in *Gardeners' Chronicle*, 1841,² continues, after describing the summer broods, "later families lying in the pupa state through the winter, and most probably some of the flies survive that season secreted in holes and crevices." Taschenberg³ in *Naturgeschichte der wirbellosen Thiere*, states that both the flies and pupæ hibernate. In 1884 Riley⁴ reports: "The insect hibernates both in the larva state in the roots and in the puparian state underground." Fyles⁵ examined radish roots in November that were known to be infested in October and found no maggots, which indicated that the insects did not pass the winter in the larval stage. Slingerland,⁶ after a discussion of hibernation, adds: "It is not at all improbable that the flies do pass the winter secreted in crevices or under rubbish." Smith⁷ states that he has found the adults so late in the fall and so early in the spring that there can be no question as to the fact that the winter is passed in this stage.

Our observations on this phase of the problem were made during the autumns of 1907 and 1910 and during the spring and fall of 1911. The data accumulated during the autumns of the three seasons is given in Table VI, while observations made in the spring of 1911 are given in chronological order in Table VII. Attention is called to the following facts that are brought out by these observations: (1) a scarcity of both adults and larvæ during the latter part of the summer; (2) a period when adults are numerous and females heavy with eggs are frequently collected; (3) a period when eggs and maggots are numerous; (4) a variable interval preceding cold weather when no adults can be found; (5) that during the spring of 1911 pupæ under normal conditions in the soil reached maturity and adults emerged from the ground on the same day that flies were observed in the field for the first time that season.

¹ Bouché, *Natur. der Insekten*, p. 74. Berlin 1834.

² *Gardeners' Chron.*, p. 396, 1841.

³ Taschenberg, *Natur. der wirb. Thiere*, pp. 172-175. 1865.

⁴ U. S. D. A. Rept. p. 320. 1884.

⁵ Rept. Ent. Soc. Ont. 21:44-45. 1891.

⁶ Cornell Exp. Sta. Bul. 78:516.

⁷ N. J. Exp. Stas. Rept. 488:1895.

In some seasons it has been almost impossible to find adults during the latter part of the summer in locations where they were present in considerable numbers both in early summer and again in the fall. During cool days of September and October flies were found hiding in wild mustard and about uncut heads and sprouted stalks of cabbage. It is thought that if the adults hibernated some of them would remain in these hiding places, but in the inspection of many fields in the autumns of 1910 and 1911, during which crop remnants were thoroughly examined, no living adults were found. On Nov. 28, 1911, twenty-three pupæ and four larvæ were taken from the soil about cabbage roots. Some of the pupæ were the color of larvæ and had apparently just transformed, while others were fully formed. It frequently happens that snow drifts cover a portion of a cabbage field for the entire winter which preserve the plants in perfect condition until the following spring. It is very probable that any late emerging adults caught in such a situation would hibernate. The winter of 1909-10 was just such a season, for the country generally was protected by snow and whole fields of cabbage stumps put forth new growth in the spring, whereas, usually the plants are killed by low temperature. These observations indicate that about Geneva, N. Y., practically all of the insects winter as puparia and that the adults do not hibernate.

TABLE VI.—FIELD OBSERVATIONS ON PRE-HIBERNATION HABITS OF CABBAGE MAGGOT.

(Data for autumns of 1907, 1910, 1911, at Geneva, N. Y., arranged chronologically.)

Date.	1907.	1910	1911
Sept. 8	.....	Adults numerous about tops of plants. No larvæ and no recent injury.	
Sept. 16	6 adults collected.....	.....	Males very scarce, none found.
Sept. 18	.....	.....	Males very scarce, 2 captured.
Sept. 20	.....	Adults observed. Only an occasional larva found on cabbage and turnips.	
Sept. 22	8 flies taken.		
Sept. 28	.....	Female taken. Adults seen on cabbage and turnips.	Adults very scarce.
Sept. 30	.....	Adults of both sexes collected on mustard.	

TABLE VI (continued).

Date.	1907	1910	1911
Oct. 2	.....	.....	Adults very scarce, 1 male taken, on sunny side of cabbage. T. $54\frac{1}{2}^{\circ}$ 4 P. M.
Oct. 3	Flies plentiful and ovipositing. Half-grown larvæ abundant.	Flies abundant, active and abdomens heavy with eggs.	
Oct. 8	.....	.....	Adults more numerous than any time this fall.
Oct. 9	A few adults present. Most larvæ ready to pupate. Some pupæ.		
Oct. 10	.....	No flies seen.	
Oct. 12	.....	Adults scarce, 1 male captured.	
Oct. 14	.....	Some flies taken on mustard.	
Oct. 16	Larvæ and adults abundant.		
Oct. 17	.....	Adults not found.	
Oct. 18	.....	Careful search. Adults not found.	
Oct. 20	.....	Larvæ numerous in stumps.	
Oct. 22	Difficult to find adults. Various sized larvæ present.		
Oct. 24	.....	Larvæ numerous in stumps.	Eggs and all stages of larvæ numerous. No adults seen.
Nov. 6	.....	Larvæ numerous in stumps.	
Nov. 9	.....	.....	Many larvæ present, but most of them of large size. No flies.
Nov. 12	Larvæ abundant about roots of turnips and cabbage. No adults present.		
Nov. 24	.....	.....	Larvæ in stalks and heads killed by frost.
Nov. 28	.....	.....	23 pupæ and 4 maggots taken from about roots of cabbage.
Dec. 10	Larvæ present in roots of turnips.		

TABLE VII.—DEVELOPMENT OF HIBERNATING PUPÆ OF CABBAGE MAGGOT.
(Chronological arrangement of notes taken in Spring, 1911.)

1911.	
March	13. Examined cabbage stumps, ground frozen, some dead larvæ noticed.
April	6. Examined 10 stumps. 14 puparia collected. The white legs could be seen through the pupal skin.
April	12. 4 pupæ dissected, legs just formed.
April	21. Collected 30 puparia from about 15 stumps. Development same as in previous examination.
April	27. 14 puparia taken about 8 stumps.
April	28. By sifting soil obtained 24 puparia from 14 stumps. 9 of these were dissected, and all showed completely formed pupæ.
May	4. 6 puparia from about 14 stumps. These were examined with the following results: 2. Pupæ shaped but no pigment. 1. Slight pigment in eyes. 2. Legs, etc., slightly pigmented.
May	6. 1. Legs, wings, antennæ pigmented. Eyes almost natural color. Another collection examined as follows: 12. Pupæ formed, no pigment. 1. Eyes slightly pink and a row of pigmented chætæ around head. 1. Eyes reddish pink, antennæ, wings and legs pigmented.
May	8. Sifted soil about 46 stumps, taking 52 pupæ, and several fresh looking specimens. A number of the pupæ appeared to be mature and ready to transform and one did transform to an adult before the following day. First adults noticed this season.
November	28. By sifting, 23 puparia and 4 maggots were taken about roots of cabbage.

EXPERIMENTAL STUDIES ON THE EGG AND PUPAL STAGES.

INCUBATION PERIOD AND INFLUENCE OF MOISTURE AND TEMPERATURE CONDITIONS.

DURATION OF EGG STAGE

Taschenberg¹ states that the eggs hatch in about ten days. Mr. P. H. Scudder of Glen Head, Long Island, reported to Slingerland that the eggs hatched in from four to ten days, depending upon weather conditions.² Smith³ states the egg stage varies from four to ten days and probably averages about a week. Washburn⁴ observed the duration of the egg stage on two individual eggs, and the period from oviposition until the eggs hatched was respectively three and five days. The following experiments were made to secure additional data on the duration of the egg stage and the effects of moisture and temperature on the length of the incubation period.

¹ Natur. der wirb. Thiere, p. 172-175. 1865.

² Cornell Exp. Sta. Bul., 78, p. 507.

³ N. J. Exp. Sta. Bul., 200, p. 7. 1907.

⁴ Minn. Exp. Sta. Bul., 100, p. 5. 1906.

EXPERIMENTS TO DETERMINE EFFECTS OF MOISTURE AND TEMPERATURE ON INCUBATION PERIOD.

The eggs used in these tests were secured from about the roots of cabbage plants in the field. The time of oviposition was ascertained within specified limits by previously removing the infested earth from about the stalk and adding fresh earth. Unless the moisture conditions are given, the eggs in each experiment were placed in an unglazed clay saucer. A uniform condition of moisture was maintained by plunging this receptacle in damp sand. The first six of the following tests were made in the laboratory which has an approximate average temperature of 68° F., and the number of eggs used in these six tests varied from twelve to two hundred in each series. Each of the other lots contained twenty-five eggs, and the temperature conditions are included in the description. An average of twenty-four hours lapsed before the conditions of the experiment were imposed.

Details of egg-hatching tests: Test No. 1. Eggs deposited on May 26, 1908, hatched by June 1st. Time, less than five days.

Test No. 2. Some eggs deposited between 8 A. M. and 4 P. M., June 3, 1908, began to hatch by five P. M., June 6th. Time, about three and one-fourth days.

Test No. 3. Eggs deposited between 8 A. M. and 4 P. M., June 4, 1908, were partly hatched by four P. M., June 7th. Time, three and one-fourth days or less.

Test No. 4. Eggs deposited between 8 A. M. and 4 P. M., June 5, 1908, were beginning to hatch 9 A. M., June 8th. Approximate time, three days.

Test No. 5. Eggs deposited between June 1st, 9 A. M. and June 2nd, 11 A. M., were hatching on the morning of June 5th. Approximate time, three and three-fourths days.

Test No. 6. Eggs deposited on June 8th were all hatched June 12th. Approximate time, four days.

Test No. 7. Eggs, twenty-five specimens, deposited May 27, 1909, were placed in a storage room with a temperature of 66 to 69 degrees F. May 30th, 6 P. M. one egg hatched. May 31st, 8 A. M., 12 eggs hatched. Average time, four days.

Test No. 8. Eggs deposited May 27, 1909, subject to an incubator temperature of 79 degrees F. May 30th, 6 P. M., 20 eggs hatched. Average time, three and one-fourth days.

Test No. 9. Eggs deposited May 27, 1909, and placed in an incubator at a temperature of 104 to 106 degrees F. No eggs hatched.

Test No. 10. Eggs deposited on June 3, 1909, were subjected to a temperature of 66 to 69 degrees F. June 6th, 10 A. M., five had hatched. June 6th, 7 P. M., 24 had hatched. Average about four days.

Test No. 11. Eggs deposited June 3, 1909, were placed in an incubator at a temperature of 79 degrees F.

June 6th, 10 A. M., 13 eggs hatched.

June 6th, 7 P. M., 20 eggs hatched.

June 7th, 9 A. M., 23 eggs hatched.

Average time, three and one-eighth days.

Test No. 12. Duplicate of number (3). Eggs deposited June 3rd were subjected to an incubator temperature of 104 to 106 degrees F. No eggs hatched.

Test No. 13. Eggs which were deposited June 3, 1909, were put in a dry unglazed saucer and exposed in a south window, unprotected from light and air. During the period the weather was cloudy. No eggs hatched.

Test No. 14. Eggs deposited June 3, 1909, were placed in a similar container to those of lot four. These were put in cold storage at a temperature of 60 to 64 degrees F. No eggs hatched.

TABLE VIII.—SUMMARY OF HATCHING TESTS OF EGGS OF CABBAGE MAGGOT.

NUMBER OF TEST.	Approximate temperature.	Moisture conditions.	Average time to hatch.
	<i>Degs. F.</i>		<i>Days.</i>
1.....	68	Moist sand	5
2.....	68	Moist sand	3 $\frac{1}{4}$
3.....	68	Moist sand	3 $\frac{1}{4}$
4.....	68	Moist sand	3
5.....	68	Moist sand	3 $\frac{1}{4}$
6.....	68	Moist sand	4
7.....	66	Moist sand	4
8.....	79	Moist sand	3 $\frac{1}{4}$
9.....	105	Moist sand	None hatched.
10.....	66	Moist sand	4
11.....	79	Moist sand	3 $\frac{1}{4}$
12.....	105	Moist sand	None hatched.
13.....	68	Dry sand	None hatched.
14.....	62 $\frac{1}{2}$	Moist sand	None hatched.

As shown by these tests the time required for the eggs to hatch in the laboratory where the temperature approximated 68° F. was about three and one-half days. Eggs held at a temperature of 79° F. in each case hatched a few hours sooner. Those subjected to a temperature of 105° did not hatch. It is significant that eggs exposed to light and air failed to incubate.

It should be noticed that all the eggs used in the above experiments were under the same temperature conditions during an average period of twenty-two hours after they had been deposited. The differences in the behavior of the eggs were apparently due to changes in temperature influences during the last two or two and a half days of the incubation period.

These tests strongly suggest that under field conditions during May and June the incubation period would vary from three to five days. Unusual temperatures would undoubtedly cause greater variations in the time of hatching.

PUPAL STAGE AND INFLUENCE OF ENVIRONMENTAL FACTORS ON DEVELOPMENT.

TIME REQUIRED FOR THE PUPA STAGE.

It appears that weather conditions influence the resting stage and that this period may be lengthened or shortened to such an extent that the insect is one-, two- or three-brooded. As stated previously¹ it was believed that the widely divergent periods given by different authors as to the time required for the pupal stage of *P. brassicae* are due to unnatural surroundings. It was further thought that placing pupæ out of doors in the soil would result in a normal period that would be approximately similar for all individuals. However, as already described, the results of this kind of breeding work during 1909 and 1910 showed a wide variation in the time of the pupal period. As the conditions of the experiment were very similar to those obtaining in the soil and the results were confirmed by field collections, it is thought that these differences occur in nature.

Further observations show that the pupal period may be influenced by such factors as temperature and moisture. The following experiments were made to ascertain the importance of these factors under field conditions.

¹ *Jour. Econ. Ent.* 4:210. 1911.

EFFECT OF DIFFERENT AMOUNTS OF MOISTURE ON PUPAL DEVELOPMENT.

Experiment 1, with varying conditions of moisture.—The pupæ were divided into two lots, one of which was placed in flower pots out of doors (discussed as 1A), and the other in glass fruit jars which were placed in the laboratory (referred to as 1B). The pupæ used in this experiment were secured at the same time from radishes, and the conditions of experiment were imposed on June 1st.

Experiment 1A was designed to learn the effect of different conditions of moisture, keeping the other factors as nearly the same as possible and have the experiment outside, being protected only from rain. Twenty-five pupæ were placed in each of the five specially prepared, 10-inch flower pots on June 1st. The earth and pots were weighed from time to time and water added to bring the moisture content up to the calculated amount. The soil was a heavy clay, very similar to the soil in many fields used for growing cabbage in this locality. The moisture contents and the emergence of adults are given in Table IX.

TABLE IX.—DATES OF EMERGENCE OF ADULTS OF CABBAGE MAGGOT UNDER DIFFERENT CONDITIONS OF MOISTURE.
(Experiment 1A.)

NUMBER OF BREEDING POT.	Variations in moisture.	ADULTS EMERGED.				
		June 10.	June 13.	June 16.	June 21.	June 26.
A-1.....	<i>Per ct.</i> 4½ to 5½	.....	7	3	.....	.....
A-2.....	6 to 7	5	.....	12	.....	.....
A-3.....	8 to 10	2	.....	7	.....	.....
A-4.....	11 to 15	.....	.....	6	1	1
A-5.....	20 to 23	.....	.....	9	3	.....

Experiment 1B was designed to test the effect of moisture variations and was made in fruit jars with tops tightly plugged with cotton. Both soil and jars were weighed. Four hundred gms. of earth and 15 puparia were placed in each jar except number 6 which contained 25 puparia. It was estimated that the soil contained 2 per ct. of moisture and this was deducted in making up the amount in each

case. The water content of these jars and dates of emergence of adults are tabulated in Table X.

TABLE X.—EMERGENCE OF ADULTS OF CABBAGE MAGGOT UNDER DIFFERENT CONDITIONS OF MOISTURE.
(Experiment 1B.)

NUMBER OF JAR.	Variations in moisture.	DATES OF EMERGENCE.			
		June 10.	June 11.	June 13.	June 16.
	<i>Per ct.</i>				
1.....	2	.....	.....	.....	2
2.....	4	5	5	1	.....
3.....	6	6	5	1	.....
4.....	8	3	3	3	.....
5.....	10	5	4	2	.....
6.....	12	4	11	4	.....
7.....	14	3	5	3	.....
8.....	16	1	4	4	.....
9.....	20	1	5	3	.....
10.....	24	.....	1	4	1

Results.—Two things are evident in the results of this experiment: 1, That at these temperatures, variations in soil moisture alone, within the limits of natural soil conditions, apparently have no effect on the pupa that has begun its development; 2, the conditions of temperature must have been very near the optimum. It is also of interest to note that in 1B, Jar 1 to which no water was added, only two adults emerged, the development of the other pupæ being arrested. As the earth used in this experiment had been previously baked for five hours at a temperature of 225°, it contained very little moisture and undoubtedly acted as a desiccator.

Experiment 2, with varying amounts of moisture.—The puparia were about five days old when the experiment was initiated on June 24th. Most of them looked very dry and some showed vacuoles of large size. Water was placed in the jars according to the following table and 10 puparia and 200 gms. of sand added. These jars remained in the laboratory from June 24th to August 16th. The outside temperature during this period ranged as high as 105° F., on July 5th, while the average maximum temperature for this time

was 88°. From August 16th to Sept. 8th, the insects were kept in a damp cellar. The data are presented in Table XI.

TABLE XI.—EXPERIMENT SHOWING THE EFFECT OF VARYING AMOUNTS OF MOISTURE ON PUPÆ OF CABBAGE MAGGOT.

(At room temperature from June 24 to August 16.)

NUMBER OF JAR.	Variation in moisture.	ADULTS EMERGED.					
		June 24.	July 1.	July 3.	July 5.	Aug. 16.	Sept. 8.
	<i>Per ct.</i>	Experiment initiated. Jars placed in laboratory.					
1.....	2		1	2			
2.....	4		1	1	1		
3.....	7			1			
4.....	9			1			
5.....	12			1			
6.....	14		1	1			
7.....	17						1
8.....	19			1	2		
9.....	22						
10.....	26			1	1		

Conclusion.—From the foregoing data it appears that increasing or decreasing the moisture within the limits of field conditions did not affect the insects after development had started, for those individuals that were nearly ready to emerge when the conditions were imposed were able to mature. The development of the majority of the puparia was probably arrested by the hot weather prior to the experiment, and during the period of high temperatures when the experiment was made these insects were apparently not affected by increasing or decreasing the amount of moisture in the soil. The death of many of the insects appears to have been due to continued high temperatures.

Experiment 3, to determine the effect on pupal development of varying amounts of moisture coupled with high temperatures.—The puparia used in this experiment were one to two days old. They were taken June 20th from about radishes that had been collected seven days previously. Fifteen puparia and 400 gms. of air-dry quartz sand were placed in glass fruit jars with the amount of water as follows:

There were ten jars, one with oven-dried sand and no moisture added, three with air-dried sand, no moisture, and six jars, two

having six per ct., two ten per ct. and two twenty-two per ct. moisture. These jars were placed in an incubator at a temperature of 93° F. but the temperature actually ranged from 90° to 105° F. The jars remained in the incubator from June 20th to July 11th and in the laboratory until Oct. 24th. The test was started on June 20th. Two adults emerged on June 27th and two on Aug. 8th from one of the jars containing air dry sand. No others emerged.

Conclusion.—The temperatures are too high for the development of the pupæ, and the addition of moisture makes conditions suitable for fungus. The fact that four adults emerged indicates the ability of some pupæ to withstand very unfavorable conditions.

Summary of the moisture experiments.—After the puparium is formed the rate of pupal development is not hastened or retarded by such changes in soil moisture as would ordinarily occur in this region. Severe desiccation arrests development while high temperatures are unfavorable to development.

EFFECT OF DIFFERENT TEMPERATURES ON THE DEVELOPING PUPÆ.

Experiment 4, to determine the delay in pupal development by deep burial.—The puparia used in this experiment were collected on April 20th from about cabbage stumps. At this time tile-drained fields were being plowed. The experiment was started the following day, or April 21st. The puparia were divided into four lots: one lot was buried nine inches in the soil while the remainder were used as controls, two of which were placed in an incubator at a temperature of 78°–80° F. and one in an ice house.

TABLE XII.—EMERGENCE OF ADULTS OF CABBAGE MAGGOT MODIFIED BY DIFFERENT TEMPERATURES.

CONDITIONS.	No of puparia.	April.	MAY.							JUNE.				
		21	3	8	13	15	17	22	27	5	5	10	13	16
Incubator A.....	4	Experiment started.	...	Flies appeared outside.	1	...	1	...	...	Removed to laboratory.	...	...	...	...
Incubator C.....	6		1		...	...	1	...	...		...	...	...	...
Ice house.....	5		...		...	...	...	...	...		1	2	...	1
9 inches soil....	5		...		...	...	...	1	1		...	1	1	1

Results.—A glance at Table XII will show that the time of emergence was materially affected by the different conditions of the experiment. As stated, the test was initiated April 21st, and the first adult to emerge from the lot buried in the soil appeared May 22nd, while the first adults appeared outside on May 8th. In other words pupæ buried to a depth of nine inches emerged fourteen days later than the earliest appearing adults under normal conditions in the field. One lot required eighteen days and the other thirty-two days to go through the same transformations. These data are confirmed to a certain extent by another test¹ in which infested soil was plowed six or nine inches. In this case there was a difference of ten days in the appearance of adults in the two situations.

Experiment 5.—This was planned to determine the effects of four different conditions of temperature upon the development of pupæ. Eight jars were prepared with one pint of soil in each, the even numbers containing fine sand just moist enough to cake when squeezed, while the odd numbers contain the same material air dry. The puparia were taken from about radishes three days previously. It is probable that they varied from four to five days in age. Ten puparia were placed in each jar.

Two important facts are shown in Table XIII. Some pupæ in a cool, moist cellar appear to have been enabled to finish their development and emerge, while of other pupæ retained at a temperature of 98° F., and of another lot at a temperature of 80° to 89° F., and an occasional maximum of 95°, none emerged. The insects placed in the basement, which was dark though not damp nor as cool as the wine cellar, did not respond to the change as quickly. Perhaps second in importance is the fact that the conditions of contained earth, whether dry or moist, seem to have had no effect on the emergence of adults.

The actual number of individuals involved in this experiment is small, and standing alone it would be lightly considered; however, this behavior is parallel to that outlined by W. Paspelow² for the Hessian fly. The results also almost duplicate those of a similar experiment performed in 1909, but not as yet recorded. In addition there were two other lots of pupæ which were placed in the wine cellar with series 7, Experiment 5, eight of which behaved in the

¹ See data on emergence of spring brood, page 117.

² U. S. D. A. Ent. Bul., n. s. 16, p. 22.

same manner. In contrast to this there were several lots of pupæ left in the laboratory subject to the continued warm, dry weather, which yielded no adults.

TABLE XIII.—EFFECTS OF DIFFERENT CONDITIONS OF TEMPERATURE UPON SUMMER PUPÆ AND EMERGENCE OF ADULTS OF CABBAGE MAGGOT.

No. of jar.	Con- dition of sand.	Con- ditions of tem- pera- ture.	ADULTS EMERGED.					
			July 27.	Aug. 8.	Aug. 10.	Sept. 14.	Oct. 26.	Oct. 27.
1	Dry....	Degs. F. 80-86 oc- casional- ly 95.....	Experiment started.	.....	.....	.....	.....	.....
2	Moist..	Same....		.....	.....	.....	.....	4 pupæ not col- lapsed.
3	Dry....	98.....		.....	.....	.....	.....	.....
4	Moist..	Same....		.....	.....	.....	.....	All shriv- eled.
5	Dry....	Basement.		.....	.....	1	1	.....
6	Moist..	Basement.		.....	.....	.....	.....	.....
7	Dry....	Wine cellar..		1	2	.....	.....	.....
8	Moist..	Wine cellar..		1	2	.....	.....	.....

OBSERVATIONS INDICATING THAT A NORMAL PERIOD RESULTS WHEN OPTIMUM CONDITIONS FOR DEVELOPMENT OBTAIN.

In most of the previous experiments the conditions have been severe and as a result many pupæ have died and only a few have developed. However, in one experiment, and several times during our observations, there have been indications of a uniform period. In experiment 1B, jars 2 to 9 inclusive, 70 per ct. of the adults emerged during a period of four days, within twelve days after the conditions were imposed, and no more adults and only one parasite

emerged during the subsequent thirty-seven days. The average of the daily maximum temperatures for the period of June 1st to 13th was 78° F., and for the minimum 56°. The average of the same readings for the period these pupæ were held in the laboratory, June 24th to 31st, was 83° and 56° respectively. During July, 1909, collections were made of adults as they emerged from the soil under a cheesecloth screen. In the unplowed portion of the experimental plat¹ about 75 per ct. of the adults were taken during a period of seven days, while the collections covered a period of thirty-two days. The average of the maximum and minimum temperatures for twelve days prior to the first collection was respectively 83° and 55° F.² These temperatures were taken at the Station while the collections were made about six miles distant. These two instances show a tendency for a normal developmental period, and it is interesting to note that the temperatures in each case ranged near 80° F. for the maximum to 55° for the minimum.

DO PUPÆ UNDER SIMILAR CONDITIONS DEVELOP AT DIFFERENT RATES?

That pupæ under the same conditions behave differently has been obvious all through our studies of the species. This is the most important premise in this investigation. Pupæ in the same breeding cage and certainly subject to very similar moisture and temperature conditions do not develop in the same length of time. This delay of development is remarkably similar to the behavior of many seeds. It is a matter of common observation that some weed seeds continue to germinate for long periods. An experiment was performed by Nobbe and Hanlein³ in which the seeds of a number of weeds were placed under conditions favorable to germination, and some of these continued to germinate throughout the experiment which lasted 1173 days. Certain facts indicate a difference in the rate of loss of moisture in the puparia of *P. brassicæ*. Referring to experiment 1B, jar 1, in which fifteen puparia were placed in a tight jar with very dry soil, two individuals showed a normal development. Seven of these puparia were examined on July 21st, at which time several of them appeared to be alive. In this experiment, the conditions were severe. Unquestionably desiccation

¹ *Jour. Econ. Ent.*, 4:215. 1911.

² N. Y. Exp. Sta. 28th Ann. Rept., p. 559. 1909.

³ *Bot. Gaz.* 42: 266.

prohibited development in thirteen individuals and failed to affect the remainder. Similar results were secured in Experiment 6, in which ten puparia were placed in a porcelain watch glass. The experiment was initiated June 27th and by July 6th one adult had emerged, one died in the act of emerging, while the other puparia appeared to be very dry. The puparia in this experiment were certainly subject to the same conditions. Such results have occurred many times, and the presence of a large vacuole in some of the retarded pupæ shows marked desiccation. These facts indicate that under some conditions pupæ lose moisture at different rates. A number of observations were made upon the relative loss of weight of pupæ in a desiccator and in water vapor and under other conditions of dryness. It was determined that weight is lost rapidly when pupæ are subjected to dry air, as in a warm room or a desiccator.

RATE OF LOSS OF MOISTURE FROM INDIVIDUAL PUPÆ.

Experiment 7.—For this work eight pupæ were selected from a lot that had pupated during the previous night. These were similar in general appearance and size. They were weighed and placed in a calcium chloride desiccator for two days, during which time two additional weighings were made as shown in Table XIV.

TABLE XIV.—LOSS AND GAIN OF WEIGHT OF PUPÆ OF CABBAGE MAGGOT.
(In desiccator for two days and subsequently placed in aqueous vapor.)

No. of pupæ.	Original weight 3 P. M. July 7th.	In desic- cator: Weight 8 A. M. July 8th.	Weight 10:30 A. M. July 9th.	In water vapor: Weight 2 P. M. July 12.	Loss July 7 to July 8.	Loss July 8 to July 9.	Loss July 7 to July 9.	Gain July 9 to July 12.
	Gram.	Gram.	Gram.	Gram.	Per ct.	Per ct.	Per ct.	Per ct.
1.....	.0105	.0058	.0038	.0049	44	34	63.8	22
2.....	.0104	.0072	.0040	.0053	31	44	61.3	24
3.....	.0104	.0075	.0033	.0046	28	56	68.2	28
4.....	.0152	.0089	.0057	.0068	41	36	62.5	16
5.....	.0145	.0099	.0058	.0073	31	41	60.0	21
6.....	.0117	.0077	.0043	.0055	34	44	63.2	22
7.....	.0130	.0075	.0046	.0058	42	33	64.6	21
8.....	.0129	.0074	.0046	.0064	42	38	64.3	28

The insects were then placed in a sealed jar containing water vapor for three days and again weighed. These figures indicate that there was an appreciable variation in the rate of daily loss, but practically no difference in the loss during two days. There was also considerable difference in the rate of gain in weight in water vapor. These figures are open to criticism on account of the difficulty of weighing such small amounts.

As these weighings show slight variations in the rate of loss and gain, they corroborate the observations mentioned above. A slight disparity in loss of water might account in part for the differences in behavior by the insects.

LENGTH OF THE PUPA STAGE.

The peculiar differences that exist in the length of the pupal period seem to be due to a delayed or arrested development in which some individuals are affected more than others. This delay has been spoken of in entomological literature as retardation, and undoubtedly it is a form of æstivation. According to Tower¹ hibernation and æstivation are fundamentally alike, both terms applying to the same physiological process, the only difference being the factors which initiate them. He found that in addition to protoplasmic changes *L. decemlineata* lost 30 per ct. of its weight preparatory to hibernation, and that *undecemlineata* in preparation for æstivation in semitropical regions goes through the same process.

Thus it appears that the loss of water which enables the insect to withstand extremes of temperature is a prerequisite for either condition. Some observations have been made upon the rate of metabolism as affected by loss of water in seeds. Kolkwitz² experimented with barley and found that respiration decreases rapidly as the seeds lose moisture and that a rise in temperature increases respiration.

The ability of many plants and animals to withstand desiccation in some stage of their existence is common knowledge. Practically all seeds and many lower forms of animal life are able to survive certain unfavorable periods. One who has bred insects could hardly fail to observe cases of retardation and numerous instances are cited in literature. Lawrence Bruner³ in discussing the great abundance

¹ Tower, W. L. Investigation of Evolution in Chrysomelid Beetles, pp. 245-252, 1906.

² Jost. Plant Physiology Ox. Ed. 1907, p. 341.

³ U. S. D. A. Ent. Bul., N. S., 38, p. 44, 1904.

of grasshoppers in some years, states that when rain falls early the eggs hatch much sooner than when the rains come later in the season. After a late spring they continue to hatch after each shower. During some seasons it may be possible that many remain over until the next year, not hatching because of lack of sufficient moisture. He believes that these retarded eggs help to swell the numbers of insects if the season is favorable for hatching. This certainly seems possible in view of the experience of C. P. Lounsbury¹ who reports that locust eggs were known to retain their vitality for three and one-half years. Tower was of the opinion that certain species of *Leptinotarsa*² in the more arid portions of the American continent were able to survive the prolonged periods of unfavorable weather which occur in these regions. To prove this he placed beetles in a dry, warm container where they remained in a condition of hibernation for about eighteen months or from the fall of 1902 until May of 1904. Twelve to sixteen days is probably the normal time for development of the pupa of *P. brassicae*, though periods of two and three months are reported by Slingerland. In our work a delay of two months in the maturing of pupæ has frequently been observed and in one instance a fly emerged from a pupa that was from nine to ten months old.³

Some plants and animals exhibit a seasonal or periodic behavior in their daily and annual functions, and the preparation for hibernation of many insects may be explained on this basis. This periodicity, which is due to an internal response, is strongly manifested in some organisms and practically absent in others. Some insects continue breeding without cessation when removed to the greenhouse,

¹ 4th Ann. Rept. South African Central Locust Bureau, p. 7.

² Tower, W. L. Investigation of Evolution in Chrysomelid Beetles, pp. 245-252, 1906.

³ A retardation such as occurs with the pupa of *P. brassicae* has long been known to occur in the resting stage of the Hessian fly. Most interesting in this connection is the summary by Osborn (U. S. D. A. Bu. Ent. Bul. 16, n. s., p. 22) of a paper by Dr. W. Paspelow of the Agricultural Institute at Moscow. This paper gives in brief the story of the broods during one season, which is as follows: The larvæ of the spring generation were numerous, and the greater portion of these transformed to the puparium stage toward the end of May. In the first half of June a number of puparia transformed to true pupæ, but the principal portion (about 70 to 80 per ct.) remained in the puparium stage until the latter half of August, when under the influence of rain, the development was completed. That this was a case of retardation due to high temperature and a dry season was proved by removing the puparia from time to time during the summer to cool, moist conditions; from whence adults emerged in two weeks. This same fact was proven by Marchal and is now said by Webster (U. S. D. A. Ent. Cir. 70, p. 11) to occur regularly in the southern part of the United States.

while others show seasonal behavior although conditions for growth obtain. To what extent the hibernation and retardation behavior in *P. brassicae* are affected by an internal response cannot be stated. Our studies were directed to determining the influences of different elements of the environment upon the life of the pupa, and no evidence was accumulated to show how various factors in the surroundings of the larva may affect pupal development. It is believed, however, that the conditions surrounding the nearly mature larvæ may influence in an important way the later development of the pupæ.

SUMMARY OF EXPERIMENTS TO DETERMINE EFFECTS OF MOISTURE AND TEMPERATURE ON RATE OF DEVELOPMENT OF PUPA.

1. Differences in soil moisture within wide limits do not alter the length of the pupal period after development has begun.

2. A marked deficiency of moisture, alone or with high temperature also, retards development.

3. A high temperature, such as frequently occurs during the summer months in western New York, is unfavorable to normal growth, and seems to cause a retardation in development which may last until low temperature returns.

4. When the conditions are severe or unfavorable, the individual pupæ respond differently to the same environment. Thus, certain pupæ may finish their development in a shorter time than usual when subjected to a high temperature, while others may æstivate for an indefinite period.

5. Some data has been accumulated to show that a normal period results for a large percentage of the pupæ when optimum conditions for this species obtain.

NATURAL ENEMIES.

Aside from hot, dry weather which is very unfavorable to the insect, and is probably the most formidable factor against its development and propagation in this region, the cabbage maggot has a number of natural enemies, chief among which are certain staphylinids of the genus *Aleochara*, a cynipid parasite, *Pseudoeucoila gillettei* and a mite, *Trombidium* sp.

If the theory proposed elsewhere be accepted, that *P. brassicae* was brought into this country in the pupa stage in soil used as ship ballast, or was introduced by means of infested root crops, such as turnips, then it would appear that the various European enemies which attack the larva and pupa stages would probably be imported in the same way.

Perhaps of most importance as an enemy of the cabbage maggot in this community is the staphylinid, *Aleochara bipustulata* L. This species, which was once thought to be both predaceous and parasitic, has been discussed in literature under the names *nitida*, *verna* and *anthomyia*. The insect was named *Aleochara nitida* in Germany in 1802. Specimens collected in Missouri were described by Say in 1836 as *Aleochara verna*. In 1869 *verna* was made a synonym of *nitida* by LeConte; but there seems to be some doubt as to this classification as *verna* has been recently listed by Fenyès¹ as a distinct species. The insect was bred from pupæ of *brassicae* in 1870 by Sprague, and in 1880 Barnard found the parasite very numerous in Ithaca and observed the adults feeding upon *brassicae* larvæ. In 1890 the beetle is mentioned by Fletcher. It is also recorded by Washburn² as having been found in Minnesota.

Recently Wadsworth³ of Manchester, England, has published the life history of a staphylinid parasite of the cabbage maggot under the name of *Aleochara bilineata* Gyll. He states as a reason for adopting this name that of a number of beetles reared from puparia only one agreed with the description of *A. nitida* while the others were regarded as belonging to the variety *bilineata* Gyll., of *A. nitida*. This variety differs from the type form in having no red spots at the apex of the elytra, which are shining black. Wadsworth states that the young of this insect hatch from the eggs as free living staphylinid larvæ, after which they enter the puparia of the cabbage fly to feed upon the pupæ and that they undergo a simple form of hypermetamorphosis as a result of their parasitic mode of life. He states that there are two generations about Manchester, England; the adults of the first generation emerging in May and June and those of the second generation in August and September. Ten to twenty-five per ct. of the puparia examined by Wadsworth were infested by Staphylinidæ.

¹ *Ent. News*, 19:64. 1908.]

² Minn. Agr. Exp. Sta. Bul. 112, p. 204, 1908

³ *Jour. Eco. Biol.* Nos. 1 and 2, 1915.

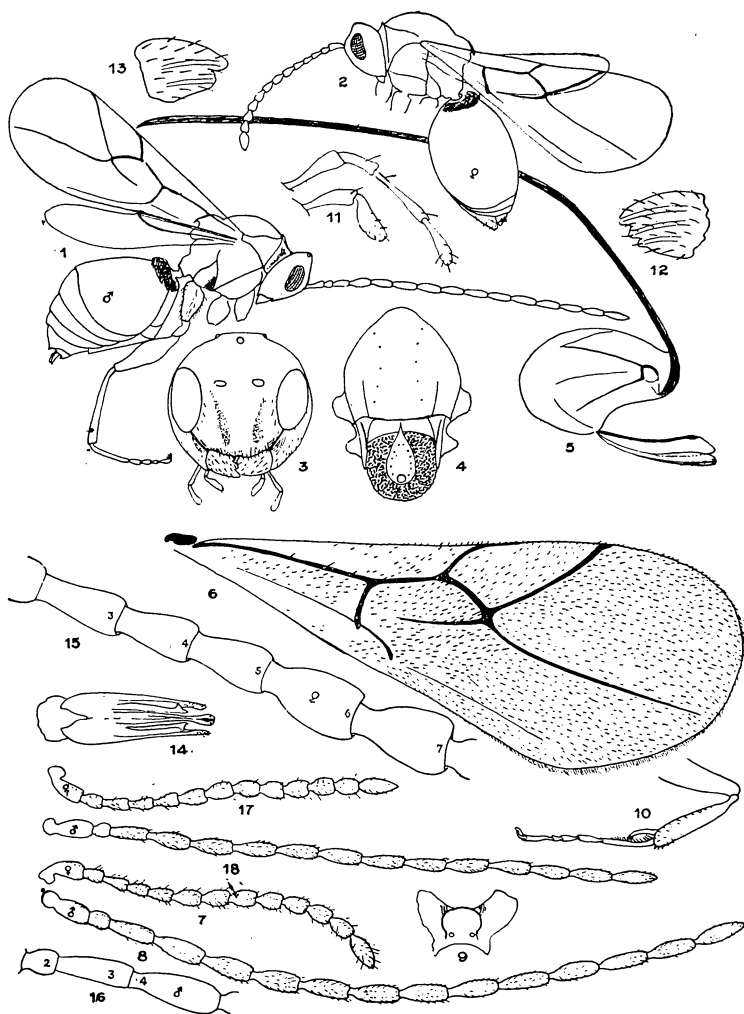


FIG. 2.—STRUCTURAL COMPARISONS OF *Colthonaspis rapae* AND *Pseudoecuoila gillettei*.

1, Male of *C. rapae* (West.). $\times 10$; 2, Female of *C. rapae* (West.) $\times 10$; 3, Head of male $\times 22.5$; 4, Mesonotum and scutellum of female $\times 22.5$; 5, Ovipositer $\times 22.5$; 6, Front wing $\times 22.5$; 7, Antenna of female $\times 22.5$; 8, Antenna of male $\times 22.5$; 9, Prothorax of female showing truncation $\times 22.5$; 10, Tibia and tarsus of front leg $\times 22.5$; 11, Maxillary and labial palpi of female $\times 50$; 12, Right mandible of male $\times 50$; 13, Left mandible of male $\times 50$; 14, Reproductive apparatus of male $\times 37.5$; 15, Segments 3-7 of female antenna $\times 75$; 16, Segments 3-4 of male antenna $\times 37.5$.

(From specimens bred from puparia of cabbage maggot, *P. brassicae*, by Mr. J. T. Wadsworth, Northenden, England. The material was preserved in alcohol, the parts were mounted in balsam, drawings were made with a camera lucida.)

17, Antenna of a female (*P. gillettei*) bred from a puparium of cabbage maggot at Geneva, N. Y.; 18, Antenna of a male (*P. gillettei*) bred from a puparium of cabbage maggot at Medina, N. Y.

(Drawings by L. H. Weld.)

In our work at Geneva we have frequently bred staphylinids (Plate III, figs. 3 and 4) and have found them in such numbers about injured cabbage and radish plants as to leave no doubt as to the nature of their activities or their importance. In addition to *bipustulata* we have occasionally bred *Philonthus nigrutilus*,¹ and *Homalota sordida*. We have taken the following species near infested cabbages, *Tachyporus jocosus*, an unknown *Aleochara* sp. allied to *athata*, *Oxytelus nitidulus* and *Staphylinus badipes*.

From a review of the literature of the cabbage maggot, it seems safe to conclude that some of the staphylinids that attack the insect in Europe are also present in America. Our studies also indicate that there are a number of species of staphylinids, native as well as of foreign origin, that are predaceous upon the cabbage maggot.

Another important parasite is the cynipid species, *Pseudoeucoila gillettei*² Ashm. (Plate III, figs. 1 and 2). This insect has been recorded by Washburn and Webster in Minnesota and by them is called the principal parasite. The insect was bred in considerable numbers by Webster³ who prepared a table showing the period of emergence of the parasite as compared with that of the host. Of the individuals of this lot of pupæ 36.6 per ct. were parasitized. In our studies of the cabbage maggot about Geneva the adults of *P. gillettei* have frequently been bred and the adults have now and then been collected in crevices in the soil about the roots of infested cabbage.

In the accompanying table are the results of a series of collections made in a screened seed-bed on the Station grounds. These results are interesting, as they tend to corroborate Webster's observations. It is very probable that had later collections been made the total percentage of flies to parasites would have been materially changed.

¹ Determinations of the species of Staphylinidæ were kindly made by Major Wm. T. Casey.

² This species was identified by Mr. L. H. Weld, Evanston, Ill., who reports that the insect has also been reared from the cabbage maggot at Port Townsend, Wash., Medina and Carlton Station, N. Y., and Trenton, N. J. The fact that the cabbage maggot is an introduced species suggested the possibility that the parasite is also of foreign origin. Comparison of specimens with *Colthonaspis octotoma* Thomas and *C. rapæ* West., obtained from Europe, led Mr. Weld to believe that the cynipid in question is closely related to if not identical with *rapæ*. The insects show great similarities, even in antennal characters, Fig. 2, but owing to some slight differences, due perhaps to methods of mounting, it seems best to regard them as distinct species until the types may be examined.

³ Minn. Agr. Exp. Sta. Bul. 112, p. 207, 1908.

TABLE XV.—RELATIVE ABUNDANCE OF *Phorbia brassicae* AND *Pseudoeucoila gillettei*.
(Adults of two insects collected from screened cabbage bed, Geneva, N. Y., 1909.)

	Aug. 27.	Aug. 31.	Sept. 4.	Sept. 7.	Sept. 12.	Sept. 15.	Sept. 20.
<i>P. brassicae</i>	27	24	29	15	6	7	2
<i>P. gillettei</i>	2	.....	.....	2	3	6	12

The cabbage fly has another enemy, a mite that attacks its eggs. The mite was first recorded by Gillette¹ who found that three mites would destroy an average of twenty-eight cabbage maggot eggs in a day. Washburn records another species *T. scabrum* Say in Minnesota² and Smith³ found both *T. sericeum* and *T. scabrum* abundant about cabbage plants in New Jersey.

*Trombidium sericeum*⁴ has been observed each season about cabbages in the vicinity of Geneva. The mites have always been in evidence during the oviposition period, and frequently several individuals were found about one plant. In one small field we have known, during the height of the egg-laying period, more than two hundred eggs per day to have been deposited by the adults of the cabbage maggot about plants and yet because of the activities of the mites with perhaps the assistance of other enemies young cabbages have in spite of abundant oviposition escaped with only slight injuries.

In addition to the foregoing species, mention has been made of a number of other enemies of doubtful importance. Washburn bred a number of hymenoptera and collected some carabids which were thought to be predaceous on cabbage maggots. He observed the following species of beetles feed on larvæ in the laboratory, *Pterostichus coracinus*, *P. leucoblandus*, *Agonoderus pallipes* and *Amara impuncticollis*. During the progress of our studies we have collected three common species of ants⁵ that appeared to be predaceous; *Stenamma brevicorne* Mayr. was collected while transporting

¹ *Can. Ent.* 20:133, 1909.

² Minn. Exp. Sta. Bul. 100, p. 8, 1906.

³ N. J. Expt. Stas. Rept. '08, p. 351; '09, p. 381.

⁴ The mite was determined by Nathan Banks through the kindness of Dr. L. O. Howard of the U. S. Bureau of Entomology.

⁵ The ants were named by Dr. W. M. Wheeler of Bussey Institution, Harvard University.

cabbage maggots; *Formica fusca* L. var. *subsericea* Say carrying an adult of *P. brassicæ*, and individuals of *Solenopsis molesta* Say were captured while conveying eggs and small larvæ. In addition individuals of *Lasius niger* L. var. *americanus* Emery have sometimes been very abundant near badly injured cabbage plants. We have observed the carabid *Clivina impressifrons* in the earth about infested cabbage plants for the past several years.

PREDACEOUS ENEMIES OF THE ADULT.

No enemies have been mentioned of the mature stage of *P. brassicæ* and the only positive evidence that we have that the flies are subject to attack by predatory forms is that we have occasionally collected adults with red mites attached to the under sides of the bodies. On one occasion an anthomyid¹ (*Cænosis flavifrons* Stein) was collected that attacked and killed adults of *brassicæ*. The predaceous habit of this fly was discovered August 23, 1911, when one individual was observed standing over an adult of *brassicæ* with its beak inserted into its neck. After sucking for a few moments the victim was turned on its back and the beak inserted in the under side of the abdomen. The fly *flavifrons* killed eight other adults in a period of about eighteen hours. A few females of *brassicæ* have been found that appeared to have been killed by a fungus and this in one case was determined by F. C. Stewart of this Station as *Empusa* sp. This last agency is certainly not important, or its effects would have been more frequently observed. As the adults of *brassicæ* hide a large portion of the time among weeds and in the loose leaves of cabbage, they are doubtless preyed upon by many species of spiders.

EXPERIMENTS FOR THE CONTROL OF THE CABBAGE MAGGOT.

DESTRUCTION OF ADULTS BY POISON BAIT.

In South Africa where the fruit fly, *Ceratitis capitata*, is very injurious, C. W. Mally² tested among other remedies the use of poisoned bait. He found that a very light sprinkling over the trees of a mixture consisting of sugar, arsenate of lead, and water almost completely controlled the pest. More recently Illingworth³ states

¹ The species was determined by Dr. P. Stein, Treptow, Ger.

² *Exp. Sta. Record*. 21:655, 1909.

³ Cornell Exp. Sta. Bul. 324:164, 1912.

that adults of *Rhagoletis pomonella* feed readily upon sweetened mixtures and that death occurs in a few minutes when soluble arsenic is used. In addition to the various methods of eradicating the house fly, such as removal of waste, etc., Prof. C. F. Hodge of Clark University, Worcester, Mass., proposes to attract and capture the hibernating adults by means of mechanical devices in April before they are sexually mature. As only a small percentage of house flies survive the winter, and a period now thought to be ten to fourteen days is required for sexual maturity, many individuals may be captured by the so-called fly traps before oviposition occurs.

As stated elsewhere it is believed females of *P. brassicæ* require a period of three to five days to become sexually mature, and if it were possible to entrap or destroy them during this interval later injury would doubtless be avoided in proportion to the numbers of flies destroyed.

After the fondness of the adults of *P. brassicæ* for sugar water had been learned experiments were made with combinations of sweetened water and arsenic. Flies confined in lantern globes appeared to feed with the same relish upon poisoned water as that containing no poison. In general one and one-half to two days were required for arsenate of lead to cause death, while more soluble forms of arsenic were frequently effective in less than two hours.

During the season of 1913 an effort was made to determine whether or not a seed-bed could be protected by the use of poisoned bait. The formula used in the preparation of the bait is that recommended by Mr. Mally which is as follows:

Cheap molasses.....	2 pounds
Paste arsenate of lead.....	3 ounces
Water.....	4 gallons

Three applications of this mixture were made to a seed-bed during the oviposition period.

The adults of *brassicæ* present in this seed-bed were very closely observed, following the application of the poisoned bait. They seemed to be slightly attracted to the spray before it dried, but decreasingly so thereafter. Following each application some of the adults which were observed to feed upon the droplets of spray were captured and taken to the laboratory for observation. These flies

lived two weeks or longer and were apparently not affected by the poison. It was not possible to tell whether the treatment of arsenate of lead affected the numbers of eggs deposited. The negative results obtained in the above experiment suggested tests with potassium arsenate instead of lead arsenate in preparing the poison bait. Accordingly some poison bait containing potassium arsenate was sprayed on weeds and grass immediately adjacent to a cabbage seed-bed and shortly after some flies were taken in the act of feeding upon the poison spray, all of which died within an hour.

While the efforts to prevent oviposition by the destruction of the flies have in the main been unsuccessful, our field observations and laboratory experience taken together indicate that some protection could be obtained by attacking the insect in the adult stage. In the laboratory the adults feed at any time upon sweetened water. In the field the females have repeatedly been taken between 7:30 and 9 A. M. at droplets of dew. If poisoned bait were distributed in a field, undoubtedly many individuals would be destroyed before becoming sexually mature. Also it seems probable that the use of arsenic for cabbage worms as sometimes practised would destroy some of the adults.

CAPTURING ADULTS WITH STICKY FLY PAPER.

During 1910 tar paper disks or pads, to which a ring of tanglefoot had been applied, were placed about ten cabbage plants that had been transplanted several weeks and were of good size. The results as measured by the number of entrapped flies, were so satisfactory that other tests on a larger scale were made that season and again during 1912. In these tests as before adults of *brassicæ* were captured, but as a result of cultivation and wind the sticky surface of the pads soon became covered with dust and ceased to be effective. For this reason the plants about which the disks containing sticky material were placed were no better protected than other plants provided with untreated paper collars. Mention is made of these efforts to call attention to the fact that adults of *brassicæ* were entrapped by the means described. With a material capable of maintaining suitable sticking qualities under field conditions, tar pads could unquestionably be rendered more effective than as ordinarily used.

CHEESECLOTH SCREENS FOR THE PROTECTION OF CABBAGE
SEED BEDS.

For many years farmers in various sections of western New York have found it almost impossible to grow cabbage seedlings. Flea-beetles attacked the leaves of the young plants as soon as they appeared above ground and immediately thereafter the flies of the cabbage maggot deposited their eggs, from which the destructive larvæ promptly emerged to attack the seedling plants at the root (Plate IV). The only means adopted by growers to overcome the work of these insects was to secure plants from without the State, or to sow large quantities of seed at varying intervals of time with the hope that some of the beds would escape injury.

In 1906 and 1907 several control measures were given thorough trials at Seneca Castle, and during the latter year various protective coverings, such as wire screen and cheesecloth were tested. The object in employing screening was to prevent the flies from ovipositing about the plants. The cheesecloth had been previously tried by local growers, but with very indifferent success as the frames were not tight. In the first experiments by this Station care was used to make the frames fly proof with the result that protection from the maggots was perfect (Plate VII). It was also shown that injury by flea-beetles was largely avoided. The tests with cheesecloth have been so satisfactory and conclusive that this method of protecting seed beds has been adopted generally by cabbage growers for at least a portion if not all of their seed beds.

The experiences of farmers about Seneca Castle during more recent years have corroborated the work of this Station and have clearly shown that the use of tight frames covered with cheesecloth of 20 to 30 threads to the inch will entirely prevent injury by the cabbage maggot, and reduce the extent of injury by the flea-beetle. In addition to protection from the foregoing insects cheesecloth helps to conserve the moisture and prevents the soil from becoming incrustated. Plants raised in screened beds grow faster during most seasons and attain the size desired for transplanting sooner than plants in open beds. A survey¹ of farms about Seneca Castle showed that the extra cost of protecting plants by this method

¹ N. Y. Agr. Exp. Sta. Bul. 334, 1911.

ranged from six to twenty cents per thousand, and in the opinion of many of the growers this additional outlay is more than met by the saving in seed over the old method of growing seedlings.

PROTECTION OF EARLY CABBAGE.

For many years truck gardeners and farmers in certain localities who make a business of growing cabbage for the early market have been unable to protect their plantings from root maggots. As our studies have shown, the growth period of the early cabbage and the production and development of the first brood of maggots are coincidental, so that each year a percentage of the crop, sometimes more and sometimes less, is liable to be ruined or so retarded in its growth as to spoil its value for the early market.

To control the injurious activities of this insect many remedies have been recommended, some of which have been tried by truck gardeners with a degree of success, but no measure has been generally adopted for the protection of early cabbage fields. As opportunity afforded preliminary tests were made by this Station of a number of the more promising control measures generally recommended. Among the measures tested, the two that stood out as being most successful as well as most practical were carbolic acid emulsion, as a liquid soil insecticide, and tar paper disks. Field experiments were then planned to test these measures on a commercial scale. The results of these tests may be briefly summarized as follows:

Carbolic-acid emulsion.—Laboratory tests with the material demonstrated that a mixture containing .33 per ct. crude acid would prevent the eggs from hatching and was fatal to the larvæ of the first and second instars and to some of the recently moulted individuals of the third instar. However, when the carbolic-acid emulsion was tested in the field it was found to be injurious to tender seedlings. Approximately 50 per ct. of the treated plants died, and the remaining plants were much retarded. Cabbage plants which had been transplanted several weeks and were well established showed no ill effect of the treatment. A serious objection to this method of treatment is that in actual practice truckers do not apply the emulsion until the injurious work of the maggots is in an advanced stage, and plants are damaged beyond recovery.

Tests with tar pads.—For a number of years cooperative experiments have been conducted by this Station with a number of truck

growers near Geneva in order to test tar paper disks for the protection of their plantings of early cabbage against root maggots. These experiments¹ have shown that the employment of tar pads is an efficient method of reducing losses to early cabbage from the insects. The actual amount of protection secured by this means has varied with different farms according to the severity of the attacks by this pest, but in plantings where the maggots were abundant and very destructive a large percentage of the plants protected by the disks have produced marketable heads (Plate VIII). In addition to reducing the number of plants killed by the insects another important result of the experiments should be noted, that the tar pads have largely prevented root injury, which, though not sufficient to kill the plants, may be extensive enough to retard growth, so that the crop fails to reach the earliest market when usually the highest prices prevail. The cost of protecting cabbages by this method ranges around \$1.40 per thousand plants, which is a small item when compared to the usual price of early cabbage.

METHODS OF CONTROL.

SCREENING FOR THE PROTECTION OF SEED-BEDS.

In localities where the injury is confined to the seed-bed the use of cheesecloth is a practical and economical means of preventing loss. It is well also to point out that in some years injuries by maggots are supplemented by flea beetle work. These insects attack the seedlings just as they appear above ground and frequently destroy the entire crop. Their work has been discussed with that of the cabbage maggot in Bulletin 334 from which the following directions, for screening of seed beds as a means of protection against both pests, are copied.

SUGGESTIONS ON SCREENING.

The seed-bed should be located on a fertile, well-drained soil, where there can be no accumulation of water or washing under the frame by rains. It is also desirable to locate the bed on land known to be free from weeds, and injurious insects such as wire worms and white grubs. The ground should certainly be free from the disease known as club-root. The soil should be thoroughly cultivated so that it is in good physical condition at seeding

¹ N. Y. Agr. Exp. Sta. Bul. 382, 1914.

time. It is customary to apply liberal amounts of high grade commercial fertilizer. The seed should be drilled rather thickly, in rows six or eight inches apart. When the early varieties of cabbage are to be grown, the seed should be planted during the first part of May or even earlier, whereas such varieties as Danish should be planted about May 15th. Before the seed is drilled, the corners of the bed should be staked, so that the frame can be built and the cheesecloth applied before the plants come up. This is important as the cloth prevents the soil from baking and conserves the moisture; also if the screening is delayed until after the plants come up, the plants are subject to injury by the flea-beetle. Six-inch boards will serve for the frame though some growers use eight and ten-inch boards with satisfaction. The cloth should not sag and rest on the plants. This may be prevented by stretching several lengths of wire from end to end of the bed. The wires should not be more than four or five feet apart. The wire can be supported on stakes to which it is held by staples. It is preferable that galvanized wire and staples be used as rusty wire wears holes in the cloth at the point of contact. All openings under the frame, due to unevenness in the soil, should be filled by banking the earth against the boards. To harden the plants so they will not wilt beyond recovery when set in the field, the cheesecloth should be removed a week or ten days before transplanting. It is well to examine the soil about the plants at intervals of several days after they have been uncovered to ascertain if eggs are being deposited. If the eggs are numerous the plants should be transplanted as soon as possible, the earth being shaken from the roots, which will dislodge most of the eggs or young maggots. When the plants have reached a desirable size they should be transplanted, as they are liable to grow too long and spindling.

TAR PADS FOR PROTECTING EARLY CABBAGE.

[The value of tar pads or hexagonal tar-paper collars for the purpose of preventing the adult of the cabbage maggot from placing eggs about the stems of the plants has been well demonstrated in experiments discussed in Bulletin No. 382 of this Station. The tests described show that tar pads will protect early cabbage at a small cost. Growers who are troubled by this insect are urged

to test this method on their own plantings. The directions for applying the protectors are given in detail in the foregoing publication and are briefly as follows:

Truckers who intend to use tar pads to protect their cabbage plants should arrange to transplant seedlings of good size with rather long stems. It is impracticable to adjust the disks about small plants especially where only the leaves protrude above the soil. To secure the greatest benefit the tar papers should be applied immediately after the work of transplanting, so that the flies will

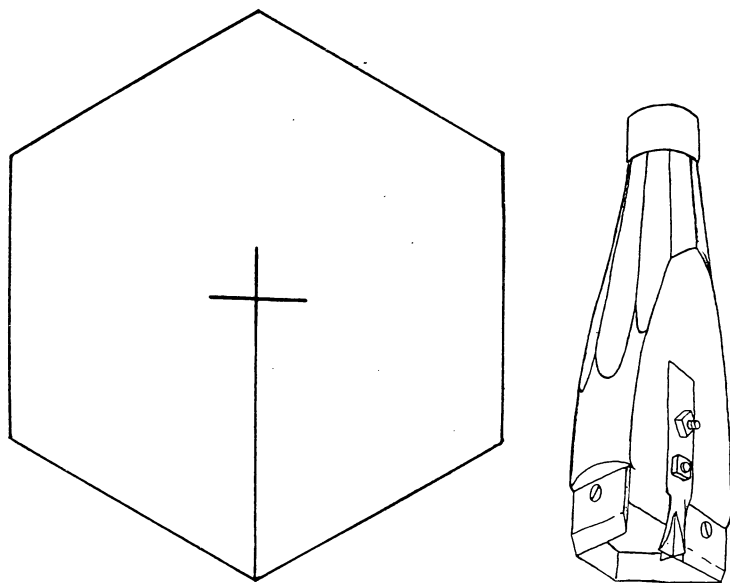


FIG. 3.—TAR-PAPER PAD AND TOOL FOR CUTTING.

not have an opportunity to oviposit about the plants. To adjust the pad, separate the two edges of the slit running to the center, slip the card around the stem of the plant and press it firmly against the soil so that it fits snugly about the stem and the radial opening is closed. It is preferable that the tar pad should be slightly above or at least level with the surface of the soil, so that it will not become covered with soil during the first washing rain.

The cards are cut in the shape of a hexagon from roofing paper known as "single-ply tarred-felt." They may be purchased or cut at home with the tool shown in Fig. 3.

FARM PRACTICES TO PREVENT MAGGOT INJURY.

The cabbage grower can reduce losses by the cabbage maggot by the destruction of crop remnants at all seasons of the year, and by not growing turnips or other succulent cruciferæ in the autumn. There are at least two broods of the insect that are numerous every year; one in the spring that infests cruciferous weeds, radishes and early cabbage, and one during September and October that depends for its food supply upon crop remnants, turnips and other field crops. As a general rule the work of the fall brood of maggots is unnoticed because the creatures feed largely on sprouted cabbage stumps or on some field crops, the value of which is not seriously lessened. The spring brood of maggots attacks early cabbage and seedlings of late cabbage at a time when they are most susceptible to injury. This brood does much damage and is the cause of considerable apprehension during some seasons by growers of these vegetables.

The numerous collections that we have made about turnips, cabbage stumps and other remnants indicate that the flies that emerge in the spring are to a large extent the adults of the fall brood of larvæ. In other words, the presence during the autumn of a large acreage of succulent cruciferous roots, furnishes food for great numbers of maggots which emerge as adults the following spring to infest radishes, early cabbage, etc.

Any measure therefore that will lessen the amount of this succulent food, such as removal of the crop remnants, will tend to reduce the numbers of maggots that develop in the fall and consequently the number of insects the next year. From an entomological standpoint it would appear desirable after the cabbage crop is removed to plow under the stumps or allow sheep to have the run of the field. In communities where the injury by the cabbage maggots is very severe, present evidence indicates that swedes, turnips and other late cruciferous crops shall as far as possible not be grown.

Another practice that has given good results in the production of seedlings for the late crop of cabbage is the growing of the seedling plants outside of the cabbage growing community. A number of large cabbage growers about Geneva and Seneca Castle, have at times arranged to have their seedlings grown several miles or at a greater distance from their own farms. As a means of obtaining seedlings free from injuries by the cabbage maggots and at a reasonable cost this practice has proven very successful.