THE ROOT MAGGOTS ASSOCIATED WITH RUTABAGAS IN PRINCE EDWARD ISLAND: WITH ESPECIAL ATTENTION TO THE SEASONAL HISTORY AND CONTROL OF THE CABBAGE MAGGOT (*HYLEMYA BRASSICAE* (BOUCHÉ): DIPTERA, ANTHOMYIIDAE)

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I INTRODUCTION

Root maggots attacking cruciferous crops were prevalent in Europe during the early part of the nineteenth century. One of the most serious of these pests, the cabbage root maggot, *Hylemya brassicae* (Bouché), was first reported in 1829 in England and it was first found in North America in the Boston area, U.S.A., in 1835. In 1901 root maggots were first discovered in Prince Edward Island. They were noted to be prevalent at that time, but it was not until about 1946 that the extent of the injury being caused by these pests to rutabaga (Swede turnip) crops was fully realized by rutabaga growers and dealers. Biology and control studies in this province were started in 1938.

Another species of root maggot that attacks turnips and rutabagas is the "turnip maggot", *H. floralis*, Fall. This pest is reported to cause serious injury to turnips in Alberta, and specimens have been found in rutabagas in British Columbia during August and September. However, it is not considered a pest in Eastern Canada and it has not been found in Prince Edward Island.

In recent years the root maggots attacking rutabagas have become so serious that farmers in some areas of the province no longer grow rutabagas for marketable purposes, and in all other rutabaga growing areas the economy of the farmers has been seriously affected because of the injury caused by these pests. Within the last ten years the acreage of rutabagas grown in this province is reported to have dropped from approximately 12,000 acres to less than 7,000 acres, with a corresponding decrease to slightly less than 1,000,000 bushels of rutabagas being shipped annually from the province as a table stock product. A major part of the decrease in the acreage grown may be attributed to the fact that root maggot injury has made it difficult for growers to secure a marketable crop.

Since about 1835 studies on the biology and control of root maggots attacking cabbage and cauliflower have been carried out in many parts of the world, but it is only within recent years that special attention has been directed towards detailed studies of the species attacking rutabagas. The present study on the life history and habits of root maggots attacking rutabagas in this province was started in 1951; a) to obtain more detailed information on the seasonal history of the pest, b) to determine if any cultural practices, such as time of planting, applications of barnyard manure or commercial fertilizers and seaonal cultivation affected maggot infestations, and c) to determine the reasons why some fields were heavily infested while others were relatively free from root injury.

In 1951 general field surveys were conducted in 150 rutabaga fields throughout Prince Edward Island. Observations indicated: a) apparent differences in infestations in early and late planted crops in different areas, b) differences in times of maggot attack in different places, c) differences in infestations in fields that were quite close together in an area, and d) differences in infestations that appeared to be caused by weather conditions and by predators and parasites. Between 1952 and 1955 these observations were studied in detail. During the five years of the study approximately 600 rutabaga fields were examined.

During the five years of the seasonal history studies field-scale control tests with DDT sprays were carried out in different areas of the province. In 1955 extensive control studies were undertaken by the writer in an attempt to determine the most effective chemical and the most efficient method of application of the insecticide for control of root maggots attacking rutabagas in Prince Edward Island.

Use of the term "generation" in reports of studies on root maggots has been the cause of considerable controversy, and it is sometimes difficult to make an exact interpretation of the term as used by different writers. Some writers have used peaks of infestation as a criterion for estimating the number of "generations" occurring during a year, while others estimate the number of generations by determining the possible number of life cycles that can be completed during a growing season when starting with one female fly emerging early in the season. In this report the term "hatch" will be used to refer to maggots produced at a given time by any number of flies; the term "generation" will refer to all the maggots produced by flies that have emerged at a given time; and the term "brood" will refer to all the maggots produced by all the flies emerging from overwintered puparia, or from succeeding lots of puparia. The distinction between a generation and a brood is made because of the prolonged period during which flies emerge from overwintered puparia.

II MAGGOT SPECIES FOUND ASSOCIATED WITH RUTABAGAS IN PRINCE EDWARD ISLAND AND THEIR RELATIVE IMPORTANCE

Experimental Methods:

During the growing seasons of 1951, 1952 and 1953 more than 400 rutabaga fields were examined throughout the province. Eggs, larvae, puparia and adults of root maggots found near rutabagas were collected from many of these fields and identified according to Brooks' (1951) key. In fields showing exceptionally high egg populations around the roots of rutabaga plants during June and July, detailed studies were made of comparative numbers of different species of eggs, and at a later date larvae were collected from the same fields, identified as to species, and records were kept of the numbers of each species.

Flies emerging from overwintered puparia in infested rutabaga fields were captured in emergence cages (discussed in detail in the following section) and identified by Brooks' (1951) key.

Results:

The species of root maggots found associated with rutabagas in this province were: H. brassicae, H. liturata (Meig.) (=H. trichodactyla Rond.), H. cilicrura (Rond.), and Muscina stabulans (Fall.). The comparative numbers of the different species varied in different areas and at different times of the season, although in any collection the H. cilicrura specimens were never higher than about one per cent of the total.

H. brassicae were always present in fields showing maggot injury. This species was present in all areas of the province during the whole growing season from May to December, although the numbers varied greatly in different areas at any one time during the season. This will be discussed fully later in the paper.

During the months of June and July H. liturata eggs were present in all rutabaga fields examined, with the highest populations being found in the sandy soil areas. Larvae of this species were never found around the rutabagas unless H. brassicae larvae were already in the roots. In four fields examined in 1952 and 1953 no H. brassicae eggs were found but as many as 26 H. liturata eggs were counted around one rutabaga plant. These fields were examined closely during the summer and roots were checked after harvest. No signs of maggot injury were found. However, in other fields where eggs of both species were present at the same time, examinations in late July and August showed counts of large numbers of larvae of both H. brassicae and H. liturata. The following data show averages of egg and larval populations, collected during the period of greatest abundance from ten plants selected at random, in each of three different soil areas; A, averages for four fields in a clay loam soil area with severe maggot injury; B, averages for four fields in a light sandy soil area with severe maggot injury; and C, averages for four fields in a light sandy soil area with no maggot injury (the dates of collections are approximate averages of the times the examinations were made in the different fields):

		A	B	C
Eggs, July 20 :	H. brassicae	3	62	1
	H. liturata	72	79	203
Eggs, July 30 :	H. brassicae	56	58	0
	H. liturata	12	34	63
Larvae, Aug. 12 :	H. brassicae	47	76	0
	H. liturata	0	167	0

The data for the "A" fields show that although *H. liturata* eggs were prevalent during late July the larvae did not develop around the rutabaga roots. It is also to be noted from the data that there were no (or very few) *H. brassicae* larvae in the roots at the time the *H. liturata* eggs were prevalent.

It was also noted that the *H. liturata* larvae in the "B" fields appeared to be feeding on decaying material on the lower surface of the roots and not on healthy plant tissue. In the two fields that showed the most severe maggot injury counts taken of the numbers of larvae in a wet soggy mass of soil around the plants and of those actually inside the roots showed the following:

		Nos. of Larvae in ten plants selected at random. Average for two fields
H. brassicae	In wet soil around rutabagas	11
	Inside rutabagas	109
H. liturata	In wet soil around rutabagas	234
	Inside rutabagas	8

M. stabulans were only found in fields near farm buildings during late May and June. Egg counts were high (eight to 34 per plant) in a few low, wet fields, but severe larval injury was noted in only one field during a period of continuous wet weather.

The above studies showed that H. brassicae was the only species of root maggot causing injury to rutabagas in Prince Edward Island, and survey studies on the other secondary species were concluded in 1953.

Emergence studies (discussed fully in the following section) conducted in 1952 and in 1953 showed that large numbers of H. liturata overwintered as puparia in H. brassicae infested rutabaga fields (as many as 250 H. liturata flies from 100 square feet of soil were captured in emergence cages in heavily infested fields). The flies emerged from overwintered puparia between the last of May and early July with the peak emergence occurring during the third week of June. The period of emergence was the same in all areas of the province.

III HYLEMYA BRASSICAE AS A PEST OF RUTABAGAS

A. Literature Review

H. brassicae was first mentioned by Major in 1829 and in 1833 it was reported to be causing great destruction in Europe (Slingerland, 1894). It was described by Bouché, P.F. in Natur der Insekten, Berlin, in 1834. In 1835 it was found in the Boston, U.S.A., area by Dr. Harris (Schoene, 1916) and Slingerland (1894) states that in little more than 50 years it spread over the greater portion of Canada and the

United States. It is reported to have been imported into North America from Europe in ships' ballast, and its progress in spreading throughout the country appears to follow closely the introduction of cultivated cruciferous crops into different areas. Although prevalent in parts of Ontario at least as early as 1875 (Couper, 1876) and along the St. Lawrence River in 1898 (Fletcher, 1899), it was not found in the St. Annes, Quebec, area until 1909. (Swaine, 1910). Between 1900 and 1902 it was found to be prevalent in New Brunswick and Prince Edward Island and in parts of Saskatchewan, Alberta and British Columbia (Fletcher, 1901; 1902. Gregson, 1902). It is now present in varying degrees of severity in all temperate climatic areas of the world. It is also known to be a serious pest of crucifers in Nigeria (Comte, 1914). The species has been reported in Texas and other Gulf States but Chittenden (1916) stated that the insect was erroneously identified.

Life history and biology studies have been carried out by different workers in all parts of the world and many varied conclusions have been drawn from the results. The reported number of broods or generations occurring during a season varies according to different workers; from one to as many as five have been reported for different areas (Kollar, 1840; Slingerland, 1894; Hopkins and Rumsey, 1896;

Quaintance, 1896; Smith, 1896; Weed, 1896; Weed, 1899; Theobald, 1904; Sorauer, 1913; Dindon, 1914; Lowry, 1915; Schoene, 1916; Hewitt, 1918;Caesar, 1922; Horsfall, 1923; Brittain, 1927; Smith, 1927; Bogdanov-Kat'Kov, 1929; Nikitina, 1939; Fulton, 1942; Whitcomb, 1944; Carlson et al, 1948; Brooks, 1951; Foott, 1954). Almost all of the early workers studying this pest were concerned with effects on plantings of cabbage and cauliflower, and little attention was directed towards rutabagas. Since the insect causes serious injury to cabbage only during the early part of the season, workers have been mainly interested in its early season habits, and it is difficult to determine the accuracy of estimates of the number of generations occurring in different climatic areas. On reviewing all reports it appears that there are at least one or two more broods per season in the warmer climatic areas.

The stage in which H. brassicae overwinters also varies according to different workers. Some have stated that hibernation of any of the last three stages (larvae, pupa or adult) may occur (Hopkins and Rumsey, 1896; Weed, 1896 and 1899; Forbes, 1911; Vasina, 1928); some believed that the insect hibernated as a fly or a pupa (Curtis, 1860; Smith, 1896; Sorauer, 1913); Fletcher (1891) believed that it overwintered as a larva or pupa; and Gibson (1913) and Smith (1927) stated that the larvae hibernated and emerged the following spring. Most workers observed the insect to go into diapause in the pupal stage only.

The influence of weather conditions on maggot infestations has also been interpreted differently. Noble (1918) believed that wet weather during the oviposition period resulted in slight maggot damage in Ontario in 1917, and Caesar (1922) concluded that both cold wet weather and hot dry weather had a controlling influence on maggot infestations. Few workers have noted a significant effect of weather on maggot populations.

Different investigators have observed the period of preoviposition for H. brassicae to vary from about two days to two weeks, but few have explained the conditions under which these observations were made. Observations have also been made by several workers (Britton and Lowry, 1917: Brittain, 1927; Caesar, 1922; Miles, 1949; Vodinskaya, 1928; Foott, 1954) on the number of eggs laid per female, and several (Slingerland, 1894; Foott, 1954; O'Kane, 1916; Schoene, 1911; Brittain, 1927) have reported on the number of eggs obtained from dissected females. The number varied considerably but the highest figure was 149 eggs from one female (reported by Vodinskaya). Since authors agree that mature females contain about 40 to 50 eggs, it is concluded that one insect may mature three batches of eggs.

The period of emergence of H. brassicae flies from overwintered puparia is reported by different workers to be anywhere from two weeks to three months or more. It is not known if each report is accurate for the areas where studies were made, but it appears that no one has given special attention to the differences in different places. Also, differences in times of first attack in different parts of the country have been attributed to climate alone. Detailed tests on emergence have been conducted by the writer in an attempt to determine the factors influencing the rate of development of different stages of H. brassicae.

Biology and control studies have been closely associated in work on H. brassicae, and until quite recently almost all attention has been directed towards control in cabbage and cauliflower. For these plants the most popular control between 1891 and 1918 was by use of tarred-paper discs devised by E.S. Goff (8th Ann. Rept. Wisconsin Agr. Exp. Stn., 1891), although chemicals such as, naphthalene, hellebore, kerosene-emulsion, nitrate of soda, carbolic wash, salt and gas-lime and many others (reviewed by

Slingerland, 1894) were used. Most of the workers were interested only in preventatives for infestations attacking cabbage during the early stages of development, and the results of their studies are of questionable value when a worker is concerned with crops, such as rutabagas, that are injured by _H. brassicae_ throughout the whole growing season.

It was reported in the Country Gentlemen in 1870 that rutabagas were attacked by _H. brassicae_, but it is only within recent years that studies have been directed towards a knowledge of the habits of the insect directly concerned with such crops. The most recent comprehensive study of _H. brassicae_ adults was presented by Foott (1954) and this study was concerned with rutabagas. The extensive studies on cabbage appear to have led workers to assume that the whole, or a large part, of the first brood of larvae cause severe injury to cabbage, and that succeeding broods attack such crops as rutabagas and radishes. The fact has not been stressed that the larvae injuring cabbage are in most instances produced by the flies emerging early in the season, and that these flies comprise a very small percentage of the total number of adults emerging from overwintered puparia.

B. Life History and Emergence Studies

1. Field Studies

Experimental Methods:

From the results of the studies carried out in 1951, field observations and variations in the degree of control obtained with DDT sprays in different areas (when sprays were applied at the same time in all areas) indicated that maggot infestations did not occur at the same time in different areas of the province. In order to determine the time that the first flies emerged and the duration of emergence, six cages were placed at random in each of 11 fields in different areas in the spring of 1952. The cages, covered with cheesecloth that was fastened to the inside of a pyramid-shaped wooden framework, were five feet square and 2½ feet high. The 11 fields, representative of the different soil areas of the province, were known to have been heavily infested with H. brassicae in 1951. Since there was a possibility that the cages would have some influence on the temperature and moisture content of the soil under them, they were moved to a new site every three or four days. The emerging flies were collected and identified by Brooks' (1951) key. A similar test was carried out in 1953.

In 1954 and 1955 twelve cages were placed in each of five fields in areas of sandy, loam and clay loam soil texture. The period of emergence was recorded for each area.

The time of first maggot attack in different areas of the province, the periods of peak abundance of larvae, and the durations of attacks were estimated from larval collections made in different fields and these were correlated with the flight period of flies in different soil areas. Of about 600 fields examined between 1951 and 1955, 300 heavily infested rutabaga crops were used in the compilation of Figure 3. The time and duration of attacks by the third brood in the light and medium textured soils and of the second and third broods in the heavy soil areas were estimated by taking 100 larvae, collected when the attack of the first brood started in each soil area, and rearing the second and third generations in five foot square cages near the laboratory. These broods were not distinguished in rutabaga crops, and there is no proof that they did actually occur in the field.

Results:

The results of the emergence studies for the four years are recorded in Table 1; emergence is recorded on the basis of 12 cages, covering an area of 300 square feet in each field.

Table 1 - Times of emergence of *H. brassicae* flies from overwintered puparia in sandy, loam, and clay loam soils, 1952 to 1955 *

Number of fields examined in each area	Soil type	Average number of flies emerging per 12 cages in each field										
		June			July			August			September	
		1-10	11-20	21-30	1-10	11-20	21-30	1-10	11-20	21-30	1-10	11-20
						Field emergence studies, 1952						
4	Light sandy		12	81	169	41	4					
4	Loam				7	12	96	30	20	14		
3	Clay loam						6	30	6	4	14	
						Field emergence studies, 1953						
5	Light sandy		6	14	21	19	17	10				
4	Loam			2	10	24	18	13	8			
2	Clay loam						12	42	38	16		
						Field emergence studies, 1954						
2	Light sandy	14	23	27	39	86	3	2				
1	Loam			18	45	56	84	40	22	14		
2	Clay loam					37	46	157	174	68	14	4
						Field emergence studies, 1955						
2	Light sandy		17	46	64	36	61	34	2			
2	Loam			28	68	200	240	85	47	10		
1	Clay loam						4	49	51	8	11	6

* The emerging flies were captured in 6 cages per field in 1952 and 1953, and 12 cages per field in 1954 and 1955, each cage covering 25 square feet. Each of the fields selected for emergence studies was known to have had a heavy infestation of *H. brassicae* in the previous season's rutabaga crop.

In 1954 the flies in all areas started to emerge about a week earlier than during the other three years, although the period of emergence was about the same. The first flies were captured on about June 12 in the light sandy soil areas, June 26 in the fine sandy loam soil areas, and about July 25 in the heavier or clay loam soil areas.

As noted by Fulton (1942) some H. brassicae flies must be present earlier than the dates on which the first flies are captured in cages, since all instars of larvae have been collected from rutabagas growing in a previous season's rutabaga field. Large numbers of cabbage maggot eggs have been collected during the latter part of May from three or four stecklings placed in a field that was known to have been infested during the previous season; and, from the literature, it appears that some workers assumed from such tests that these early collections constituted the egg stage of the complete first brood of maggots. However, no flies were captured in the emergence cages and no larvae were found in rutabaga fields before the second week of June in this province. Also, the emergence data show that flies producing eggs in May constitute an extremely small percentage of the adults emerging from overwintered puparia. They could possibly cause some injury in limited areas of early cabbage, but they are obviously negligible in rutabaga fields.

The number of broods of H. brassicae attacking rutabagas in different soil areas of Prince Edward Island is given in Figure 3. In the light sandy soil areas there are two complete broods, each of which causes severe injury to rutabagas. In the clay loam areas only one brood causes severe injury in the field, although serious damage to rutabagas in storage has been caused by a second brood. Generally only one complete brood attacks a particular rutabaga crop in either the light or the heavy soil areas. If a crop is planted early enough (late April or early May) in the light soil areas to be attacked by all of the first brood (from early June to early August) it is harvested in late July or early August - before the second brood becomes prevalent.

2. Greenhouse Studies

Experimental Methods:

A 200 pound sample of soil, collected from each of five different areas, was placed in a small caged area on a bench in the greenhouse, and 250 puparia were placed at a depth of two to four inches in each of the plots.

During the test the soil moisture (total) was retained at between 8 and 20 per cent, and the room temperature was kept at between 70° and 75°F. The puparia were collected in the fall from an infested rutabaga field. Before being placed in the soil for emergence testing they were subjected to below-freezing temperatures for about two weeks and then gradually brought up to room temperature.

After emergence started, the flies were moved to another caged plot containing growing rutabaga plants and a five per cent sugar solution on blotting paper in petri dishes. Progeny from these flies were allowed to develop to the pupal stage and the puparia were then stored at 38°F. for future tests.

Fifty male and 50 female H. brassicae flies that had emerged during a period of four days were placed in a cage containing slices of rutabaga in moist sand. The sand, in screen-bottomed boxes resting in sphagnum moss, was kept moist by periodically adding water to the moss. During this test the chamber was kept at a temperature of 70° to 75°F. and at a relative humidity of 60 to 70 per cent.

Four tests similar to the one described above were carried out during the period of this study, and the results given are average figures for four such tests.

Studies were also conducted on the effects of temperature on the time required for development of larvae.

Results:

From four tests conducted in the greenhouse using field-collected puparia (600 to 1000 for each test), the following data was obtained: a) Approximately 90 per cent emergence occurred over a period of about 70 days. b) Oviposition by one day's hatch of flies began between two and three days after emergence but eggs did not become prevalent until the 5th or 6th day. c) The flies lived for an average of 22 days. d) The period from egg hatching to pupation of larvae was 20 to 26 days. e) An average of over 30 mature larvae were produced per female fly. f) Larvae produced by a group of flies emerging at a given time were present in rutabaga roots for approximately 50 days.

The results of the emergence studies from different types of soil are given for the species _H. brassicae_ and _H. liturata_ in Figures 8 and 9.

The length of life of _H. brassicae_ flies in an insectary is reported by various authors (Schoene, 1916; O'Kane et al, 1923; Brittain, 1927; Smith, 1927; Vodinskaya, 1928; Foott, 1954); some give an average duration of 14 days while others report flies living for four weeks, with the females surviving about a week longer than the males. Vodinskaya reported the greatest length of life for one fly, - three months and six days. In tests in the greenhouse the writer found the average length of life of the flies to be 22 days. In cages (five feet x five feet x 2½ feet) placed outside, ten male and ten female newly-emerged flies lived for an average of 24 days (the flies were provided with growing rutabaga plants and flowering wild radish plants (Raphanus raphanistrum, L.) for oviposition sites, shelter and food. Water was added as required to keep the surface soil moist).

Different figures have been given by various authors for the time required for H. brassicae to complete a life cycle. The shortest average period, 34 days, was reported by Caesar (1922), but most investigators place the time at about 45 to 55 days. At temperatures of approximately 70°F. the writer obtained the same results as reported by others. At lower temperatures the development of all stages of the insect was prolonged, and larvae, particularly, live much longer at low temperatures. In one test larvae kept in rutabagas at 36° to 40°F. lived for four months before pupating, and larvae have often been found late in January in rutabagas in dark storage bins. They were continually tunnelling inside the rutabagas and, although their rate of development was slower, they were not in diapause.

In another test where larvae were subjected to different temperatures, the duration of the larval stage was prolonged as the temperatures were lowered (Table 3).

Table 2 - Time Required for Complete Development of H. brassicae larvae at different temperatures, 1955

Storage Temperature (°F.)	No. of larvae used in each test	Days from time of hatching to time of pupation, and numbers of larvae pupating at five day intervals								
		15	20	25	30	35	40	45	50	55
75	200		76	47	43	24	4			
60	173			40	18	42	52	10	1	
50	137				8	54	17	11	35	9

3. Plot Emergence Studies

Experimental Methods:

In order to conduct more detailed studies on factors affecting emergence of H. brassicae, puparia were placed at a depth of three inches in five feet x five feet x eight inch blocks of sandy, loam, and clay loam soils. The soil blocks were situated near the laboratory in excavated holes, eight inches deep, and each was covered with an emergence cage. Two lots of puparia were used in the test; one lot was collected in the spring from an infested rutabaga field in a sandy soil area, and the other was reared in the greenhouse from the larval stage and stored overwinter at 38°F. Duplicated blocks of light sandy, loam, and clay loam soils were used for each lot of puparia. The flies emerging from each block of soil were counted and moved to other rearing cages.

Soil samples were collected at 2-day intervals from the 12 soil blocks and analyzed for total moisture content (samples dried at 105°C.). The samples were obtained with a $\frac{3}{4}$-inch soil sampling tube by taking a 3-inch core of soil, discarding the upper two inches, and retaining the lower one inch of soil for moisture analysis. The variation in soil moisture for the three soil types during June, July and August is given in Figure 10.

Results:

The results of the emergence studies are given in Table 3. When puparia had formed and overwintered in a rutabaga field in a light soil area, and were then transferred to the different-textured blocks of soil, the times of emergence followed a pattern similar to natural field emergence (Table 1), although the emergence period for the loam and clay loam soils started about ten days to two weeks earlier. For puparia that had been reared in the greenhouse, stored for a time at 38°F. and then

Table 3 - Times of emergence of H. brassicae adults from different textured soils when puparia were reared under natural and artificial conditions, 1955 *

Number of plots	Soil type	June 1-10	June 11-20	June 21-30	July 1-10	July 11-20	July 21-30	August 1-10	August 11-20	August 21-30	September 1-10	September 11-20	Per cent emergence
		Average numbers of flies emerging per plot											
		Emergence from puparia that were collected in the spring from an infested rutabaga field in a sandy soil area											
2	Sandy	10	40	129	107	102	61	7					91
2	Loam		12	98	112	132	72	28	14				93
2	Clay loam				3	47	130	104	136	57	6		96
		Emergence from puparia that were reared in the greenhouse and stored overwinter at 38° F.											
2	Sandy	78	38	12	14	37	9	0					25
2	Loam	95	44	5	19	45	12	0					28
2	Clay loam	96	36	13	9	56	27	16					34

* The different textured soils, ranging from light sandy to clay loam, were samples collected from various parts of Prince Edward Island and placed in excavated holes, 5 feet square and 8 inches deep, near the laboratory. Puparia were distributed in the soil at a depth of 3 inches and they were kept at least one foot in from the outer edge of the artificially placed soil.

placed in the sandy, loam, and clay loam soils, the times and periods of emergence were the same in all three soil types.

Moisture readings for the three soil types averaged 11.4, 15.8, and 18.5 per cent for the sandy, loam and clay loam soils respectively; the heavier soils absorbed more moisture during a rainfall and retained it longer (Figure 10).

C. Factors Influencing Seasonal History and Intensity of Infestations of *H. brassicae*

1. Weather Conditions

Experimental Methods:

Throughout the period of this study variations in the time of first emergence, and in a normal rise and fall in the rate of emergence of *H. brassicae* flies from over-wintered puparia, were noted in different fields and in different areas. These variations were correlated with occurrences of periods of wet and dry weather during the period of emergence.

Between 1952 and 1955 general observations were made of seasonal weather conditions, and an attempt was made to determine if dry or wet periods significantly influenced maggot infestations.

In each of six rutabaga fields, known to have been heavily infested in 1953, two rows of rutabagas were planted in the spring of 1954. At the time of thinning the plants were left three inches apart and samples (20 plants per row) were collected periodically during the season. The eggs around each sample plant were counted and the numbers of each instar of larvae in the roots were counted. In 1955 a similar test was conducted in five infested fields.

Results:

The 1952 growing season was quite dry throughout; the period of emergence was shorter than during the following three years, and the beginnings of emergence in the loam soil areas appeared to be delayed. During 1953 wet conditions prevailed throughout the whole growing season and the rate of emergence rose and declined gradually in all areas. In 1954 there was a dry period during late May and early June and continual wet weather during the remainder of the season; emergence started earlier and the duration of emergence was longer than during the other years. In 1955 the weather was cool and wet during May and June, followed by very dry periods in July and August; emergence began at about the normal time in all areas but in the lighter soils there was a marked decrease in the rate of emergence about the middle of July.

During the four years of the emergence studies it was noted that the rate of emergence in an area (particularly near the peak emergence period) decreased significantly during a period of a week of more of dry weather. Since each dry period never lasted for more than two weeks, the fluctuations do not show in the data of Table 1. In one of the fields being studied in 1952 the rate of emergence declined rapidly and then stopped completely during a 10-day period of dry weather in late July; it was assumed that all the flies had emerged. However, on August 2 a heavy rainfall occurred and by August 4 the rate of emergence was higher than at any time during the full period of emergence (116 flies emerged from 150 square feet of caged soil in four days). The rate then declined gradually and ended during the last week of August. This particular field was high, sloping and well drained and the soil dried quickly following the onset of dry weather. Because of the marked influence of weather conditions on the emergence in this field, the data were not included in Table 1.

General field observations on severity of maggot injury showed the following: In 1951, a relatively wet season, maggot infestations generally were very severe and the overwintering population of puparia was high.

The 1952 growing season was dry and maggot infestations were light. The 1953 and 1954 seasons were wet throughout; the 1952-53 overwintering population of puparia was low and infestations in early crops of 1953 (harvested in July or early August) were relatively light - even in the light soil areas; however, maggot populations built up during the season with the result that infestations in the late-harvested crops were severe and the overwintering population (1953-54) of puparia was high; in 1954 infestations were very severe and even the late plantings in the light soil areas were seriously affected (Figure 7). In 1955 wet weather persisted until the latter part of June, and infestations were severe in early planted rutabagas in the light soil areas. During July, August and September relatively dry conditions prevailed and infestations in all rutabaga crops grown in the clay loam soil areas, as well as late-planted crops in the light soil areas, were relatively light.

From the data collected during 1954 and 1955 in the 2-row plantings in different fields, it was found that, during the flight period of the flies from overwintered puparia: a) the numbers of eggs being deposited did not decrease during either wet or dry periods of weather;

b) throughout wet periods of weather larval populations in the plants continued to rise and all instars were present; c) during dry weather larval counts dropped sharply, - after about a week of dry weather only second or third instars were found, and after ten days to two weeks of dry weather maggot populations almost completely disappeared. During the periods of attack by H. brassicae it was noted that populations of predators, as staphylinids and Coenosia tigrina (Fall.), were exceptionally high. This was presumed to be due to the fact that a major part of the population of predators, as well as maggots, from two or more acres of infested soil were concentrated into the two rows of the test plots (in setting up the tests it was determined that no rutabaga crops would be sown within about 200 yards of the test rows or the source of infestation).

2. Host Attraction

It has been assumed that rutabagas serve as a strong attractant to H. brassicae flies. However, Vodinskaya (1928) reported that the flies were more strongly attracted to radish, rape and cabbage than to rutabagas, and Foott (1954) in detailed studies with special cages and olfactometers did not find rutabagas to be a significantly strong attractant. Mass observations, particularly along shore-line areas throughout Prince Edward Island, partially confirm the results of these authors, and the slight attractant power of rutabagas may account for major differences between infestations occurring in two fields which are quite close to one another. For example, on many occasions it has been observed that along southern shore-line areas a rutabaga field situated south of a source of infestation always has much lighter maggot injury than one located the same distance to the north of the source. Again, if two rutabaga fields are about 100 feet or more apart and in a direct line south of an infestations source, the one nearest the source is heavily infested while the one farther to the south is practically free of injury. On the other hand, if two fields are in a direct line north of the source of infestation both are infested, although the one nearest the source has more severe maggot injury.

Wild radish plants appeared to be more attractant to H. brassicae flies than rutabagas. In grain fields containing large numbers of wild radish plants it was noted that the wild radish were heavily infested with maggots while an adjoining rutabaga field was very slightly infested. Also on several occasions between 1951 and 1955, situations were observed where large numbers of wild radish plants were growing in rutabaga fields. Ninety-five to 100 per cent of the wild radish were infested, whereas less than 20 per cent of the rutabagas showed maggot injury. However, in either situation, within about two weeks after all of the radish plants were pulled and destroyed, the rutabagas became heavily infested with H. brassicae larvae.

In situations where rutabagas have overwintered in a field, the roots develop as seed-producing plants during the following spring. It is not known if these plants are strongly attractant to H. brassicae flies but tremendous numbers of eggs are laid (over 450 have been collected from around one plant) and large numbers of flies have been found around them during cold weather; on wet windy days up to 46 flies have been found in crevices in the soil or clustered in shelters around one rutabaga. Also, in dry calm weather large numbers of flies have been collected around these rutabaga stecklings with sweep nets, while very few have been captured in sweeps made in other parts of the fields. If no rutabagas survived over the winter, net sweeps made in the spring during the period of emergence yielded approximately the same number of H. brassicae adults in all parts of the fields.

Although several authors have reported finding eggs of H. brassicae deposited indiscriminately on aerial parts of plants or on soil (Gibson and Treherne, 1916;

Vodinskaya, 1928; Miles, 1949; Foott, 1954), the writer has found eggs of this species only in cracks or crevices in the soil near the roots of host plants. During wet weather they have occasionally been found on the soil surface. However, eggs of _H. liturata_ and _M. stabulans_ are laid under decaying leaves or slanting plants that are lying on the soil, or on the crowns and leaf bases of the plants. In greenhouse tests _H. brassicae_ eggs were deposited anywhere in the cage (although mostly around rutabagas) but this is assumed to be due to crowding of a large number of flies in a confined area; or possibly, as Miles (1949) concludes, because of the removal of drought conditions and the limitations of sunlight.

3. Soil Texture

Experimental Methods:

Since the observations made in 1951 indicated that there was a wide variation in the time root maggots first appeared in rutabaga fields, soil samples were collected in the fall from infested fields throughout the province. These were tested for per cent sand (40 second reading) by the Bouyoucos Mechanical Analysis method, and this measure of texture was correlated with the time _H. brassicae_ larvae first appeared in the 1952 rutabaga crop that adjoined each soil-tested field. The soil samples, consisting of 20 random subsamples of 6-inch cores of soil from a 2-acre area, were collected with a ¾-inch soil sampling tube.

Naming of the different textured soils into classes of sandy, loam, and clay loam was based on the soil class system used by Lyon and Buckman (1947). According to the Prince Edward Island soil survey classification, the "sandy" soils correspond to the Kildare Sandy Loam, the "loam" to the Charlottetown Fine Sandy Loam, and the "clay loam" to the Queens Clay Loam (Whiteside, 1950).

The above procedure of soil sampling, and correlation of soil texture with time of first infestation in following year's rutabaga crops, was carried out each year from 1951 to 1955.

Results:

The results of the four years' study on the relationship between soil texture, recorded as per cent sand, and the time of first appearance of _H_. _brassicae_ larvae in rutabaga crops are shown in Figure 1. There was a highly significant correlation between the two factors for each year of the test (Table 4). Nevertheless, after the first two years of these studies it was noted that, particularly in certain areas of the province, there were wide discrepancies from the expected time of maggot attack in different fields. It was found that there was a difference in the permeability of the subsoil in different areas and this resulted in differences in the amount of moisture retained by similar-textured soils. Because of these differences a study of soil moisture was started in 1955.

Table 4 - Correlation Coefficients for Diagrams in Figure 1

Year	df	$r_{(calculated)}$	$r_{0.01}$
1952	86	-.8498	.273
1953	52	-.9152	.348
1954	36	-.9312	.413
1955	74	-.8181	.294

4. Soil Moisture

Experimental Methods:

As a test of the relationship between soil moisture and the time *H. brassicae* first appear in rutabaga fields, soil samples were collected at weekly intervals during June and July, 1955, from 19 fields in different areas of the province and tested for total field moisture. Each composite sample, consisting of 20 random subsamples per acre in *H. brassicae* infested soil was collected by taking ¾-inch cores of soil to a depth of three inches, discarding the upper two inches, and retaining the remaining 1-inch samples for moisture analysis. Data collected from each field during the two months were averaged, and the results from all fields were correlated with the time of first infestations of H. brassicae in rutabaga fields.

Results:

The correlation diagram in Figure 2 shows the very close relationship between total field moisture (averages for June and July) and time of first maggot attack (r(calculated) = .9626 and $r_{.01}$ = .575). General observations also indicated that the heavier textured soils absorbed more moisture during a rainfall and retained it longer.

D. Field and Storage Injury in Rutabagas Attacked at Different Stages of Development

During the period of this study many infested samples have been obtained from rutabaga shipments that were being delivered to retailers. From these samples the following observations were made: a) Infested rutabagas grown in light soil areas and harvested in late August were distorted in shape (Figure 4, A); those grown in heavy soil areas and harvested in late August had surface tunnelling (Figure 4, B); and those grown in light soil areas and harvested in October had surface tunnels, as well as early healed-over injury (Figure 4, C). b) If the rutabagas contained only third instar larvae at the time they were harvested no internal injury resulted after seven days of storage at room temperature (Figure 5). c) If the rutabagas contained first or second instar larvae at the time they were harvested, severe internal injury resulted after seven days of storage (Figure 6).

Observations in rutabaga crops and in storage bins have shown that, except for the large holes in plants resulting from early injury, internal tunnelling does not occur until after the plants are removed from the soil. During prolonged dry conditions larvae will pupate inside the surface layers of the root, although in general they feed near the root surface and enter the soil to pupate.

IV CONTROL MEASURES FOR *H. BRASSICAE* IN RUTABAGAS IN PRINCE EDWARD ISLAND

A. Literature Review

Many hundreds of articles concerned with control of root maggots in cruciferous crops have been published during the past 100 years. The majority of these have dealt with attacks of *H. brassicae* in cabbage and cauliflower, and it is only within recent years that special attention has been directed towards a control of this pest in rutabagas and turnips. Since the discovery of the newer chlorinated hydrocarbon insecticides, much investigational work on root maggot control has been conducted and adequate control of the maggots in rutabagas has been obtained in western North America. However, with the standard methods of application even these newer chemicals have proven ineffective in controlling the pest in Prince Edward Island.

Of the older insecticides, Glendenning (1944) found that five to seven applications of corrosive sublimate or calomel dust substantially reduced maggot infestations but the cost was excessive. No other materials were found to be effective. Following the discovery of DDT many tests with this material were carried out, but no one has reported successful results.

Recent work in British Columbia and Washington by Stitt (1953), King et al (1953), King and Forbes (1954), and by King et al (1955) has shown that under conditions in western North America sprays and soil treatments of aldrin and heptachlor gave highly significant control of root maggots in rutabagas and turnips. In control studies at the Charlottetown laboratory conducted by F. M. Cannon (unpublished data), many insecticides were tested for root maggot control in rutabagas. However, none of the chemicals proved effective, and even the newer materials, aldrin and heptachlor, when applied as sprays or surface soil treatments did not provide significant protection against maggot attacks. In 1955 extensive tests were conducted by the writer in an attempt to determine whether adequate control of the pest could be obtained in Prince Edward Island by using different methods of application of the insecticides. The reasons for changing the methods of application from those used in the West are presented in the discussion.

B. Control Studies with DDT Applied on a Field Scale

Experimental Methods:

During the five years from 1951 to 1955 and with the cooperation of interested growers, DDT sprays, at rate of one pound toxicant per acre per treatment, were applied to rutabaga fields in different areas of the province. Except for the six fields tested in 1951, the treatments in each area were applied during the period of emergence of *H. brassicae* flies from overwintered puparia. Treatments were started when the first *H. brassicae* eggs were found in the fields. In 1954 and 1955 the time to begin the treatments in a particular field were calculated in the following manner: using the per cent sand in the farmer's previous season's infested rutabaga field, the time of first maggot attack was read from the regression line in the correlation diagram that had been compiled for the previous season (Figure 1); growers were advised to begin treatments one week earlier than the time estimated.

Results:

The results of the DDT field control studies for the years 1951 to 1955 are given in Table 5. With the exception of a few farmers who did not follow the recommended spray schedules, all growers were well satisfied with the results. No attempt was made to categorize the degree of injury, and the control estimates in the tables were based on readings of either injured or completely clean plants. In all of the check fields examined during the five years 90 to 100 per cent of the plants were injured. In 1954 infestations were very severe throughout the province, and even though the control percentages in the treated fields were lower than for the other years of the tests the results were very satisfactory to the growers. The 1954 growing season was very wet throughout and it was found that to obtain adequate control more frequent applications had to be made (note results in New Haven test field, Table 5).

C. Experimental Plot Studies Using Sprays and Soil Treatments

Experimental Methods and Materials:

Duplicated experiments on early and late planted

Table 5 - Results of Field Scale Tests with DDT to Control Infestations of *H. brassicae* in Rutabagas in Prince Edward Island, 1951 to 1955.

Location of field	Soil Type	No. of treat-ments	Per cent control* 1951	1952	1953	1954	1955
Carleton	S	4	-	85	75	-	-
Mt. Stewart	S	6	-	60	50	10	65
Tryon 1	SL	3	-	40	40	20	45
Tryon 2	SL	5	-	45	60	35	65
Augustine Cove	SL	5	-	70	60	30	70
Hampton	SL	4	0	70	55	15	65
New Haven	SL	9	0	90	95	95	95
Clyde River	SL	7	-	80	60	60	80
Mt. Herbert	L	6	30	70	85	45	75
Hazelbrook	L	4	-	50	50	20	-
Pownal 1	L	6	85	90	60	45	85
Pownal 2	L	4	80	80	70	-	60
Pownal 3	CL	4	75	70	70	40	65
Waterside	L	5	-	70	-	45	70
Mt. Albion	CL	5	-	80	70	50	75
Cherry Valley	CL	5	-	85	70	55	70
China Point	CL	4	-	70	70	40	-
Earnscliffe	CL	4	-	-	60	45	-
Seal River	CL	6	-	80	75	60	85
Vernon River	CL	5	-	70	60	55	75
Vernon Bridge	L	6	-	75	-	65	80

* The degree of control in each instance was estimated by subtracting the percentage of injured plants in a treated field from the average percentage of injured plants in 2 to 5 nearby (100 to 200 yards distant) untreated rutabaga fields - all crops being planted at approximately the same time.

** Treatments, each of 1 lb. toxicant per acre, were applied as sprays (40 pounds pressure) at weekly intervals. In 1951 applications were begun on July 29 in all fields. From 1952 to 1955 applications were made during the period of emergence of *H. brassicae* flies from overwintered puparia.

Note: In the above table, any measure higher than 50 per cent is to be considered very good control, since the method of appraisal shows only complete elimination of root injury. Injury in the remainder of the crops is greatly reduced and most of the plants are marketable.

rutabaga crops were carried out in four different soil areas of the province. To assure the highest possible degrees of infestation, the duplicated tests were located so that they adjoined fields that had contained heavily infested rutabaga crops in the previous season. Also, the experiments were designed so as to minimize the danger of obtaining uneven degrees of infestation between and within blocks; that is, long narrow areas along one side of the source of infestation were used in preference to square block areas, and the tests were located in the centre of large fields as far as possible from sheltering hedges. Six of the experiments, each consisting of four randomized blocks, with each block comprising ten treatments and two checks, were located at Mt. Stewart, Augustine Cove and Earnscliffe. Each plot in an experiment consisted of four rows 30 feet long with 30 inches between rows within the plot and three feet between plots.

The insecticides tested were heptachlor, aldrin and DDT. Heptachlor was used as a 25 per cent wettable powder and a 25 per cent granular formulation; the aldrin formulation was 20 per cent and the DDT 50 per cent, both as wettable powder. The rates and application schedules are given in Table 6. The spray treatments were applied with a hand-pump sprayer fitted with two nozzles pointing inward and downward so as to give an 8-inch spray band that covered the top and sides of the rutabaga drill. Sprays were applied at 40 pounds pressure.

In each of the remaining two experiments, located in a loam type soil at Cherry Valley, there were three randomized blocks, each block comprising five treatments and two checks. Each plot consisted of two rows 200 feet long with 30 inches between rows and three feet between plots. Heptachlor and aldrin, in the same formulations as given above, were used as soil treatments. In the early planted experiment supplemental spray treatments were applied to half of each plot that had received a soil treatment.

The reasons for setting up the Cherry Valley experiments as described above were as follows: firstly, by applying surface spray treatments to randomized plots there was the danger of interference with infestations in adjoining soil-treated plots by having the sprays destroy flies moving from one plot to another; and secondly, supplemental spray treatments, applied to half of the soil treated plots of each block in the early planted experiment, were used to determine their value in providing additional protection to the rutabagas in the event that the residual effect of the soil treatments would not be long enough to give control (remembering that the soil treatments were applied early in June and the first severe maggot attack did not occur until the latter part of August).

The soil treatments were applied with a hand-operated apparatus (Figure11, A & B). In placing the insecticide at the proper depth in the seeding drill, a low, flat-topped ridge (about two inches above ground level) was made with a horse hoe or disc hiller and levelled off with a roller. The 5-inch band and the furrow applications of insecticide were spread on this flat surface, and the hiller was again used to place the required amount of soil over the chemical. Finally, the rutabaga seed was sown in the surface about 1½ inches above the centre of the band of insecticide. Seed of the Laurentian variety was used in all of the control experiments.

When the rutabagas in each experiment were being thinned to a 6-inch spacing, the surface of the rows was removed and approximately ½-inch of soil was left over the insecticide.

Because there are two main periods of attack by _H. brassicae_ larvae in the light soil areas (Figure 3), the early-planted experiments in Augustine Cove and Mt. Stewart were examined in August as well as in October so that estimates of control of each brood of larvae could be determined. Early-planted tests in Cherry Valley and Earnscliffe were examined in early September and again in October.

Injury records were taken from 50 plants per plot in the Cherry Valley experiments and from 25 plants per plot in examinations of all other experiments. The final records were taken during the last two weeks of October and, in all, more than 15,000 plants were examined. The method of appraisal of root injury was that of counting the number of larval tunnels in each plant examined. This method was found to be more sensitive than the "index method" developed by King & Forbes (1954) for pointing out minor variations of effects of different treatments and different methods of applications. It was also noted that the index method was not accurate for comparing the results of different experiments when the plants in each test were at a different stage of development at the time of first maggot attack. All results were tested for significance by an analysis of variance.

Results:

The control results are given in Tables 7 to 14, and the per cent control is given for treatments in all

Table 6 - Results of Root Maggot Control Experiments on Early and Late Planted Rutabagas in Four Different Soil Areas of Prince Edward Island, 1955

			Percent control of *H. brassicae* injury[1]									
			Preplanting treatments applied 1½ inches below the seed in drills 4-5 inches high							Post-thinning spray treatments applied during the period of emergence of *H. brassicae* flies from overwintered puparia.		
			5 lbs. toxicant per acre					2.5 lbs. toxicant per acre		1 or 2½ lbs. toxicant/acre per application		
		Date of planting of each experiment	6-inch band applications		Furrow applications			Furrow applications		2 applications at 4-week intervals		6 applications at weekly intervals
Experimental area	Soil type		Heptachlor	Aldrin	Heptachlor	Heptachlor[2]	Aldrin	Heptachlor	Aldrin	Heptachlor (1 lb.)	Aldrin (2½ lbs.)	DDT (1 lb.)
Mt.Stewart	Light sandy	June 6	88**	62*	58*	39	49	57*	26	-15	- 8	-13
		June 28	95*	83*	82*	75*	66*	77*	68*	61*	34*	15
Augustine Cove	Sandy loam	May 27	84*	82*	87*	89*	62*	73*	60*	- 4	10	-10
		July 12	94*	77*	85*	81*	43	58*	57*	20	- 2	- 3
Cherry Valley	Loam	June 8	91*	67*	82*	86*	49*	-	-	-	-	-
		June 29	99*	93*	89*	85*	86*	-	-	-	-	-
Earnscliffe	Medium clay loam	June 14	98*	92*	73*	67*	67*	63*	65*	39	33	32
		June 30	93*	74*	87*	66*	81*	51*	51*	48	27	-26

[1] Percent reduction of larval tunnels between check and treated plots, estimated on the basis of 100 plants per treatment in each experiment.
[2] Granular formulation; all other treatments were wettable powder formulations of Heptachlor 25%, Aldrin 20% and DDT 50%.
*Significant at the 1% level (calculated from a tunnel-count estimation of injury).
**At the 5% level treatment gave significantly better control than all other treatments in experiment.

experiments in Table 6, except for the plots in the Cherry Valley test where supplemental spray applications were made. With the exception of the furrow treatments of granulated heptachlor at five pounds and aldrin at five and 2½ pounds toxicant per acre in the Mt. Stewart experiment planted June 6, all preplanting soil treatments in all of the experiments showed highly significant control. The chemicals provided protection to the crops throughout the whole season. In the lighter soil areas second brood larvae were controlled by insecticides applied in May or early June, and in the heavier soils at Cherry Valley the supplemental sprays were found to be unnecessary (there was no significant difference between the control obtained with soil treatments plus the additional sprays and with the soil treatments alone (Table 11).

Mid-season analyses were made in all of the experiments (Figure 12) but, since the insecticides were effective in providing protection for the whole growing period of the rutabaga crops, there were only slight differences in the results of the mid-season and the fall analyses. Only the final results are given in this report.

Band applications of heptachlor, in all eight of the experiments, gave consistently better control than all

Table 7 – Control of root maggots in rutabagas in Prince Edward Island, 1955, computed by tunnel-count method of appraisal.

Experimental area: Mt. Stewart
Date of planting: June 7, 1955
Date of examination: October 12, 1955

CHEMICAL (wettable powder formulations)	ACTIVE INGREDIENT PER ACRE (pounds)	INFESTATION (No. of larval tunnels in 100 plants selected at random from 4 replications)	CONTROL (per cent reduction of larval tunnels)	MARKETABLE PLANTS (per cent)
Untreated	-	857	-	14
		6" Band Method		
Aldrin	5	325*	62	65
Heptachlor	5	100**	88	94
		Furrow Method		
Aldrin	2½	638	26	40
Aldrin	5	435*	49	55
Heptachlor	2½	367*	57	64
Heptachlor	5	357*	58	70
Heptachlor[1]	5	527*	39	50
		Spray Method[2]		
Aldrin	7½	925	- 8	25
Heptachlor	3	991	-16	22
DDT	6	970	-13	10
L.S.D. (at levels) 1%		259.4		
5%		193		

[1]Granular formulation.
[2]Applications made during flight period of over-wintering generation of H. brassicae flies.
*Highly significant control.
**At the 5% level treatment gave significantly better control than all other treatments.

Table 8 - Control of root maggots in rutabagas in Prince Edward Island, 1955, computed by tunnel-count method of appraisal.

Experimental area: Mt. Stewart
Date of planting: June 28, 1955
Date of examination: October 28, 1955

CHEMICAL (wettable powder formulations)	ACTIVE INGREDIENT PER ACRE (pounds)	INFESTATION (No. of larval tunnels in 100 plants selected at random from 4 replications)	CONTROL (per cent reduction of larval tunnels)	MARKETABLE PLANTS (per cent)
Untreated	-	789	-	24
		6" Band Method		
Aldrin	5	134*	83	90
Heptachlor	5	42*	95	98
		Furrow Method		
Aldrin	2½	249*	68	74
Aldrin	5	269*	66	80
Heptachlor	2½	181*	77	84
Heptachlor	5	139*	82	90
Heptachlor[1]	5	200*	75	82
		Spray Method[2]		
Aldrin	5	520*	34	40
Heptachlor	2	308*	61	65
DDT	4	682	15	30
L.S.D. (at levels) 1%		211.5		
5%		157.4		

[1]Granular formulation.
[2]Applications made during flight period of over-wintering generation of H. brassicae flies.
*Highly significant control.

Table 9 - Control of root maggots in rutabagas in Prince Edward Island, 1955, computed by tunnel-count method of appraisal.

Experimental area: Augustine Cove
Date of planting: May 27, 1955
Date of examination: October 2, 1955

CHEMICAL (wettable powder formulations)	ACTIVE INGREDIENT PER ACRE (pounds)	INFESTATION (No. of larval tunnels in 100 plants selected at random from 4 replications)	CONTROL (per cent reduction of larval tunnels)	MARKETABLE PLANTS (per cent)
Untreated	-	1122	-	11
		6" Band Method		
Aldrin	5	199*	82	80
Heptachlor	5	177*	84	86
		Furrow Method		
Aldrin	2½	452*	60	65
Aldrin	5	423*	62	67
Heptachlor	2½	299*	73	75
Heptachlor	5	145*	87	90
Heptachlor[1]	5	119*	89	94
		Spray Method[2]		
Aldrin	7½	1008	10	25
Heptachlor	3	1167	- 4	10
DDT	6	1239	-10	6
L.S.D. (at levels)	1%	305.9		
	5%	228		

[1]Granular formulation.
[2]Applications made during flight period of over-wintering generation of _H. brassicae_ flies.

Table 10 - Control of root maggots in rutabagas in Prince Edward Island, 1955, computed by tunnel-count method of appraisal.

Experimental area: Augustine Cove
Date of planting: July 12, 1955
Date of examination: October 27, 1955

CHEMICAL (wettable powder formulations)	ACTIVE INGREDIENT PER ACRE (pounds)	INFESTATION (No. of larval tunnels in 100 plants selected at random from 4 replications)	CONTROL (per cent reduction of larval tunnels)	MARKETABLE PLANTS (per cent)
Untreated	-	225	-	74
		6" Band Method		
Aldrin	5	52*	77	90
Heptachlor	5	14	94	99
		Furrow Method		
Aldrin	2½	97*	57	90
Aldrin	5	129	43	90
Heptachlor	2½	94*	58	92
Heptachlor	5	33*	85	98
Heptachlor[1]	5	43*	81	95
		Spray Method[2]		
Aldrin	5	229	-2	76
Heptachlor	2	181	20	80
DDT	3	231	-3	75
L.S.D. (at levels)	1%	103.2		
	5%	77		

[1]Granular formulation.
[2]Applications made during flight period of overwintering generation of H. brassicae flies.
*Highly significant control.

Table 11 - Control of root maggots in rutabagas in Prince Edward Island, 1955, computed by tunnel-count method of appraisal.

Experimental area: Cherry Valley
Date of planting: June 8, 1955
Date of examination: October 17, 1955

CHEMICAL (wettable powder formulations)	ACTIVE INGREDIENT PER ACRE (pounds)	INFESTATION (No. of larval tunnels in 100 plants selected at random from 4 replications)	CONTROL (per cent reduction of larval tunnels)	MARKETABLE PLANTS (per cent)
Untreated	-	396	-	60
		6" Band Method		
Aldrin	5	131*	67	88
Heptachlor	5	37*	91	98
6" Band Method + Supplemental Post-thinning Spray Treatment[2]				
Aldrin	7½	110*	72	89
Heptachlor	6	7*	98	99
Aldrin	5	203	49	85
Heptachlor	5	73*	82	95
Heptachlor[1]	5	57*	86	96
Furrow Method + Supplemental Post-thinning Spray Treatment[2]				
Aldrin	7½	151*	62	90
Heptachlor	6	57*	86	95
Heptachlor[1]	6	34*	91	98
L.S.D. (at levels)	1%	231		
	5%	187		

[1] Granular formulation.
[2] Spray applications made during flight period of overwintering generation of H. brassicae flies.
* Highly significant control.

Table 12 - Control of root maggots in rutabagas in Prince Edward Island, 1955, computed by tunnel-count method of appraisal.

Experimental area: Cherry Valley
Date of planting: June 29, 1955
Date of examination: October 24, 1955

CHEMICAL (wettable powder formulations)	ACTIVE INGREDIENT PER ACRE (pounds)	INFESTATION (No. of larval tunnels in 100 plants selected at random from 4 replications)	CONTROL (per cent reduction of larval tunnels)	MARKETABLE PLANTS (per cent)
Untreated	-	466	-	45
		6" Band Method		
Aldrin	5	31*	93	96
Heptachlor	5	4*	99	99
		Furrow Method		
Aldrin	5	65*	86	94
Heptachlor	5	52*	89	96
Heptachlor[1]	5	71*	85	93
L.S.D. (at levels) 1%		269		
5%		194		

[1]Granular formulation.
*Highly significant control.

Table 13 - Control of root maggots in rutabagas in Prince Edward Island, 1955, computed by tunnel-count method of appraisal.

Experimental area: Earnscliffe
Date of planting: June 14, 1955
Date of examination: October 14, 1955

CHEMICAL (wettable powder formulations)	ACTIVE INGREDIENT PER ACRE (pounds)	INFESTATION (No. of larval tunnels in 100 plants selected at random from 4 replications)	CONTROL (per cent reduction of larval tunnels)	MARKETABLE PLANTS (per cent)
Untreated	-	284	-	63
		6" Band Method		
Aldrin	5	24*	92	97
Heptachlor	5	7*	98	99
		Furrow Method		
Aldrin	2½	99*	65	90
Aldrin	5	93*	67	90
Heptachlor	2½	105*	63	91
Heptachlor	5	77*	73	94
Heptachlor[1]	5	95*	67	90
		Spray Method[2]		
Aldrin	7½	191	33	70
Heptachlor	3	173	39	80
DDT	6	193	32	81
L.S.D. (at levels)	1%	115		
	5%	86		

[1]Granular formulation.
[2]Applications made during flight period of over-wintering generation of H. brassicae flies.
*Highly significant control.

Table 14 - Control of root maggots in rutabagas in Prince Edward Island, 1955, computed by tunnel-count method of appraisal.

Experimental area: Earnscliffe
Date of planting: June 30, 1955
Date of examination: October 28, 1955

CHEMICAL (wettable powder formulations)	ACTIVE INGREDIENT PER ACRE (pounds)	INFESTATION (No. of larval tunnels in 100 plants selected at random from 4 replications)	CONTROL (per cent reduction of larval tunnels)	MARKETABLE PLANTS (per cent)
Untreated	-	247	-	65
		6" Band Method		
Aldrin	5	64*	74	94
Heptachlor	5	17*	93	98
		Furrow Method		
Aldrin	2½	122*	51	90
Aldrin	5	46*	81	95
Heptachlor	2½	120*	51	85
Heptachlor	5	31*	87	96
Heptachlor[1]	5	83*	66	90
		Spray Method[2]		
Aldrin	5	181	27	80
Heptachlor	2	129	48	89
DDT	3	310	-26	60
L.S.D. (at levels) 1%		105		
5%		78		

[1]Granular formulation.
[2]Applications made during flight period of over-wintering generation of H. brassicae flies.
*Highly significant control.

other treatments, although they proved to be significantly better in one test only; and heptachlor (showing an average of 93 per cent control) proved to be better than the band applications of aldrin (averaging 80 per cent control) (Figure 13). Furrow applications of heptachlor at five and 2½ pounds toxicant per acre showed significant control in all experiments, and the 5-pound application was not significantly better than the 2½-pound application. The degree of control obtained with furrow applications of aldrin was consistently lower than that of heptachlor, although significant control was obtained in six of the experiments.

Post-thinning spray treatments in the randomized block experiments did not prove effective in controlling infestations of _H. brassicae_. However, interesting observations were noted in the results. Considering the early-planted experiments in the lighter soils and the late-planted experiment in the heavier soil area (the experiments which received the most severe maggot attacks; note Figure 3), it will be noted that the plots in two of the tests with heptachlor, one test with aldrin, and all of the tests with DDT were more severely damaged than the check plots; also, most of the other spray tests showed only slight control.

D. Effects of Insecticides on Plant Development

Experimental Methods:

At the time of the mid-season examinations for control estimates in the early-planted experiments, measurements were taken of the root size of the plants collected from all plots. Each root (80 plants per treatment) was measured (diameter in inches) at the widest point. Because of the labor involved in cleaning and trimming no attempt was made to take weight measurements.

Results:

The results of the root-size analyses in the four early-planted experiments are given in Table 15. It is shown that there is a stimulating effect on early development of the rutabagas when the chemical is placed below the seed. The increased rate of growth was significant only for the band application of heptachlor in one of the experiments but it was consistent, although slight, for most of the soil treatments. It must be stressed that the insecticide was placed below, and not in direct contact with, the seed.

Table 15 - Influence of preplanting applications of insecticides (placed about one inch below the seed) on rate of development of rutabagas. Experiments conducted in different soil areas of Prince Edward Island, 1955.

CHEMICAL (wettable powder formulations)	ACTIVE INGREDIENT PER ACRE (pounds)	ROOT DIAMETER (inches)[1] Mt. Stewart (sandy soil)	Augustine Cove (sandy loam soil)	Cherry Valley (loam soil)	Earnscliffe (clay loam soil)
Untreated		1.58	1.34	3.95	3.38
		6" Band Method			
Aldrin	5	1.75	1.43	3.95	3.52
Heptachlor	5	1.89	1.65*	4.13	3.55
		Furrow Method			
Aldrin	2½	1.73	1.51	-	3.45
Aldrin	5	1.78	1.50	3.88	3.45
Heptachlor	2½	1.82	1.59*	-	3.52
Heptachlor	5	1.66	1.59*	3.73	3.61
Heptachlor[2]	5	1.77	1.43	3.92	3.44
		Spray Method[3]			
Aldrin	7½	1.71	1.40	-	3.45
Heptachlor	3	1.68	1.32	-	3.36
DDT	6	1.66	1.22	-	3.45
L.S.D. (5 per cent level)		not significant	0.22	not significant	not significant

[1]Mean values (average root size of 20 plants from each of 4 replications selected at random). The values for the check plots in each experiment indicate the stage of development of the rutabagas at the time of examination.

[2]Granular formulation.

[3]Applications made during flight period of overwintering generation of H. brassicae flies.

*Roots were significantly larger than those in untreated plots.

V DISCUSSION

H. brassicae is the only species of root maggot that is of economic importance to rutabaga growers in Prince Edward Island. High populations of H. liturata and H. cilicrura are present in rutabaga fields under certain conditions, but the evidence presented shows that they do not injure healthy plant tissues. M. stabulans are sometimes very prevalent in June, but unless extremely wet weather prevails during the period of egg hatching they do not cause economic damage.

Several factors appear to be connected with the severity of injury caused in any rutabaga field, but the most important of these are weather conditions, the stage of development of the plants at the time of attack, and the position of a field with respect to the source of infestation. Parasites and predators appear to noticeably reduce larval populations only after a period of dry weather has cut to a minimum the entry of new larvae into the roots.

Sunlight and dry weather play an important role in reducing maggot populations, particularly if the leaf coverage does not protect the surface soil around the plants from drying quickly. For example, assuming that a dry period of weather occurs in late July and August, the effects on maggot infestations in different areas may be summarized as follows: in the sandy soil areas maggot attacks occur mainly in late June, July and early August; the dry weather does not influence the degree of injury in early-planted crops but it does result in a marked reduction in injury to late-planted crops. On the other hand, in clay loam soil areas maggot attacks occur mainly in August; the early-plantings are not severely injured since the roots are large when the attack starts and they are harvested before the heaviest attack occurs. Late-planted crops are also lightly infested, because the plants are small, the soil around them becomes very dry, and larvae either die or are destroyed by predators before they gain entry to the roots. By noting the times of maggot attacks in different soil areas of the province (Figure 3), it is readily seen that a dry period of weather occurring at a particular time during the growing season influences the maggot infestations in only one area or in crops planted at a particular time.

H. brassicae flies travel most readily in the direction of the prevailing winds (south-west to north-east). Their movements become sluggish during cold wet weather and during a heavy rainfall they may be found in cracks or crevices in the soil near host plants. Because of these habits of the flies, rutabaga fields that do not have a source of infestation within a mile or more to the south are very slightly injured by maggots. Also, once settled in a rutabaga field the flies tend to remain in that field; therefore, a rutabaga crop that is farther from a source of infestation than are other crops in the vicinity has only a slight maggot infestation.

The difference in the time H. brassicae maggots first appear in rutabaga crops in light sandy soil areas and in clay loam soil areas is about seven weeks. There is a close relationship between the soil texture and the time of first attack and also between the field moisture percentage and the time of first attack. It is therefore concluded that these factors or some other factors influenced by texture and/or moisture are responsible for the differences in the times of adult emergence. Tests conducted to date on soil temperatures have shown an average difference of only 3.5 degrees between the light and heavy soils. It is felt that this minor variation alone could not be responsible for such a wide variation in the time of attack.

The number of broods of H. brassicae depends on the time the first brood begins. In the light soils of Prince Edward Island there are two complete broods, while in the clay loam soil areas there is only one complete brood and probably a partial second. Since early-planted crops are generally harvested in August, only one full brood of larvae causes injury to a particular rutabaga crop. In the light soil areas farmers who plant rutabagas only for the early market are advised to remove all plants from the field in August. A small percentage of plants left in the field until October provides host material for propagation of a second brood of maggots, thus making the field a good source of infestation for the following season's rutabaga crop.

The emergence studies carried out in blocks near the laboratory show that the insects reared in the greenhouse were not similar to those collected in the field. Since puparia collected in a light soil area and transferred to a heavy soil yielded earlier-emerging flies than puparia that had developed in the heavy soil, it is concluded that the factor causing a delay in the time of emergence in the clay loam soil areas acts from the time the puparia are formed in the fall, as well as in the spring and early summer. Thus, the factor controlling the development of a fly inside the puparium must be stronger and must act more quickly in the light sandy soils. Also, as the factor must be active in the fall (particularly in the sandy soils), it is indicated that the insects are not in the same stage of development in the different soils at the time they go into diapause. When pupae are reared in the greenhouse they are formed under artificial conditions and in the tests conducted by the writer the factor controlling adult development appeared to be either very active or almost inactive. A small percentage of adults developed and emerged soon after the puparia were placed outside in soil under emergence cages in the spring, while the remainder did not emerge during the whole growing season (compare the percentage emergence for the greenhouse-reared and field-reared puparia in Table 4).

The four years results from the field-scale treatments of DDT sprays show that this chemical will give almost complete control of root maggot injury in rutabagas if the treatments are applied at weekly intervals during the flight period of the overwintered generation of flies. More frequent applications are required during wet weather.

The results of the spray treatments of heptachlor, aldrin, and DDT in the 1955 randomized block experiments indicated that these materials provided no protection against root maggot attacks. However, by comparing these results with those of the field-scale tests with DDT the writer concludes that experimental designs as used in the 1955 tests are of no value in determining the effectiveness of insecticide sprays against free-flying insects such as *H. brassicae*. This conclusion is drawn because; a) since newly emerged adults are continually entering the plots throughout the period of emergence, the chemical residues would have to be potent enough to kill all flies as soon as they entered the treated plots (before any eggs were laid); and b) if the chemical were powerful enough to destroy all flies entering the treated plots during the interval between treatments, it would probably kill all insects in the experimental block, since the adults move freely to and from untreated and treated plots. Nevertheless, the 1955 spray tests gave interesting results. The field-scale, DDT tests showed that this chemical gives control of root maggot infestations if applied at the proper time, whereas in the plot tests the DDT sprays did not provide any protection to the plants. On the other hand, both aldrin and heptachlor applied as sprays appeared to give some protection, so that they could be assumed to be better than DDT. There is therefore a possibility that aldrin and heptachlor sprays would give good control of maggot injury in rutabagas if used on a field scale and applied at the proper time.

Again, the randomized plot spray tests indicated that, since in several instances the sprayed plots were more severely damaged than the check plots, the sprays probably destroyed predators and parasites that would otherwise have helped to check populations of *H. brassicae*.

Also, these indications emphasize the importance of the proper use of insecticide sprays applied on a field scale; applying one or two treatments or not treating the fields at the proper time may result in more severe injury than if no treatments are used at all.

Results of the eight control experiments have provided sufficient information to show that heptachlor and aldrin, applied as a five inch band in the seeding drill 1½ inches below the seed, will adequately control infestations of H. brassicae in rutabagas grown in different areas of the province and under different conditions. Even when applied in early June the materials provide almost complete protection against infestations occurring in August and September.

Furrow applications also provided some protection, and observations made during the season in the 1955 tests indicated that smaller quantities would provide protection to the plants if the materials could be applied at the proper depth directly below the seed. To use the method of making a shallow drill, applying the insecticide, hilling the soil over the chemical to a depth of two inches, and finally sowing the rutabaga seed, it was impossible to be certain that the seed was being sown directly over the furrow of chemical at all times.

In comparing root maggot control methods in Prince Edward Island with those used in British Columbia, the important factor which has to be taken into account in devising a suitable method of application of an insecticide is the method of planting the rutabaga crops in the two areas. In Quebec, Ontario and the western provinces most rutabaga growers sow the rutabaga seed at ground level, whereas all growers in Prince Edward Island and some growers in Nova Scotia, New Brunswick and Newfoundland sow the rutabaga seed in ridged drills that vary in height from four to six or seven inches. At the time of thinning the drills are torn down with a scuffler and hoe. The rutabagas that are left develop in sloping-sided ridges of soil about three or four inches high.

In British Columbia King et al (1955) found that spray treatments of aldrin and heptachlor applied at intervals during the season gave better control than preplanting soil treatments. With their methods of planting and applying the insecticide it is quite probable that preplanting treatments are leached from the soil during the season. Therefore, applying smaller quantities of chemical at different times during the season would logically provide better protection, and the advantage of using a spray instead of a dust or powder is that the chemical can be forced into the soil surrounding the roots at high pressures. It is, of course, assumed that the spray materials are applied to destroy the young larvae and not the adults.

In some of the experiments conducted by King et al (1955), where the chemicals were placed at ground level, phytotoxicity resulted with both the band and furrow applications of the preplanting treatments.

With the method of planting used in Prince Edward Island the situation is entirely different. When sprays are applied during the season the chemical has to be sprayed on the sides of a sloping ridge of soil. The material soon becomes washed out into the furrow between the drills, and for this reason sprays can only be considered for control of the adults. However, by using preplanting applications of insecticides that are placed in a band below the surface of the roof-like, ridged drill, the chemical is situated so that the young larvae must pass through it to get down into the soil where they begin their feeding on the secondary roots. The sloping shape of the ridge prevents rain water from leaching the insecticide away from the rutabaga plants. With this method of preparing the seeding drill and applying the insecticide, both aldrin and heptachlor were found to provide almost complete protection against root maggot injury throughout the whole growing season. No supplementary, mid-season treatments were necessary. Also, no phytotoxic effect was noted with either the band or furrow applications of the insecticides.

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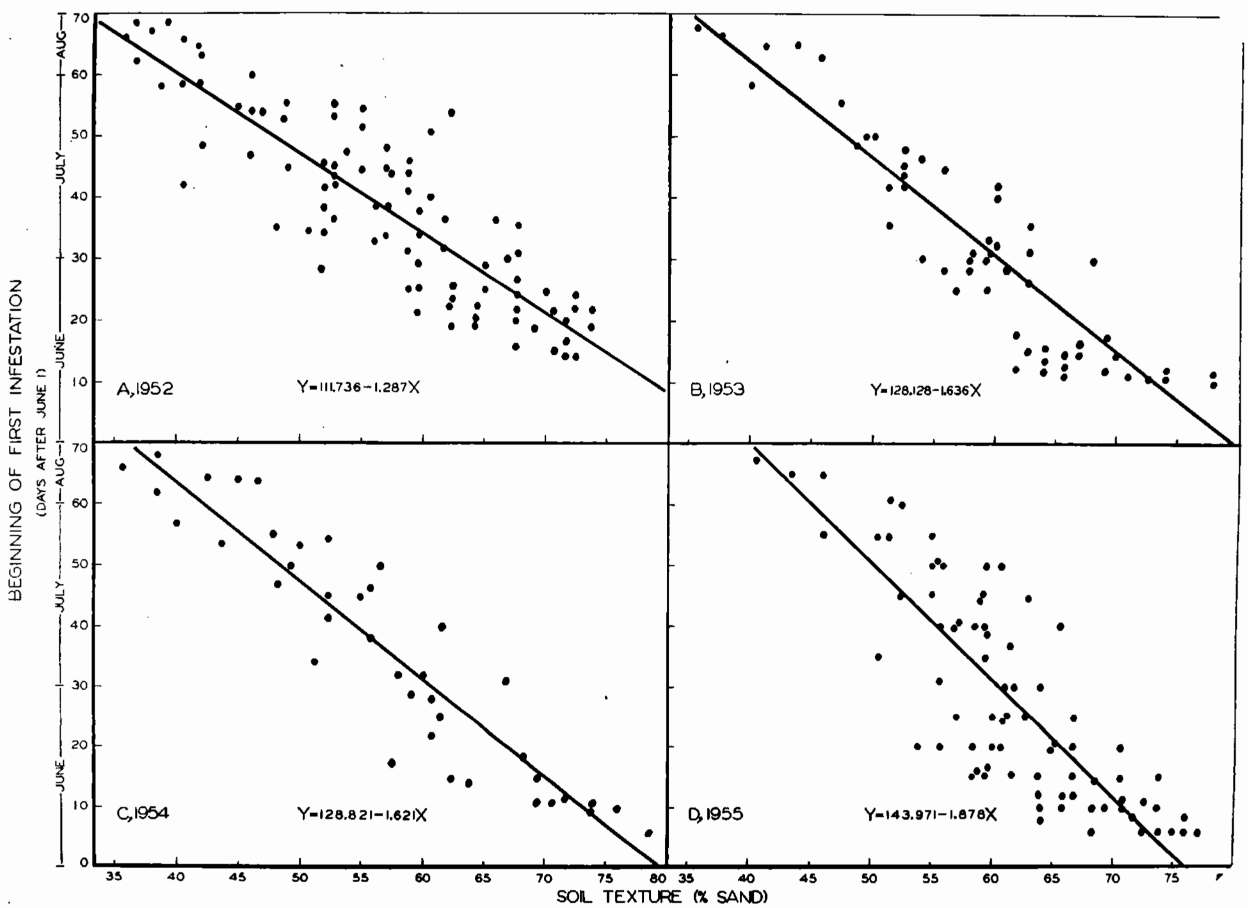


Figure 1 - Relationship between soil texture and the time *H. brassicae* larvae first appear in rutabaga fields in different areas throughout Prince Edward Island, 1952 to 1955. Different fields on the same farms were examined during the four years.

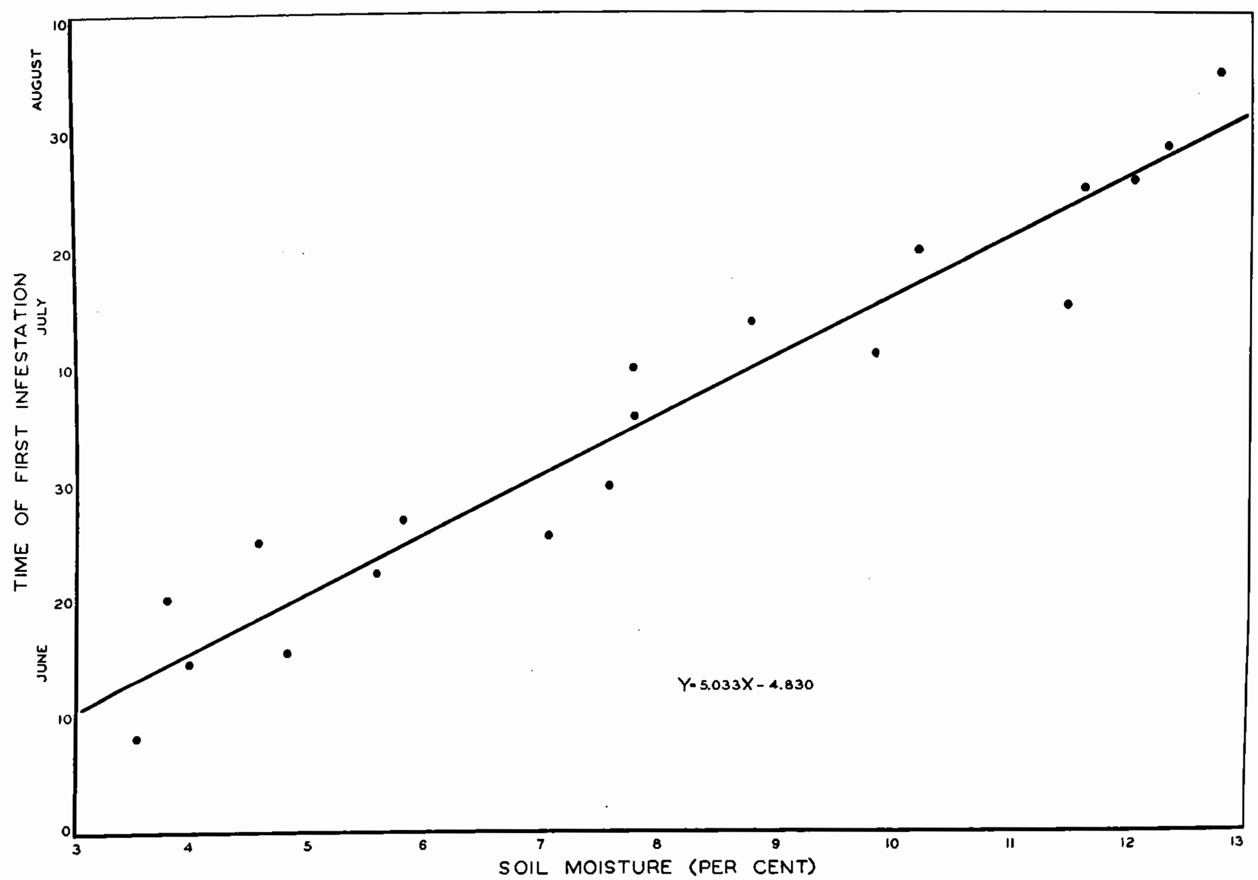


Figure 2 - Relationship between the per cent total field moisture in rutabaga fields of different textured soils throughout Prince Edward Island and the time <u>H. brassicae</u> larvae first appear in the rutabaga crops. Moisture percentages for each field are mean values of samples taken at weekly intervals during the months of June and July.

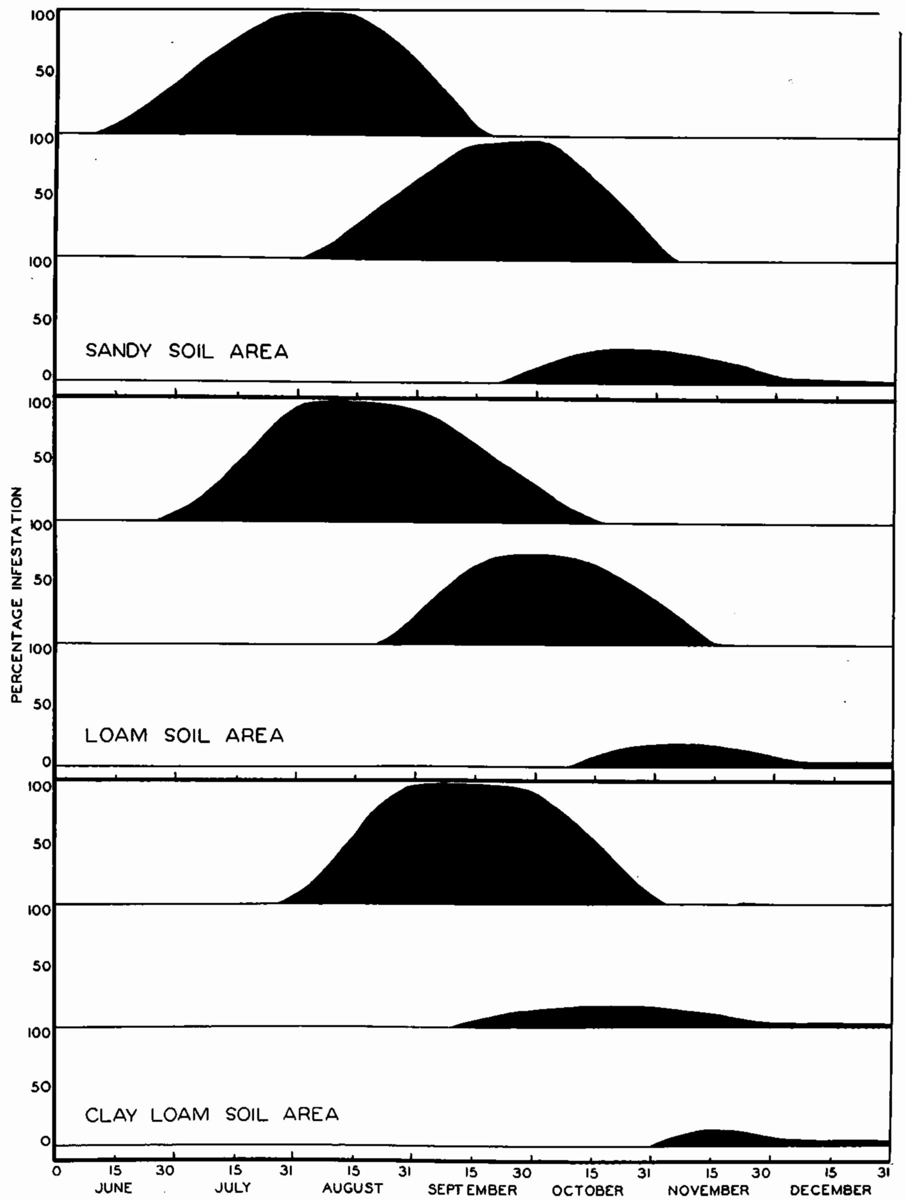
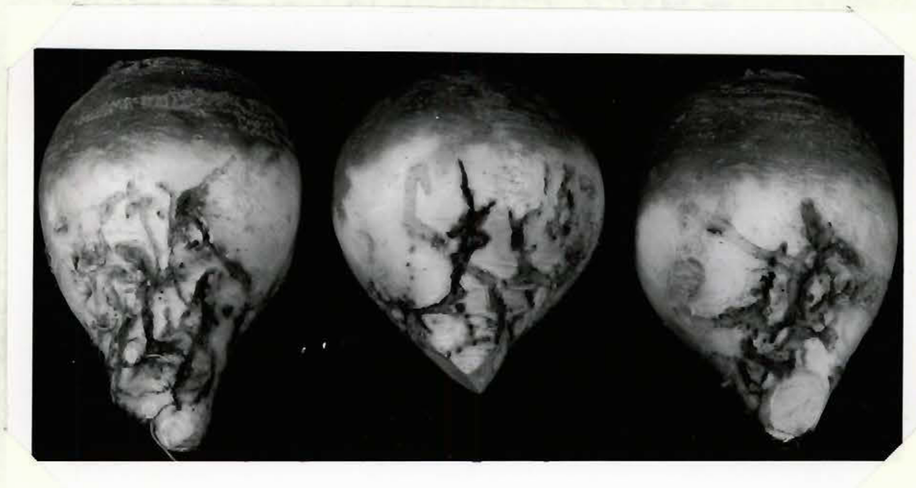


Figure 3 - Periods of attack and population densities of different broods of H. brassicae larvae in 3 soil areas of Prince Edward Island. Data are averages of records from approximately 100 heavily infested rutabaga fields in each soil area examined between 1951 and 1955.

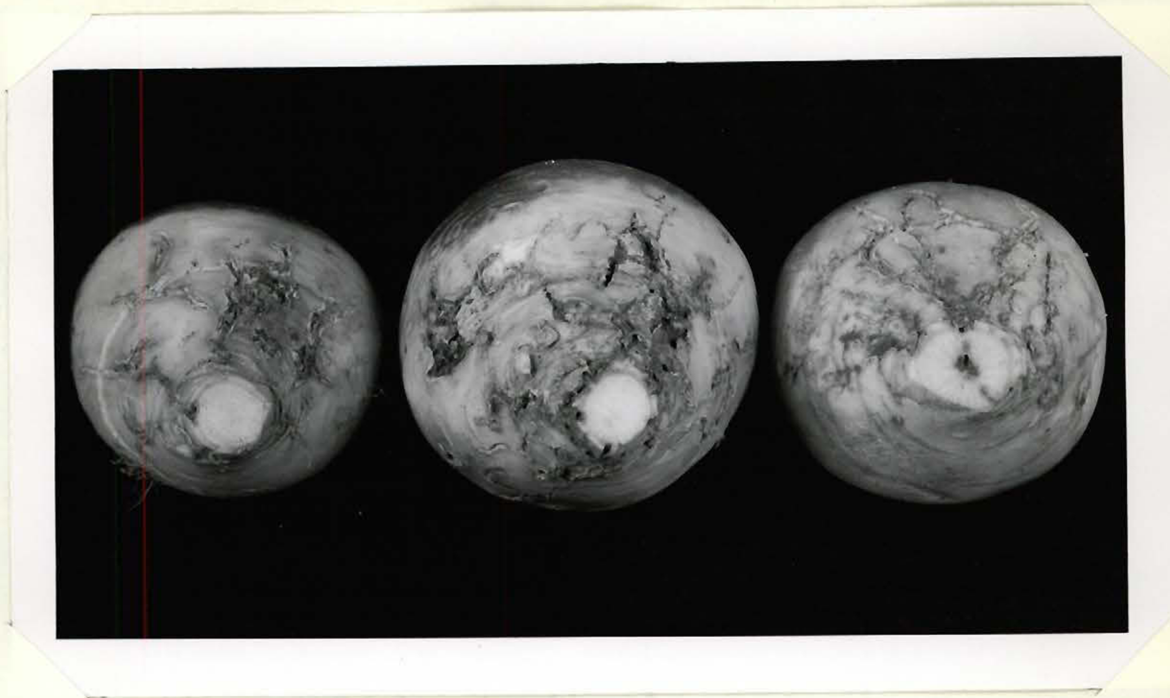
A.

B.



C.

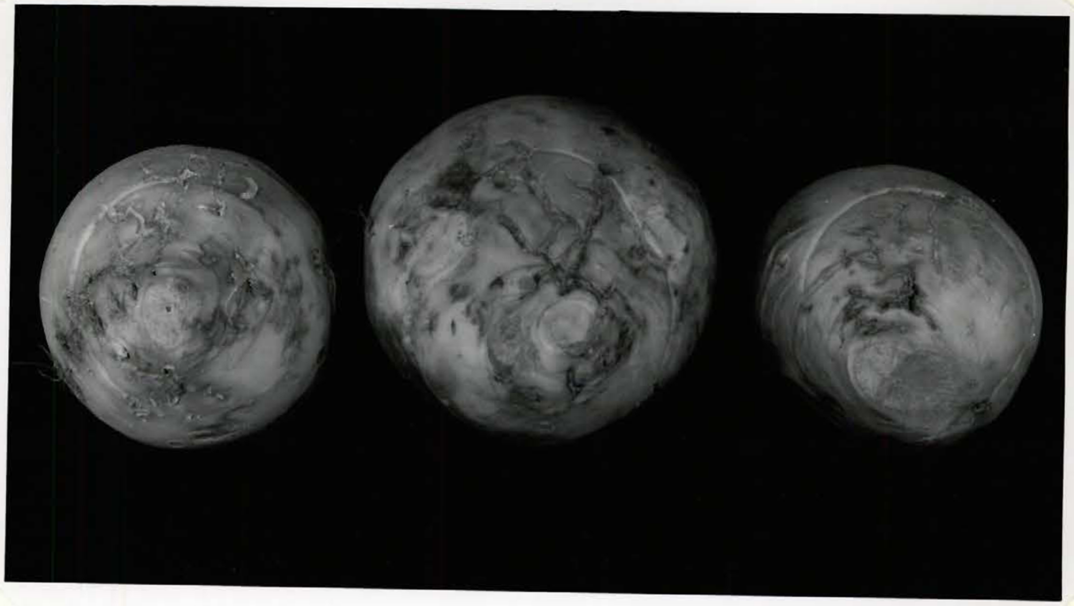
Figure 4 - H. brassicae injury in rutabagas.
A. Roots of an early planting in a sandy soil area.
B. Roots of an early planting in a clay loam soil area.
C. Roots of an early planting in a sandy soil area, showing early and late injury.



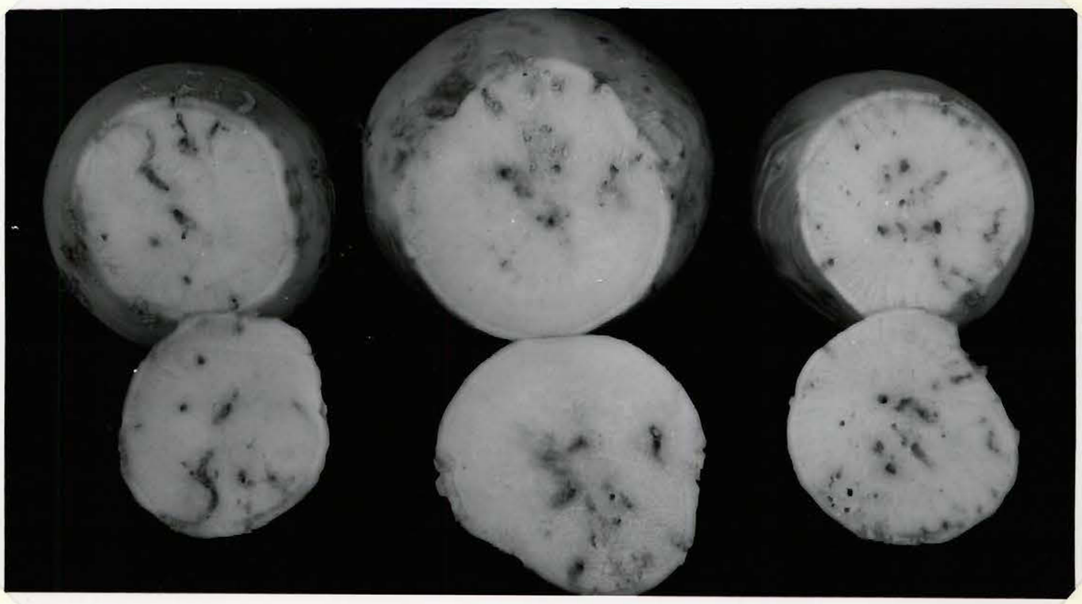
A.

B.

Figure 5 - Rutabagas that were removed from the soil towards the end of the first brood attack by H. brassicae (containing mostly third instar larvae).
A. External surface of roots.
B. Roots cut open to show internal injury after 6 days of storage at room temperature.



A.



B.

Figure 6 - Rutabagas that were removed from the soil shortly after the attack by first brood larvae had started (containing mostly first or second instar larvae).

A. External surface of roots.

B. Roots cut open to show internal injury after 6 days of storage at room temperature.

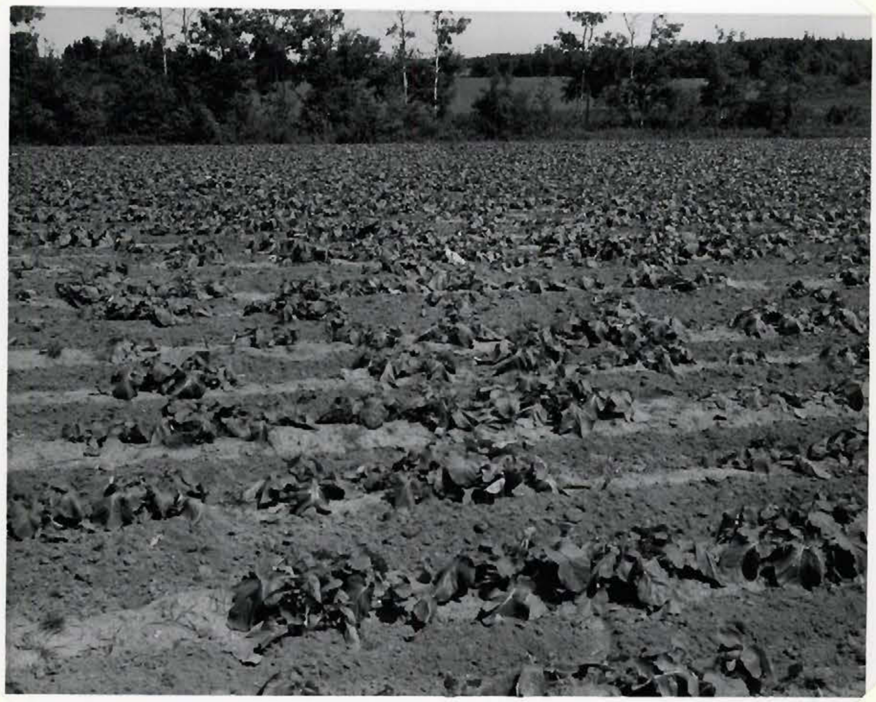


Figure 7 - Late-planted rutabaga crop in a sandy soil area, 1954. More than 40 per cent of the plants were completely destroyed by _H. brassicae_ and the remainder, shown in the photograph, were heavily infested and distorted roots developed.

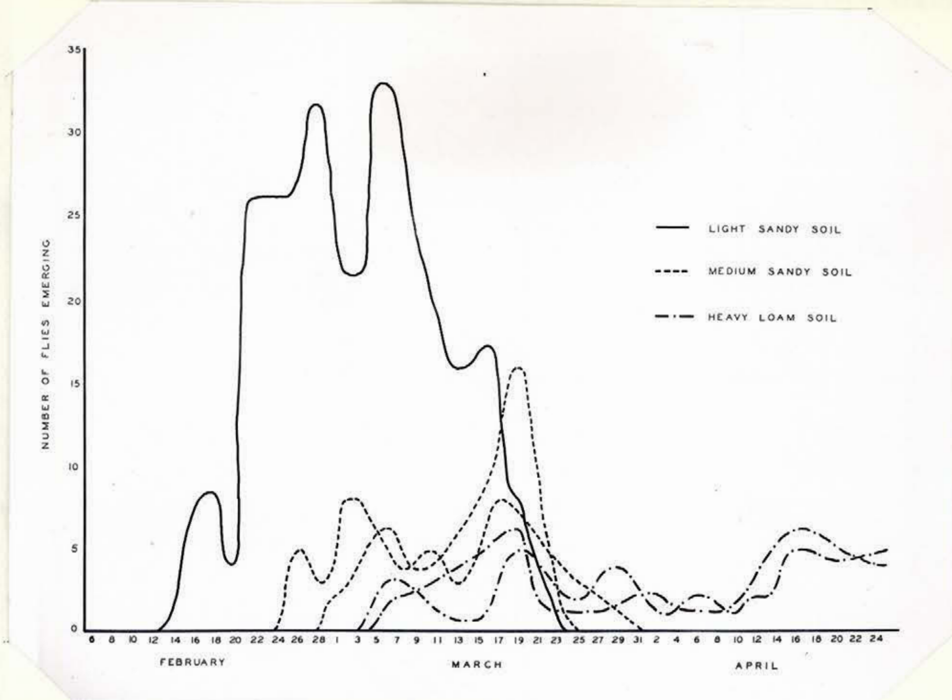


Figure 8 - Times of emergence of H. brassicae flies from 3 soil types. Greenhouse test.

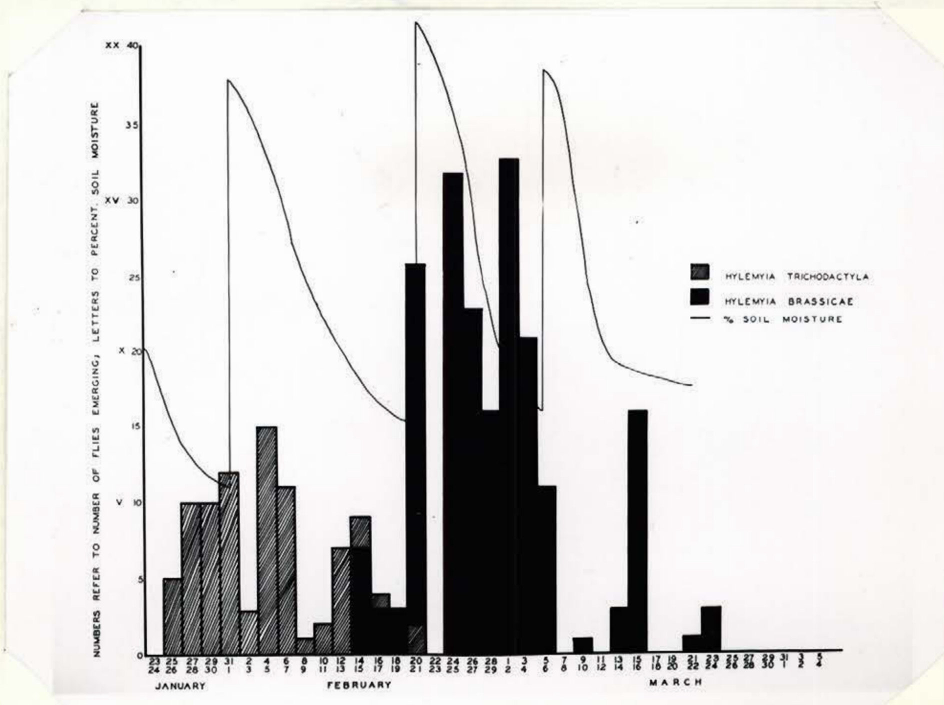


Figure 9 - Times of emergence of H. brassicae flies and H. liturata flies from puparia in a light sandy soil.

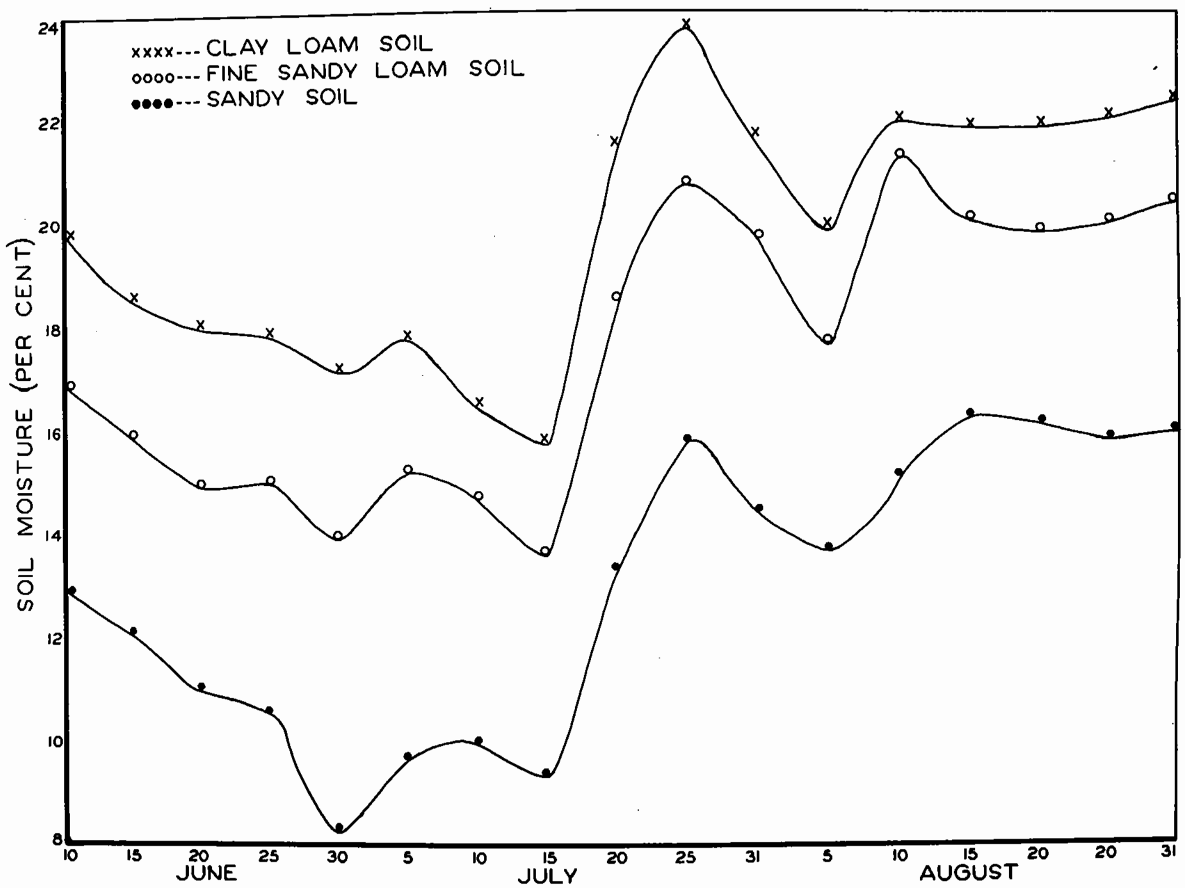


Figure 10 - Range of moisture percentages in different textured soils during June, July and August. Records were taken at 2-day intervals from duplicate plots of soil and each point on the chart is the mean of 4 readings.

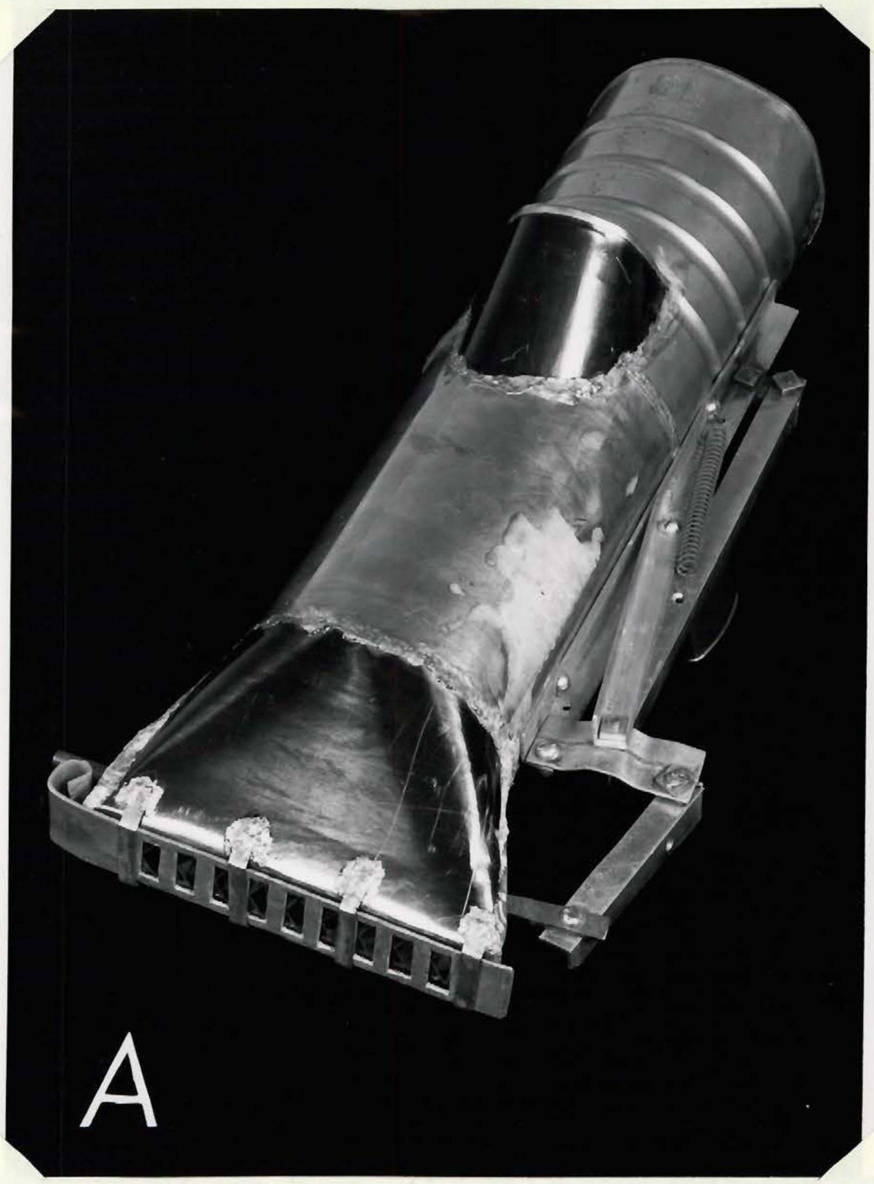


Figure 11 - A. Hand-operated insecticide applicator used for applying band and furrow pre-planting soil treatments.

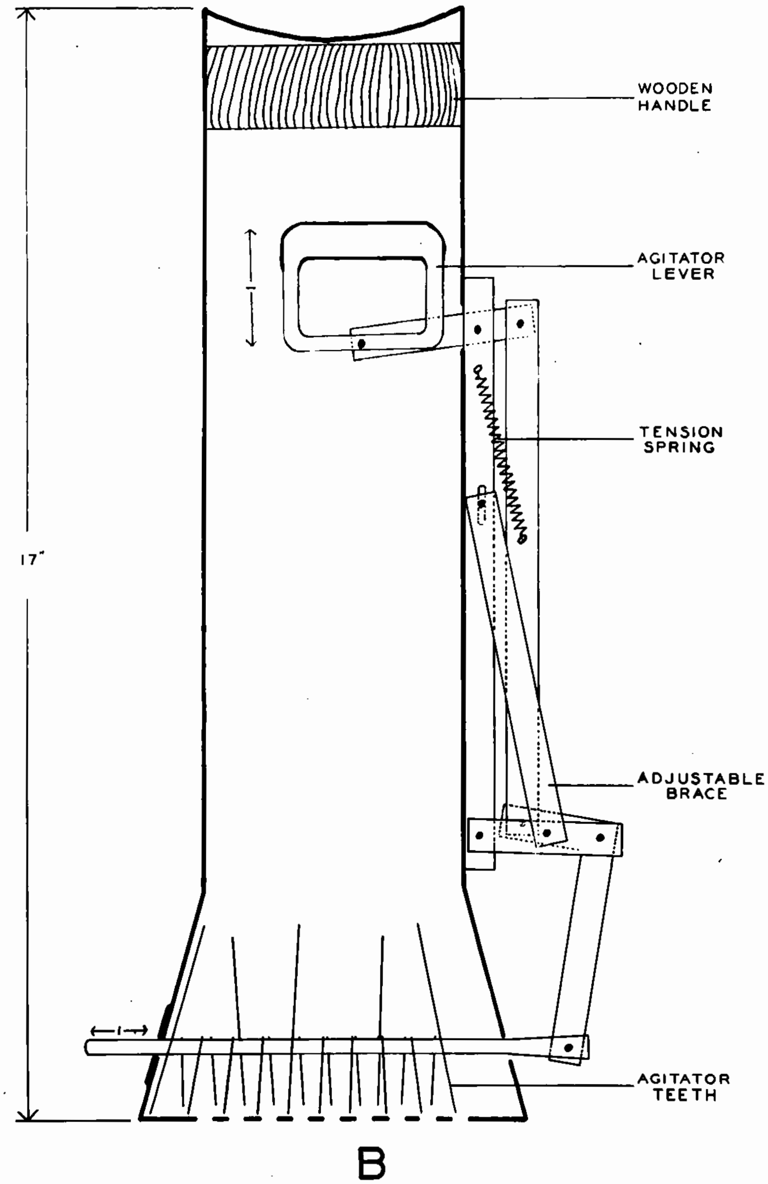
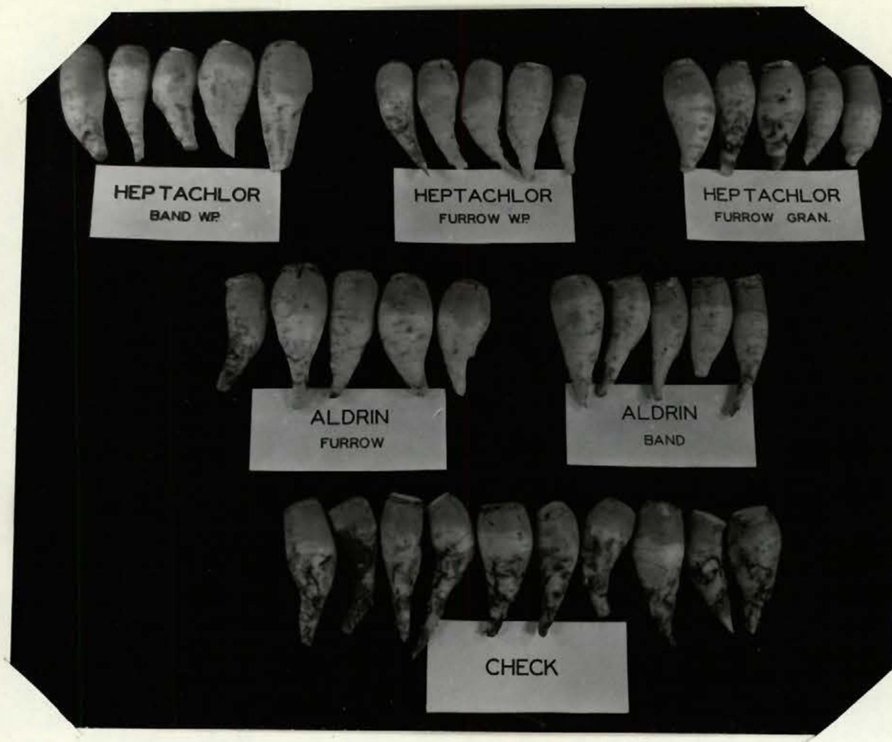


Figure 11 - B. Diagram of insecticide applicator showing method of operation.

A.

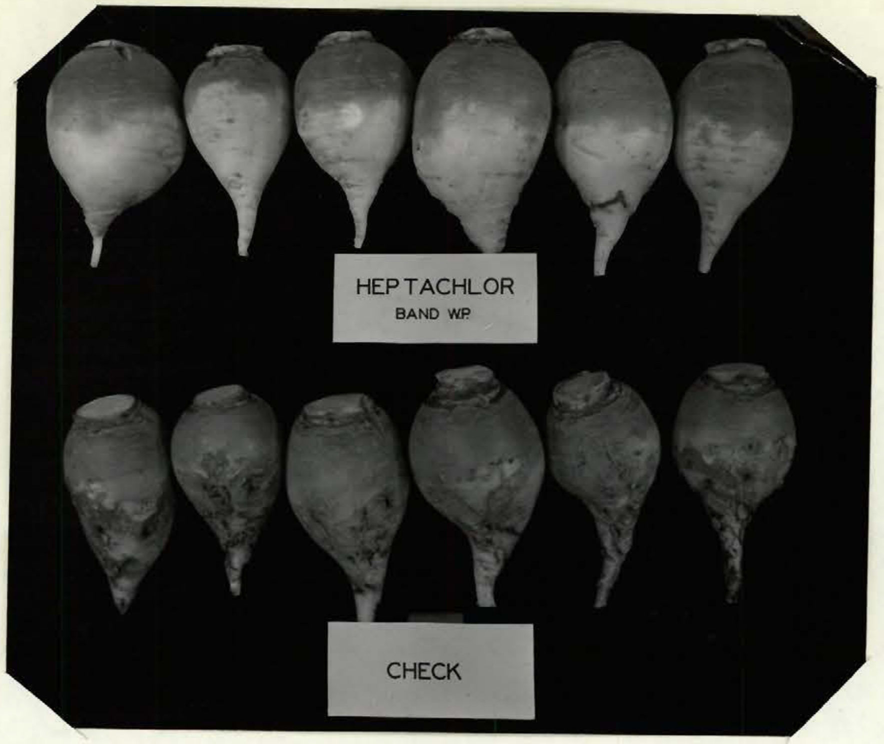


B.

Figure 12 - A. Injury to rutabagas in treated and untreated plots in an early-planted experiment in a light soil area, examined July 26.

B. Roots split open to show internal injury caused by larvae in 6 days after the plants were removed from the soil.

A.



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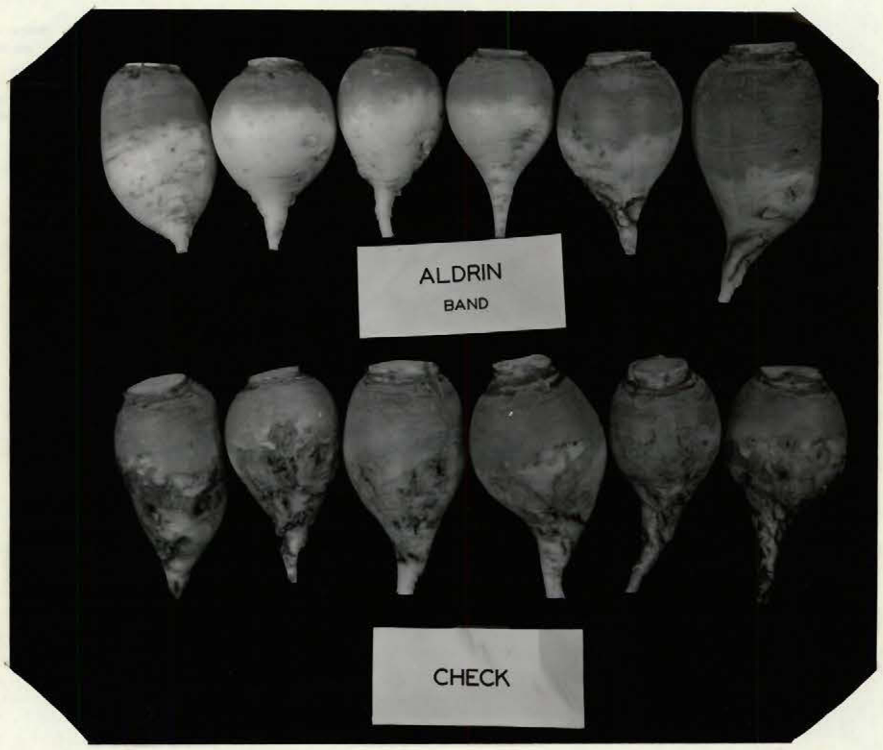

Figure 13 - Injury in rutabagas grown in treated and untreated test plots, 1955. In all tests heptachlor appeared to give slightly better control than aldrin, each chemical being applied at rate of 5 lbs. toxicant per acre in the seeding drill.