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THE SUGAR BEET ROOT APHIS

PEMPHIGUS BETAE DOANE

IN SOUTHERN ALBERTA

Thesis
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THE SUGAR BEET ROOT APHIS
PEMPHIGUS BETAE DOANE IN SOUTHERN ALBERTA

A DISSERTATION
SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES
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OF MASTER OF SCIENCE

FACULTY OF AGRICULTURE
DEPARTMENT OF ENTOMOLOGY

by

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PREFACE

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ABSTRACT

Information is presented on synonymy, distribution, economic importance, life history, habits, and control of Pemphigus betae Doane in southern Alberta. Galls formed by P. betae and by three other species of aphids that infest poplars in Alberta are described. Preliminary information is given on the influence of soil type, soil temperature, and varietal differences. The effect of sugar, nitrogen, and moisture content of the sugar beet on the sugar beet root aphid infestation is also discussed. The spring migrant form of P. betae is important because it initiates the apterous summer infestation that does the damage to the sugar beet crop. Some of the apterous adults that are present on the beet during the summer overwinter in the soil in the beet fields, but they can be controlled by thorough fall or spring cultivation. Two species of Diptera, a chloropid and a syrphid, were found to be important in the reduction of the P. betae population in Alberta.

THE SUGAR BEET ROOT APHIS,
PEMPHIGUS BETAE DOANE, IN SOUTHERN ALBERTA

INTRODUCTION

Although the sugar beet root aphid, Pemphigus betae Doane, has been present for several years it was not until 1949 that it was considered an important pest of sugar beets in southern Alberta. The tonnage and sugar content of the beets was much lower than normal that year owing to the aphid infestation. The losses due to P. betae were further increased by a dry season and an early frost.

P. betae became important in the sugar beet growing areas of the western United States shortly after the turn of the century. In Montana it was reported in some years to have reduced yield by 30 per cent and reduced the sugar content by two per cent (13-16). It has been shown recently that P. betae can transfer the virus disease known as curly top from one plant to another (6).

Since very little work had been done in Canada on this insect a study was begun in 1950 on life history, ecology, distribution, economic importance, and control of P. betae.

LITERATURE REVIEW

All sugar beet root aphid work of importance has been reviewed. At the beginning of each section literature pertaining to the section is briefly presented. A review of literature on production of winged and sexual forms of aphids generally is also included, as this has a bearing on the problem of sugar beet root aphid infestation in southern Alberta.

SYNONYMY

Baker (38) considered Pemphigus betae Doane to be a form of Pemphigus balsamiferae Williams or Pemphigus populivenae Fitch. This view was upheld by Lange (73) in 1939 when he stated Pemphigus balsamiferae was commonly considered a synonym of Pemphigus betae. Maxon and Knowlton (85) in 1929 claimed P. balsamiferae was the spring form of P. betae.

Gillette and Bragg (49) in 1915 stated that galls of P. betae had been called P. balsamiferae and Pemphigus populicaulis Fitch. The latter, they claim, is confined to the eastern United States.

P. betae Doane and Smynthrodes betae West (now Forda betae (West)) were thought to be synonymous until Baker (5)

separated the two species in 1919. He found P. betae Doane to have more slender antennae with the spine-like hairs less prominent, and segment five of the antennae longer.

P. balsamiferae was described by Williams in 1890 and specimens were deposited in the U. S. National Museum labelled 6/24/90. However this description was not published until 1910 (128). The description of P. betae was published by Doane (35) in 1900. Therefore, under the law of priority (Article 25), P. betae is the valid name of the species and P. balsamiferae is reduced to synonymy.

Not all reports of P. betae on sugar beets and other hosts are necessarily correct (83, 119). P. betae has been confused with P. populimonilis Riley and P. populi-transversus Riley (73) and P. populivenae Fitch (38).

ORIGINAL DESCRIPTION OF PEMPHIGUS BETAE DOANE (35)

"Winged, viviparous females; length 2 mm.; alar expanse 6.75 mm.; head, thorax, and appendages, bluish-black, pruinose. Abdomen, after the hoary secretion is removed, dark green with considerable flocculent matter on the posterior segment. Antennae 1 mm. long, annulations indistinct; joints all somewhat constricted at the base; third joint longest, last joint next in length and more slender than the rest; ungues distinct. Third and fourth joint with transverse sensoria. Eyes large, very dark brown. Wings somewhat smoky; stigma, all veins and narrow space between the costal and subcostal veins, brown; first and second discoidals arising close together, more rarely a very short distance apart; basal third of cubital

obsolete. Apterous individuals yellowish, sometimes so covered with the whitish secretions as to make them appear almost white; legs, antennae, distal half of back, and a rather large spot on the dorsal aspect of the head, very dark brown; eyes very small, almost black; the white flocculent secretion is confined to the last three segments of the abdomen, and is often 1 mm. long, sometimes even longer.

Larvae, like the apterous individuals, only more slender, and in the earlier stages with only five joints to the antennae, the last of which is the longest."

DISTRIBUTION

P. betae Doane occurs in most states west of the Mississippi. Its distribution is roughly correlated with that of the narrowleaf poplar, Populus angustifolia (83).

In Canada sugar beet root aphids have been reported from southern Alberta (78, 79, 126), southern British Columbia (79), southern Ontario (79) and several localities in Quebec (79).

ECONOMIC IMPORTANCE

During the period from 1909 to 1920 the sugar beet crop in irrigated districts of Montana was reduced in many fields by 30 per cent in tonnage and two per cent in sugar content (13-16). Periodically P. betae has been reported as the most serious threat to the sugar beet industry in Oregon (9), Utah (57, 58), Washington (9, 89), and California (39).

In southern Alberta local losses in tonnage and sugar content have occurred frequently between 1929

and 1951, attributed to the activity of P. betae (126). In 1949 the damage was so severe that Canadian Sugar Factory officials requested the Dominion Department of Agriculture to initiate a research project on P. betae in southern Alberta irrigated districts.

LIFE HISTORY AND HABITS

The following account of life history is essentially that of Parker (93). The fall migrants fly from the summer host to the native poplars, Populus balsamifera and Populus angustifolia, and apparently prefer trees on which the leaves are yellow to those with green leaves or without leaves.

The aphids usually alight on the leaves, then immediately start moving down the stem to the main branches and to the trunk, where some enter suitable cracks, while others continue to the ground and conceal themselves among leaves, or in the soil around the base of the tree. Once hidden they produce four to seven yellow nymphs.

These nymphs which are the sexual forms, are mostly female. The female is nearly twice the size of the male and contains a single large egg, which shows plainly through the body wall. Both sexes have rudimentary mouth parts and they do not feed. The nymphs pass through four stadia in approximately four days.

Sexual activity is not shown until the fourth stadium, when the aphids mature. Then the males crawl blindly about attempting to copulate with any female they can find. Seven to twelve days after birth the female deposits a single pale yellow egg, and dies. Sometimes death occurs before the egg is extruded, in which case the walls of the abdomen gradually shrink away leaving the egg exposed. Normally a mass of bluish-white threads are secreted in which the egg rests after deposition.

The eggs laid by the sexual females remain in the crevices of the bark until the following spring. Early in April they become darker in color, and eye spots appear. A dark spot is also seen on the abdomen.

Hatching of the eggs of P. betae starts when the weather begins to warm up. The shell splits near the cephalic region and the first instar aphid forces its way out by expansions of the body.

The nymphs, which later become stem mothers, crawl up the trees and cluster upon the expanding buds. As soon as the leaves unfold, feeding begins, generally on the upper sides of the leaves in the angle between the midrib and the first or second vein. The resulting gall first starts as a depression at the point of attack, which gradually deepens and is finally closed from above by the growth of the leaf. The opening is an obscure

narrow slit parallel with the midrib or one of the large veins. Stem mothers give birth to young early in June. The number of young averages 75, however it may be as high as one hundred and seventy-two.

All progeny of the stem mother develop wings and leave the galls during the later part of June and most of July. These winged aphids are the spring migrants which fly to the summer host and produce young on the leaves. The nymphs wander around on the leaf of the summer host for a short time, then go down the leaf stalk to the root where they are seen during the summer as the apterous parthenogenetic forms.

During the summer wingless viviparous females alone are produced. This method of reproduction continues until fall and appears to be checked only by cold weather, lack of food, and unfavorable soil conditions.

From midsummer until fall a portion of the progeny of the wingless viviparous females develop wing pads, and when fully grown acquire wings and fly to the winter host. Parker claims that water content of the soil has much to do with the number of winged forms produced. If the soil is kept moist or rootlets of the host plant are succulent, few winged aphids are produced. However, if the soil becomes dry and the rootlets tough, production of migrants is

greatly accelerated. Gillette and Bragg (49) claim that only half of the summer forms migrate. Most writers agree that there is not a total migration.

Lange (72, 73) claims that there are no sexual forms in California. Essig (39) stated that fall migration occurs at approximately the same time as in Alberta, but in California no galls are formed and the fall migrants are probably only a means of dispersing the population of aphids.

Maxon (84) stated that aphids could migrate from beet to beet in the field, and that the infestation could be increased from 68 to 100 per cent in two weeks by irrigation and other factors.

Paddock (91) stated that in Texas the host relationship of P. betae is completely reversed. Alate viviparous females are found on turnip foliage in October and apterae feeding on its roots during the winter. The alates were found again in March and produced young which spent the summer in galls on cottonwood trees. Eggs were not found.

In other species of migrating aphids, for example, Aphis rumicis L., there are three forms of alate parthenogenetic females, namely migrants, dispersal forms, and sexuparae. These females resemble each other morphologically but differ in their relation to the migrating habit. Sanderson (106), Doane (35), and Essig (39) suggest that

dispersal forms of the aphid occur. Other workers report only two forms: spring migrants, and fall migrants which are the sexuparae. Parker (93) stated that the fall winged forms could not possibly start a winter colony but he gives no evidence for this statement.

FALL AND WINTER PERIOD

Fall migration

In southern Alberta the overwintering eggs and the sexuales have not been found. It has been observed however that the fall migrants fly from the beets to the poplars from September to November. In Alberta, the number of migrants formed varies between plants and between fields.

Object:

To determine the effect of temperature on the length of life of fall migrants of P. betae.

Methods and materials:

Fall migrants were placed in cheesecloth covered vials at constant temperatures ranging from 0 to 25° C. in five degree intervals. The vials were kept in darkness and at a constant relative humidity of 60%. At each temperature two hundred aphids were used in ten replicates of twenty. The twelve hundred aphids used in the experiment were collected on the

same day and all had emerged from the soil during the previous twelve hours.

Results:

The results which are shown in Figure 1 indicate that within the limits of the experiment the fall migrants live longer at the lower temperatures. The experiment also shows that fall migrants can withstand temperatures as low as 0° C. The aphids were completely inactive at 0° C. and had to be warmed up slightly to tell whether they were alive or dead. Obviously this affected the results at this temperature.

The production of sexuales has been studied by many workers in the past. Phillips (100) working with Macrosiphum granarium (Kby.) in 1916, stated that cold weather favored the production of sexual forms. Uichanco (125) believed development of sexuales was brought about by cold and lack of food. Shull (112) moved winged mothers from low to high temperatures and found that they produced gamic daughters at first, but gradually, over a period of ten days changed completely to the production of parthenogenetic daughters, while similar females continued at low temperatures yielded almost exclusively gamic offspring. Wadley (129) could not induce production of sexuales in Rhopalsiphum prunifoliae by cold treatment.

Figure 1. Effect of various temperatures on length of life of fall migrants of *P. betae* Doane.

Davidson (20-22) brought forward the view that food controlled gamic reproduction, but had no experimental proof for his statement. Wadley (129) was not able to induce R. prunifoliae to produce sexual forms by starvation or artificial colonization on the winter food plant.

Marcovitch (81) was able to get the strawberry root louse, Aphis ferbesi Tenn., to produce sexual females in spring by exposing the plants on which they were feeding to eight hours of light a day. Davidson (28) was able to get adults of Aphis rumicis to produce sexuales by supplying the same light duration as Marcovitch.

Object:

To find a method of handling that will cause migrants to produce sexuales.

Methods and Materials:

Aphids were kept at temperatures of 25°, 20°, and 15° C. in glass vials covered with cheesecloth. Two series of eighty aphids each were used at each temperature in four replicates of twenty. The first series was started on October 17, and the second on October 27. On October 30 the experiment was repeated using temperatures from 0 to 25° C. in five degree intervals. In the last series ten vials were used, each containing twenty aphids. In all these tests the aphids were kept in the dark. In the first two

series no attention was paid to humidity, but in the last part of the experiment the humidity was kept at 60% by keeping the vials in a desiccator, partially filled with sulfuric acid and water.

Results:

No sexuales were produced under the conditions used in this experiment. In these tests the moisture available to the aphids would be less at the higher temperatures. The saturation deficiency should have been constant rather than the relative humidity.

Object:

To determine whether the fall migrants had already produced young or whether this species dispensed with the production of sexuales in this area and the migrants produced haploid eggs themselves.

Methods and Materials:

At the same time as the previous series of tests were being run another sample of the population was dissected.

Results:

In the twenty aphids examined, three to six young were found in each at various stages of development. This suggests that the fall migrants cannot produce eggs, but can produce live young if reared under the proper conditions.

Aphids in the soil

According to Parker (93) some of the aphids overwinter in the soil in Montana.

Object:

To determine whether P. betae overwinters in the soil in southern Alberta.

Methods and materials:

Fields were located where a heavy infestation had been recorded the previous year. The soil in these fields was carefully examined in April and early May for overwintering adults.

Results:

In 1950 and again in 1951 fields were found in the Lethbridge Northern Irrigation District which contained overwintering aphids. These aphids were found only in fields that had not been cultivated the previous fall. The aphids were not present in large numbers but could have formed a nucleus for an outbreak; they were found in cracks in the soil and were associated with secondary roots or some other organic matter.

Object:

To determine whether the overwintering aphid

population is of economic importance in the irrigated areas of southern Alberta.

Methods and materials:

Fields that contained overwintering aphids were carefully examined from the time that the aphids were found, until a crop was sown.

Overwintering aphids were placed in soil in pots. For a period of two weeks the soil in these pots was cultivated.

Results:

In fields that were fall cultivated it was not possible to find an overwintering aphid population in the following spring. One week after spring cultivation no aphids were found in fields that had contained an overwintering population earlier in the season.

By mechanical agitation of the soil in the pots in the greenhouse overwintering aphids were totally destroyed. This experiment indicates that the overwintering aphid population can be controlled by thorough spring or fall cultivation. The aphids are probably destroyed by desiccation, starvation, and mechanical injury.

SPRING AND SUMMER PERIOD

Spring migration

In the spring of 1950 and 1951 galls of P. betae were found on Populus angustifolia, Populus balsamifera, and one specimen of Populus trichocarpa. These galls were formed by the same means as described by Parker (93).

Object:

To establish the period of emergence of migrants and number of young produced in galls caused by P. betae and P. populicaulis.

Methods and materials:

A survey was undertaken to find trees in irrigated districts and along river banks that had produced galls caused by the two species of aphids. The galls were examined from time to time, and when winged migrants were reaching maturity the galls were covered by small clip cages (see appendices page 79).

The cages were emptied regularly and the number of aphids emerging from the galls were counted.

Results:

The period of emergence of P. betae was from June 21 to July 20 in 1950 and from June 30 to August 7 in 1951. The number of young emerging from each gall averaged 25 with a maximum of sixty-four. This was much lower than the number obtained by Parker (93).

The period of spring migration of P. populicaulis was much longer than that of P. betae extending from June 28 to September 22 in 1950. The number of young emerging from one gall averaged 60 but the maximum was as high as one hundred and forty.

Object:

To determine the effect of temperature on rate of emergence of the spring migrants from galls caused by Pemphigus populicaulis Fitch.

Methods and materials:

Leaves of Populus sargentii that had galls caused by P. populicaulis were removed from trees in the Picture Butte irrigation district on August 12. The galls were placed on moist blotting paper in jars covered with cheesecloth and kept at constant temperatures from 25 to 50° C. in five degree intervals. Records of emergence from galls were taken. The experiment was run twice. Ten galls were kept at each temperature in each test.

Results:

The effect of temperature on emergence is shown in Figure 2. This experiment shows that an increase in temperature reduces the number of days for total emergence of the migrants from the galls. A cool spring and summer

Figure 2. The effect of temperature on emergence of the spring migrants from galls caused by Pemphigus populicaulis Fitch.

would thus extend the duration of migration from these poplar galls.

Under field conditions the number of aphids migrating daily from one gall varied considerably even though the temperature on some days was the same.

Object:

To determine whether there is a variation in the number of aphids emerging daily from galls kept at a constant temperature.

Methods and materials:

Fifty P. populicaulis galls were taken from Populus sargentii in the Picture Butte irrigation district on the same day. These galls were kept on moist blotting paper in jars covered with cheesecloth, at constant temperatures of from 5 to 25° C., in five degree intervals. There were ten galls at each temperature. Records of emergence were made daily for nineteen days.

Results:

The results which are shown in Table 1 indicate that under conditions of constant temperature there is considerable variation in daily emergence of the migrants from galls caused by Pemphigus populicaulis.

Table 1

VARIATION IN NUMBER OF MIGRANTS EMERGING DAILY FROM
PEMPHIGUS POPULICLAUS GALLS KEPT AT CONSTANT TEMPERATURES

No. days at the constant temp.	5°C.	10°C.	15°C.	20°C.	25°C.
1	6	1	0	4	76
2	2	0	4	15	89
3	5	0	10	69	71
4	0	0	10	49	18
5	0	0	11	105	24
6	5	1	93	58	0
7	3	1	5	34	6
8	3	3	33	9	1
9	3	1	142	1	2
10	5	1	19		
11	2	4	63		
12	8	3	30		
13	8	3	11		
14	5	3	7		
15	1	17	1		
16	6	37			
17	9	26			
18	0	46			
19	0	12			

Aphids on beets

The summer infestation of the root aphids on beets in Alberta is similar to that described by Parker (93) in Montana.

Much work has been done on the influence of light, temperature, and nutrition on rate of reproduction of aphids. Davidson (20-22) and Evans (40) noted that plants grown under poor light conditions produced fewer aphids

than those grown under normal light conditions. Ewing (41-44) noted that fewer aphids were produced at lower temperatures.

Davidson (20-22) found that the rate of reproduction of Aphis rumicis varied on different plants, and even on different varieties of the same plant. Evans (40) did not find any correlation between soluble sugars in cabbage and rate of reproduction of the aphid, Brevicoryne brassicae L. He did find however that under late summer conditions of light, the rate of reproduction is positively correlated with the nitrogen content of the host plant, and, in particular, with the protein content. Evans (40) also noted that the pH of cell sap of eleven varieties of trees was positively correlated with fecundity of the aphids. Creighton (18) noted that zinc and copper deficient plants seemed to meet the requirements of certain aphids. Haseman (54) showed that deficiencies in the plant of iron, calcium, potash, phosphorus, magnesium or nitrogen reduced the number of offspring produced by female aphids.

Since P. betae is difficult to observe during the summer because it lives under the ground, there are no records of frequency of reproduction or the number of progeny from one female. When lambsquarters was found to be infested in the field it was noted that the infestation was lower than on beets in the immediate vicinity.

This suggests that aphids do not reproduce as rapidly on this host as on the beet.

METHODS OF DISPERSAL

The aphids are dispersed in southern Alberta by wind, irrigation water, flight, and movement through cracks in the soil. Chittenden (9) claimed ants aided in dispersal, but this has not been observed in Alberta.

HOSTS

WINTER HOSTS

Workers in United States found that Populus angustifolia, the narrowleaf poplar, and Populus balsamifera, the balsam poplar, were the only poplar species that could serve as the winter hosts of P. betae (45, 47, 85, 86, 93). In Texas, Paddock (91), found that P. betae overwintered on turnip roots.

In California this species does not require a primary host (38). The fall migration which occurs at the same time as in Alberta appears to be only a means of dispersal.

Object:

To determine the winter hosts of P. betae.

Methods and materials:

During the springs of 1950 and 1951, poplar trees

in shelter belt and river areas near irrigated districts, were examined for galls formed by P. betae.

Results:

The following species of poplar were found to have P. betae galls: Populus angustifolia James, narrowleaf poplar; Populus trichocarpa Torr. and Gray, black cottonwood; Populus balsamifera L., balsam poplar. P. betae galls were not found on Populus acuminata Rydb., lanceleaf poplar; Populus sargentii Dode., plains cottonwood. Many hybrids of the above species of poplar were found. Some of these hybrids had galls, but most of them were free of infestations. In connection with these studies three other species of Pemphigus were found to be forming galls on poplars along the river banks or in shelter belts.

Pemphigus populicaulis Fitch was found to cause galls to be formed on: Populus angustifolia, Populus balsamifera, Populus sargentii, Populus trichocarpa, and Populus acuminata.

Pemphigus populimonilis Riley was found to cause galls to be formed only on Populus angustifolia.

Pemphigus populitransversus Riley was found to cause galls to be formed only on Populus sargentii.

SUMMER HOSTS

Plants recorded in the literature as summer hosts

of P. betae are listed below. Maxon (16) and Swain (119) claim that all the reported cases of infestation of beets and other hosts by P. betae do not necessarily refer to this species. Some of the plants may not, therefore, be hosts of P. betae because of errors in identification of the aphids.

<u>Plant</u>		<u>Reference</u>
Alfalfa	<u>Medicago sativa</u>	38, 83, 93
Aster	<u>Aster multiflora</u>	83
Blue joint grass	<u>Agropyron occidentale</u>	93
Carrots	<u>Daucus carota</u>	83
Docks	<u>Rumex sp.</u>	38, 83
Door mat weed	<u>Polygonium aviculare</u>	35, 83
Flax	<u>Linum sp.</u>	38, 93
Foxtail (Wild barley)	<u>Hordeum jubatum</u>	93
Garden beets	<u>Beta vulgaris</u>	38, 49, 83, 93
Horse weed (False ragweed)	<u>Iva xanthifolia</u>	49, 93
Knotweed	<u>Polygonum achoreum</u>	38, 39
Lambsquarters	<u>Chenopodium album</u>	83
Lettuce	<u>Lactuca sativa</u>	73
Manger wurzels	<u>Beta vulgaris</u>	49
Poverty weed	<u>Iva axillaris</u>	38
Salt grass	<u>Distichlis specata</u>	93
Sugar beets	<u>Beta vulgaris</u>	38, 49, 83, 93
Sweet clover	<u>Melilotus sp.</u>	83

<u>Plant</u>		<u>Reference</u>
Wheat	<u>Triticum sp.</u>	38, 93
Wild aster	<u>Aster sp.</u>	38, 49
Wild dock	<u>Rumex crispus</u>	93
Wild grasses	<u>Agropyron sp.</u>	38, 83
Wild yarrow	<u>Achillea lanulosa</u>	35, 38, 83
Winged pigweed	<u>Cycloloma</u> <u>atriplicifolium</u>	83

Object:

To determine the summer hosts of P. betae.

Methods and materials:

Plants were dug up in the field and examined for root aphid infestations.

Plants were grown in pots in the greenhouse and apterous forms of the aphid placed on the soil in the pots.

Results:

Winged root aphids collected from sugar beets, lettuce, and lambsquarters were identified as P. betae. Apterous aphids were obtained from dandelions, alfalfa, and red root pigweed but no winged forms, so identification was not obtained. Goldenrod, stinkweed, Russian thistle, Canadian thistle, wild barley, flax, and roadside grasses were found to be free from infestations.

In the greenhouse alfalfa, stinkweed, Russian thistle, flax, and wheat were grown. It was not possible to get infestations of P. betae established on any of these plants.

TYPES OF INJURY

DAMAGE TO BEETS

The sugar beet root aphid sucks the juice from the root hairs as well as from the tap root. The presence of a few aphids on the roots of a beet may not result in any change in appearance of the foliage. However, as the numbers increase, the leaves become flaccid and pale in color, the beet root shrivels and becomes spongy. Finally, if infestation is severe, the leaves wither, and the plant dies.

In 1939 Bennett and Wallace (6) showed that P. betae was even more important than formerly supposed. In some of their experiments it was noted that P. betae transmitted the virus disease curly top.

EFFECT OF FROST ON INFESTED BEETS

In 1949 it appeared that sugar beet plants that were infested with sugar beet root aphids were more severely damaged with frost than those in the same field that were not infested.

Object:

To determine the effect of aphid infestation on the extent of frost damage to sugar beet leaves.

Methods and materials:

An impartial observer was asked to pick ten beets that appeared to show the most severe frost damage and ten which showed the least damage in two fields. These beets were then dug and examined for root aphid infestations.

Infested and uninfested beets were transplanted from laboratory plots to pots and placed at temperatures of -5, -10, -15, and -20° C. The beets were examined for frost damage.

Results:

Field No. 1

Severe frost damage	9 heavily infested 1 uninfested
Light frost damage	7 lightly infested 3 uninfested

Field No. 2

Moderate frost damage	2 lightly infested 8 uninfested
Very light frost damage	10 uninfested

Field observations indicate that a severe infestation increases frost damage. There was no apparent difference

between severity of frost damage on infested and uninfested beets in the temperature rooms. The infested beets were not however supporting a heavy root aphid infestation. The laboratory experiment would thus suggest that an infestation of sugar beet root aphids would not increase visible frost damage.

GALL FORMATION

Comparison of galls produced by *P. betae* and three other species.

The common galls on poplars in southern Alberta that might be mistaken for *P. betae* galls are those caused by *Pemphigus populimonilis* Riley, *Pemphigus populitransversus* Riley, and *Pemphigus populicaulis* Fitch. Therefore, a description and pictures of these galls are presented.

<u>Species</u>	<u>Host</u>	<u>Description of Gall</u>
<u><i>Pemphigus populimonilis</i></u>	<u><i>Populus angustifolia</i></u>	The poplar leaf usually has a bead-like row of galls down each side of the midrib. These galls open on the upper surface and are formed by an invagination of the leaf.
<u><i>Pemphigus populitransversus</i></u>	<u><i>Populus sargentii</i></u>	The galls are roughly spherical and vary in size from 1/4 to 3/4 inch in diameter. These are formed somewhere along the petiole, usually at the junction of the petiole and the blade.

<u>Species</u>	<u>Host</u>	<u>Description of Gall</u>
<u>Pemphigus</u> <u>populicaulis</u>	<u>Populus</u> <u>angustifolia</u> <u>P. sargentii</u> <u>P. acuminata</u> <u>P. balsamifera</u> <u>P. trichocarpa</u>	The galls are roughly spherical and vary in size from 1/4 to 1 inch in diameter. The gall which is between the petiole and blade of the leaf is formed by the twisting and swelling of the petiole to form a pocket with a long angular slit.
<u>Pemphigus betae</u>	<u>Populus</u> <u>angustifolia</u> <u>P. balsamifera</u> <u>P. trichocarpa</u>	The galls are formed by an invagination of the leaf near the midrib and are 1/4 to 1/2 inch deep, and 1/2 to 3/4 inch long. More than one gall may be formed on a leaf.

Variations in P. betae gall formations on poplar leaves.

The galls of P. betae are not always formed singly on the poplar leaf as generally described in the literature. During the summer of 1951 leaves showing various combinations of P. betae galls were collected and some are reproduced in the photographs on the following pages. Other leaves were found on which there was a gall caused by P. populicaulis at the base of the blade and one caused by P. betae part way up the midrib of the same leaf.

Figure 3

Galls caused by
Pemphigus populimonilis
Riley on Populus
angustifolia, the narrow-
leaf poplar.

Figure 4

Figure 5

Galls caused by
Pemphigus populitrensvetus
Riley on Populus sargentii,
the plains cottonwood.

Figure 6

Galls caused by
Pemphigus populi-
caulis Fitch.

Fig. 7. An opened gall
showing the aphids
inside.

Fig. 8. Gall on
Populus balsamifera
leaf.

Fig. 9. Double
galls on Populus
sargentii. leaf.

Figure 7

Figure 8

Figure 9

Figure 10

Typical galls caused
by Pemphigus betae on
Populus balsamifera,
the balsam poplar.

Figure 11

Figure 12

Variations of galls caused
by P. betae.

Fig. 12. Leaf of Populus
balsamifera showing a gall
caused by P. betae and one
caused by P. populicaulis.

Fig. 13. Four P. betae
galls on one leaf.

Figure 13

Figure 14
Variations of P. betae galls.

Figure 15

Preliminary studies of gall formation

In the Lethbridge Northern Irrigation District galls formed by Pemphigus betae could not be found within several miles of most of the sugar beet root aphid infested fields. Galls were found only along the banks of the Old Man River on Populus balsamifera and Populus angustifolia. Throughout the irrigated district Populus sargentii is prevalent in the shelter belts, and galls formed by Pemphigus populicaulis and Pemphigus populitransversus were observed on this species of poplar close to infested fields.

This suggests that there might be more than one species of aphid infesting beets, or that the same species might be forming different types of galls by feeding at different places on the trees.

Object:

To determine the relationship between gall formation and feeding of P. betae and P. populicaulis at different parts of the leaf.

Methods and materials:

Aphids that were starting to form P. betae galls were transferred from their position next to the mid vein, and placed at the junction of the petiole and the blade. Aphids that were starting to form P. populicaulis galls were transferred from their position at the junction of the blade and the petiole, and placed part way up the leaf blade next

to the mid vein. Transfers were also made to other leaves. Populus balsamifera was used as the test species of poplar. The aphids, after being removed from their initial site, were retained in the second position by the leaf clip cages. The experiment was carried on during the last week in May 1951.

Results:

All attempts to get the aphids to form a second gall failed. Present observations indicate that either the aphids did not feed after being transferred, or they lost the ability to cause gall formation when moved to another leaf, or another part of the same leaf.

The stem mothers of many species of aphids produce only thirty young. In galls of P. betae and P. populicaulis there are often many more than thirty spring migrants produced.

Object:

To determine whether the stem mother produces all the young that are in the galls caused by P. betae and P. populicaulis.

Methods and materials:

The small clip cages were placed over galls in which all aphids, except a single mature migrant, were removed.

In other cages where a large number of young were present, all but the stem mother were removed. Ten galls of P. betae and ten of P. populicaulis were used for the test with migrants; ten P. populicaulis were used for the stem mother test.

Results:

No young were produced in any gall by the spring migrants. This was not expected for it would appear that they should produce woolly apterous forms at least. It is possible that the cages might have some influence on the reproduction of the migrants. The stem mothers in all cages continued to produce young.

REARING

IN THE GREENHOUSE

During the summer of 1950 greenhouse cultures were readily established by two methods: galls containing migrants were brought into the greenhouse, the summer apterous forms were put in pots containing beets. At first considerable difficulty was encountered in getting the aphids to reproduce rapidly. This was overcome by placing the pots in a dish which was filled with water regularly, the amount being not quite sufficient to wet the soil to the surface. Thus a moisture gradient was available to the aphids. This method was satisfactory until fall.

In fall and again in March a large number of migrants appeared in the culture. In the greenhouse the fall

migration occurred at the same time as the fall migration from beets to poplars in the field. The spring migration from the pots appeared at approximately the same time as the spring migration in California, and at the same time as the migration of Pemphigus populitransversus, from crucifers to poplars, in Colorado.

Usually in collecting aphids, the soil was examined, and the aphids picked up with a camel hair brush. When infestation was high, some of the root hairs and aphids were brought to the surface of the soil by covering it with boards. When the boards were lifted, the aphids were readily collected to be used in experiments.

ARTIFICIAL FEEDING

It was difficult to study the root aphid readily when it was feeding on the beet root. To facilitate work on aphid diseases, nutrition, and wing formation, it was decided to test various artificial means of feeding the aphids.

The following methods have been tried without success:

1. Pieces of sugar beet root were supplied on moist blotting paper.
2. Aphids were kept on a layer of plaster of paris in tins and were supplied with moisture and germinating beet seeds.
3. Aphids were placed in vials which contained sugar beet root hairs on moist blotting paper.

4. Aphids were placed in vials which contained sugar beet root hairs and moist soil.
5. Aphids were put in petri dishes, the bottoms of which were moistened with a solution of glucose.
6. Aphids were put on blotting paper covered with the extracted juice of the sugar beet.
7. Ground up beets were put in agar plates and aphids placed on the plates.
8. Aphids were kept on plates of agar containing sucrose and beet juice. (The bacteria on the aphids contaminated the sterile plates.)
9. The aphids were put in tins in which small tubes were placed. These small tubes contained honey or juice extracted from the beet root, and the open end was covered with the outer beet leaf membrane or outer beet root membrane.

IN PLOTS

Species infesting beets

Object:

To determine whether P. betae, P. populimonilis, and P. populitransversus can infest sugar beets.

Methods and Materials:

Three plots were set out with eight copper screen cages of 32" mesh in each. Then individual cages were placed over single beets and galls were introduced.

The galls were those formed by P. betae, P. populimonilis and P. populitransversus. Two replicates were run in each plot using each species, and two caged beets were left as checks.

Results:

No infestations of the sugar beets were obtained when galls of P. populicaulis or P. populitransversus were employed. The checks were also free from root aphids. Only one out of the six caged beets became infested with P. betae. These results suggest that P. betae migrants are the only ones that infest sugar beets.

EFFECT OF ENVIRONMENTAL FACTORS ON ROOT APHIDS

TYPE OF SOIL

In the Taber area of southern Alberta the very light soils were generally free of infestations and the district as a whole had a much lighter infestation of sugar beet root aphids than any other district.

Object:

To determine whether sugar beets grown in each of the three common types of soil in the irrigated districts of southern Alberta can be readily infested with sugar beet root aphids.

Methods and materials:

The leaves were removed from 60 beets grown in laboratory plots. The beets were then washed to remove any aphid infestation and transplanted into sterilized soil in pots, in a greenhouse. Twenty beets were planted in each of the three types of soil: sand, clay loam, and heavy clay. Twenty-five apterous sugar beet root aphids were put on top of the soil next to the growing beet. The beets were dug and checked for infestation after six weeks.

Results:

Every beet was found to be infested with the root aphids. This indicates that sugar beets grown in these three types of soil can become infested with root aphids, and that soil texture is not an important factor in preventing such aphid infestations.

TEMPERATURE OF SOIL

Object:

To determine the effect of high temperature on sugar beet root aphids.

Methods and materials.

Twenty four beets that had been grown in pots in a greenhouse were placed in a room where the temperature was kept above 90° F. The plants were grown under artificial fluorescent light of an intensity of 300 foot candles and

were watered regularly by placing water in a dish under the pots.

Fifty apterous aphids were placed on the soil around the plants. The plants were then allowed to grow for three weeks.

Results:

The beets grew normally but when examined they were completely free from aphid infestations. At the end of the experiment the temperature was found to be 88° F. just below the soil surface. Aphids had been kept at temperatures lower than 90° F. and under the same conditions of light and moisture. This test would indicate that a constant temperature of 90° F. would prevent root aphids from becoming established on sugar beets.

LIGHT VARIATIONS

Causes of migration

Much work has been done on the effect of various factors on wing production in aphids. Many workers considered only one factor important and disregarded others.

Ewing (43), Wadley (129), Ackerman (1), and Call (8) found temperature influenced wing formation. Ackerman (1) noted that certain ranges of temperature were more likely to produce winged forms than others; optimums for high wing production were 16° C. and 24° C. to 26° C., and for low wing production 12° C. and 18° C. to 20° C. When aphids that have

been living at a particular temperature are transferred to a new temperature, they produce a higher percentage of winged forms during the first two or three weeks than they do later. A period of three to ten days must elapse before the effect of temperature changes on wing production becomes noticeable.

Marcovitch (81) and Shull (110-113) found that light influenced wing formation. Shull (110-113) showed that aphids produced winged offspring when they were reared in intermittent light (8 hours of light alternating with 16 hours of darkness). Intermittent light of low intensity required a longer period to induce complete wing production than did light of high intensity. Shull reared aphids whose previous offspring were all winged because they were developed in intermittent light and moderate temperature (20° C.). When these aphids were placed in continuous light, wings were suppressed in 50% of the offspring in three days. High temperature (30° C.) applied to similarly reared aphids suppressed wings in 50% of the offspring in one day. Temperatures lower than 30° C. (29°, 28°, 27° and 26° C.) took progressively longer to produce the same effect.

Shull (110), Wadley (129), Gregory (50), Mason (82), Davidson (20-22), Ackerman (1), and Reinhard (100) noted that the parentage of the aphid was important as a factor in wing formation. Apterous aphids have a greater tendency to produce alate offspring, and alate aphids generally produce larger number of apterous progeny.

Baker and Turner (3) pointed out that the percentage of winged forms varies in different strains, and may be a heritable character.

Davidson (20-22) found that changes in the composition of plant sap induced wing production. Gregory (50), Wadley (129), and Ackerman (1) found that starvation caused apterous aphids to produce alate offspring while starvation of winged parents caused a decrease in the production of alate offspring. Evans (40) showed that under late summer conditions of light, the formation of wings is negatively correlated with the nitrogen content of the host plant, and, in particular, with the protein content. Haseman (55) stated that wing formation in the field as well as the laboratory is due to the chemical composition of the plant which the aphid consumed.

Davidson (20-22), Woodworth (132), Neils (88), Shinji (109), and Ackerman (1) found that growing plants in certain chemicals caused the aphids that were feeding on them to produce winged progeny.

Prevention of migration

In the greenhouse used for rearing the aphids the only apparent variable factor at the time of spring migration was the duration of light. The temperature and moisture conditions were constant, and overcrowding did not occur. In an attempt to prevent migration the duration of light was

increased by using fluorescent lamps to supplement daylight. The culture was maintained. It cannot be stated definitely that the light was the factor responsible for preventing migration, as a total migration never appears to occur in the field. The maintenance of the culture may have been due to a build up of infestation by the aphids that would not have migrated under any conditions.

NUTRITIVE QUALITY OF SUGAR BEETS

Object:

To determine relationship between nitrogen, sugar, and moisture content and liability to infestation by aphids.

Methods and materials:

During the summer, twenty-four sugar beets were grown under varying conditions of light, nutrition, moisture, and temperature. After the beets were growing well, root aphids were released on them. The plants were then left for six weeks. Only eleven of the beets were large enough for analyses of the desired factors. Nitrogen was estimated by the micro-Kjeldahl method using a five to ten milligram composite sample of the root. The total sugar analysis was done on a twenty gram sample by a polarographic method at the Canadian Sugar Factory Chemistry Laboratory at Taber, Alberta. The moisture content was determined by weighing the

sample, drying for twenty-four hours at 100° C., cooling it in a desiccator, then reweighing.

Results:

Statistical analyses appear in the appendices pages 76, 77, and 78.

Table 2

RELATION OF THE PERCENTAGE SUGAR IN SUGAR BEETS
TO THE SEVERITY OF INFESTATION BY P. BETAE

Percentage total sugar (wet weight basis)	No. of aphids
18.0	2
17.8	488
16.0	2
16.0	4
14.2	703
13.0	770
12.6	1
12.2	567
8.0	292
7.8	45
4.8	31

These results showed that there was no correlation between root aphid infestation and total sugar content of the beets.

Table 3

RELATION OF THE PERCENTAGE NITROGEN IN SUGAR BEETS
TO THE SEVERITY OF INFESTATION BY P. BETAE

Percentage nitrogen in the dehydrated beet	No. of aphids
2.3	1
2.3	4
2.3	703
1.7	31
1.6	770
1.6	488
1.6	567
1.6	2
1.5	2
1.5	45
1.0	292

No correlation between nitrogen and root aphid infestation was indicated by these results.

Table 4

RELATION OF THE PERCENTAGE MOISTURE IN SUGAR BEETS
TO THE SEVERITY OF INFESTATION BY P. BETAE

Percentage moisture in the whole beet	No. of aphids
27.37	4
26.33	2
23.78	488
22.70	2
20.57	703
19.63	1
18.76	770
18.25	567
15.47	292
15.02	45
14.19	32

These results indicate that there is no correlation between the percentage moisture in the sugar beet and the root aphid infestation.

It was interesting to note in this experiment that there was a positive correlation between the percentage of moisture in the beet and the percentage sugar. This

might be the reason Parker (96) obtained an increase in sugar content of the beets that were irrigated most frequently.

The results in this experiment are only an indication, for the sample size was inadequate, and the infestation was extremely variable. Modifications of light, moisture, temperature, and nutrition cause a variation in the sugar, nitrogen, and moisture content of sugar beets. The methods of analysis appeared to be satisfactory.

VARIETAL DIFFERENCES

Object:

To determine the relationship of different varieties of sugar beets to sugar beet root aphid infestation.

Methods and materials:

The following varieties of beets were examined for sugar beet root aphid infestation: Hel E 2400, Glostrup S, Sharpe KE, Hel E 2410, Glostrup P, Kuhn 34918, Alta 9, SKE, 215 x 216, Bush E, MS 49, BR GR 492, Kuhn P, Hel E 2404, Hel 2408, and EH 657 111.

Six rows of each of these varieties were examined and rated. The ratings were as follows:

0 none

1 present

- 2 light, patchy
- 3 light, general
- 4 severe patchy, or moderate generally
- 5 severe general

Results:

Table 5

RELATIONSHIP OF DIFFERENT VARIETIES OF SUGAR BEETS TO
SUGAR BEET ROOT APHID INFESTATION

Variety trials	Ratings in rows					
	1	2	3	4	5	6
Hel E 2414	0	1	1	1	1	1
Hel E 2408	1	1	1	1	1	1
EH 657 111	1	1	1	2	1	1
Hel E 2400	0	1	0	1	1	1
Glostrup S	1	0	1	0	1	1
Sharpe KE	0	0	2	1	1	2
Hel E 2410	0	0	0	1	1	1
Glostrup P	0	0	1	1	1	1
Kuhn 24918	0	0	2	1	2	1
Alta 9	0	1	0	1	3	2
SKE	0	0	1	2	2	1
215 x 216	1	1	2	1	3	1
Bush E	0	0	0	0	2	1
MS 49	1	0	1	1	1	1
BR GR 492	1	0	1	1	1	1
Kuhn P	0	1	2	2	1	1

The infestations were very low in this experiment. The analysis of variance (appendices page 75) shows that there is no significant difference between varieties.

CONTROLLING FACTORS

BIOLOGICAL

Predaceous insects

Numerous predators are influential in the control of P. betae. The most important is the chloropid, Chloropisca glabra Meig. (83, 95, 117). The coccinellids Hippodamia convergens Guerin, Scymus collaris Meish and Scymus appaculus have also been reported as being predatory on the aphids (11, 83). Reduvicolis ferus was reported to be feeding on autumn migrants of the sugar beet root aphid (14). The syrphid Syrphus paxillus has been observed feeding on summer aptera in the soil (83).

In Alberta large numbers of Chloropisca glabra were found to be reducing P. betae populations on the beet roots.

A number of syrphid larvae were found in galls of P. betae. These larvae were fed on live aphids in the laboratory for several weeks, but only one larva pupated and the adult did not emerge from the pupal case. These larvae controlled the aphids in several hundred galls of both P. betae and P. populicaulis in the St. Mary's and Old Man River areas.

Two other insects were found to be predatory on the aphids in the galls. One is a small hemipteran, which

has been tentively identified to the genus Anthocoris, and the other is a coccinellid larva.

Pathogenic microorganisms

Maxon (83) reported that the fungus, Empusa aphidis (Hoff.) aided in controlling the sugar beet root aphids.

Certain microorganisms appeared to reduce the population in the greenhouse. Three fungi and one bacterium were isolated from aphids that had died. These were cultured on potato dextrose agar.

Object:

To determine if microorganisms isolated from dead aphids are primary pathogens of P. betae.

Methods and materials:

Three methods of inoculation were used for these tests.

- 1) Potato dextrose agar plates were covered with a suspension of organisms and aphids placed in them.
- 2) Aphids were placed in sterile petri dishes and covered with a suspension of organisms.
- 3) Aphids were dropped into the disease organism suspensions, then taken out and placed in dry sterile petri dishes.

Distilled water was used in the checks.

The aphids were collected from greenhouse cultures and washed for several minutes in sterile distilled water to

reduce number of surface contaminants before being used in the tests.

Results:

In these tests the aphids died as rapidly in the checks as in the treated dishes. The aphids were not fed because a method of artificial feeding had not been developed and it was not possible to observe them on their natural host.

In the galls, many specimens of both P. betae and P. populicaulis were apparently destroyed by a microorganism. The galls contained partly decomposed aphids and a fungus growth which may have been secondary.

ARTIFICIAL

Irrigation

A modification of irrigation practices has been recommended as the main method of root aphid control since the work of Parker (94, 96). He recommended frequent irrigation, four to six times a year, starting with an early irrigation in mid-June. Parker (94, 96), Hansen (51, 52), and Cooley (15) have shown that these practices reduce infestations and increase sugar content and yield.

In the Lethbridge Northern Irrigation District and in the St. Mary's River District, fields were observed where infestations were heavy, even though as many as six irrigations

had been applied. In these areas it would appear that frequent irrigation did not control infestations.

Two farmers in the L.N.I.D. have not been troubled with root aphid infestations in their fields, although their neighbors' fields have been infested. Both men irrigate and cultivate their fields earlier and usually more frequently than their neighbors. In the spring of 1951 two experiments were set up on fourteen farms to test the effects of early irrigation and early cultivation on root aphid infestations. These experiments were abandoned owing to heavy rains during the period from June 15 to August 1 when irrigations and cultivations were to have been done.

Crop rotation

Dustan (36) and Sanderson (106) recommend crop rotation as a control measure. Maxon (83, 84) however stated that hibernating aphids are a source of infestation but that rotations are of no value.

Rotations in the irrigated areas of southern Alberta did not appear to prevent or reduce infestations. Beets were grown in fields that had contained infested beets the previous year. Some of these fields had a lighter infestation than fields that had been summerfallowed the previous year while others were more severely infested. Some farmers interviewed claimed that they had encountered a greater infestation in fields that had been growing alfalfa prior to beets.

Observations in 1950 indicated that there was no apparent difference in the infestation in the fields that had grown alfalfa and those that had grown other crops the previous year.

Cultivation

Field observations indicate that early and frequent cultivations reduce the level of infestations. A thorough spring or fall cultivation destroys most of the overwintering root aphids in the field. Most farmers in the irrigated districts of southern Alberta cultivate thoroughly in the spring, consequently the overwintering population would seldom be of any importance in this area.

Location of field

Both Maxon (84) and Dustan (36) recommend planting susceptible crops at some distance from cottonwoods as a means of control.

This is probably not important in irrigated areas of southern Alberta because the sugar beet root aphid galls are only found on poplars along the river banks. The aphids are thus often at a distance from the fields they infest. The aphids are generally distributed over the whole area growing sugar beets, so that growing beets at different places on the farm would probably neither reduce nor prevent infestations.

Weed control

Dustan (36) recommends control of secondary hosts as a means of control of the aphids.

In one field examined, lambsquarters became infested before the beets and acted as a centre for a local infestation, thus its control may aid in reducing infestations.

Ant control

Chittenden (9) recommends breaking up ants' nests as an aid in control of root aphids, because ants act as distributing agents. This does not seem important in southern Alberta as ants have not yet been found associated with P. betae in the field.

DISCUSSION

In life history studies, two important parts of the life cycle were not established: site of oviposition and production of sexuales. The studies on predators should be continued because predation may be one of the main reasons that P. betae has not severely damaged crops several years in succession in southern Alberta. The reports (79, 126) in the past indicate that this insect is very troublesome for one to two years, then it disappears as a major pest in the irrigated areas, to return again a few years later. Additional information should be obtained on the syrphid larvae that are destroying aphids in the galls. The small hemipteran and the coccinellid larvae that were killing the aphids are being identified to species. A study should be made on their life histories.

It should be pointed out that in the temperature experiment with fall migrants the saturation deficiency should have been constant rather than the relative humidity. In the experiment the aphids at the higher temperatures were subject to a much greater moisture loss than those at lower temperatures.

Much information could be obtained on migration, production of sexes and natural control of P. betae if an artificial feeding medium could be developed.

The secondary hosts of P. populicaulis and P. populitransversus are not known in this area. As these aphids are present on poplars and are closely related to P. betae further investigations on their host relationship may lead to further information on the sugar beet root aphid problem. No secondary host has been recorded for P. populicaulis.

Results of the experiment on nitrogen, sugar, and moisture content of the beets indicated that there was no correlation between these factors and the root aphid infestations. This work should be carried further and done on a much larger scale.

Variety studies were of little value because of the low aphid infestation. These should be repeated since there is a possibility that some resistance might be shown by certain varieties.

A thorough study of control methods was not attempted. Work should be started on the effect of systemic insecticides and chlorinated hydrocarbons on the root aphids. Studies should

be continued on the cultural control with special reference to irrigation.

SUMMARY

The sugar beet root aphid is present in Alberta throughout the sugar beet growing area.

Secondary hosts were found to be sugar beets, lambs-quarters, and lettuce.

The number of days for total emergence of alates from galls of P. populicaulis is negatively correlated with temperature under laboratory conditions.

The primary hosts of P. betae were found to be Populus angustifolia, Populus balsamifera and rarely Populus trichocarpa.

Galls caused by Pemphigus populicaulis, Pemphigus populitransversus, and Pemphigus populimonilis may be mistaken for those caused by P. betae.

The galls of P. betae were first noticed to be forming on May 22. The flight of the spring migrants extended from June 20 to August 7. The flight of the fall migrants extended from September 4 to October 30.

Some apterous forms of P. betae overwinter in the soil in sugar beet fields in southern Alberta. The overwintering populations are not generally economically important because thorough spring or fall cultivation can control this form. Field observations indicate that early and thorough cultivation

of the beets during the summer aids in controlling the infestation of P. betae. In this area the spring migrant is the form that usually produces the economically important summer infestation on beets.

No correlation was found between sugar, nitrogen, and moisture content of the sugar beets, and the extent of sugar beet root aphid infestation.

Rotations are of little value as a control measure for the root aphids. Contrary to work done by Parker in Montana, frequent irrigation did not aid in controlling the root aphids.

A measure of biological control is effected by the following predators: Chloropisca glabra Meig. (Chloropidae, Diptera), a species of Syrphidae (Diptera), Anthocoris species (Anthocoridae, Hemiptera), and certain Coccinellidae (Coleoptera).

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APPENDICES

DEFINITION OF TERMS

Fundatrices or stem mothers

Apterous or alate viviparous parthenogenetic females hatching from overwintering eggs on the primary host. Sugar beet root aphid stem mothers are wingless.

Fundatrigeniae

Apterous or alate, viviparous, parthenogenetic females arising from fundatrices.

Spring migrants

Alate, viviparous, parthenogenetic females arising from stem mothers and migrating from the primary to secondary host. Spring migrants of the sugar beet root aphid are fundatrigeniae.

Alienicolae, seconds or summer forms

Apterous, viviparous, parthenogenetic females born on the secondary host and comprising several to many generations.

Sexuparae or gynoparae

Apterous or alate, viviparous, parthenogenetic females that are offspring of the alienicolae, and which give birth to apterous or alate sexuales. The sexuparae of P. betae are winged and produce apterous sexuales.

Fall migrants

Offspring of the alienicolae that migrate from the

secondary to the primary host. Sugar beet root aphid fall migrants are the sexuaparae.

Sexuales or sexes

Male and female progeny of the sexuaparae, either born on the secondary host, whence they migrate to the primary host, or on the primary host. They usually do not feed at all, develop rapidly and mate. The females lay one to several eggs which overwinter. Both adults normally perish before winter. The sugar beet root aphid sexes are born on the primary host, and the female lays one egg only.

STATISTICAL ANALYSIS

Analysis of variance

$$(\sum x) = 87$$

$$nk = 96$$

$$\sum (x)^2 = 123$$

$$(\sum x)^2/nk = (87)^2/96 = 7569/96 = 78.84 = C$$

$$\text{Total SS} = \sum (x)^2 - (\sum x)^2/nk = 123 - 105.13 = 19.17$$

$$\text{Variety SS} = (\sum x_1)^2/k_1 + (\sum x_2)^2/k_2 - \dots - (\sum x_{16})^2/k_{16} - C$$

$$= (5)^2/6 + (6)^2/6 - \dots - (7)^2/6 - 78.84$$

$$= 4.17 + 6 + 8.17 + 2.67 + 2.67 + 6 + 1.5 + 2.67 + 6 + 8.17 +$$

$$6 + 13.5 + 1.5 + 4.17 + 4.17 + 8.17 - 78.84$$

$$= 85.53 - 78.84 = 6.69$$

$$\text{Individual SS} = 19.87 - 6.69 = 13.18$$

Source of variance:	DF	SS	MS	F
Total	95	248.52		
Varieties	15	6.69	0.45	0.45/1.65 = 0.27
Individuals	80	13.18	1.65	

$$2.14^*$$

$$2.99^{**}$$

There is no significant difference between varieties.

Correlation between Sugar Beet Root Aphid Infestation
and the Moisture Content of the Sugar Beet Root

$$\sum x_1 = 2905 \quad \sum (x_1)^2 = 1735017 \quad \sum x_2 = 222.07 \quad \sum (x_2)^2 = 4682.90$$

$$x_1 x_2 = 5673.69$$

$$\begin{aligned} \sum (x_1 - \bar{x}_1)^2 &= \sum (x_1)^2 - (\sum x_1)^2 / n \\ &= 1735017 - (2905)^2 / 11 \\ &= 967832.91 \end{aligned}$$

$$\begin{aligned} \sum (x_2 - \bar{x}_2)^2 &= \sum (x_2)^2 - (\sum x_2)^2 / n \\ &= 4682.90 - (222.07)^2 / 11 \\ &= 199.71 \end{aligned}$$

$$\begin{aligned} \sum (x_1 - \bar{x}_1)(x_2 - \bar{x}_2) &= \sum x_1 x_2 - (\sum x_1)(\sum x_2) / n \\ &= 5673.69 - (2905)(222.07) / 11 \\ &= 1934.16 \end{aligned}$$

$$\begin{aligned} r &= \frac{\sum (x_1 - \bar{x}_1)(x_2 - \bar{x}_2)}{\sqrt{[\sum (x_1 - \bar{x}_1)^2][\sum (x_2 - \bar{x}_2)^2]}} \\ &= \frac{-1934.16}{\sqrt{(967832.91)(199.71)}} \\ &= 0.0014 \end{aligned}$$

Applying t test

$$\begin{aligned} t &= r \sqrt{(n-2)/(1-r^2)} \\ &= 0.0014 \sqrt{(11-2)/1-(0.0014)^2} \\ &= 0.0014 \times 3 = 0.0042 \end{aligned}$$

The t test is not significant so there is no correlation between infestation of the sugar beet root aphid and the moisture content of the sugar beet.

Correlation between Sugar Beet Root Aphid Infestation
and the Nitrogen Content of the Sugar Beet Root

$$\sum x_1 = 2905 \quad \sum (x_1)^2 = 1735017 \quad \sum x_2 = 18.9 \quad \sum (x_2)^2 = 3405$$

$$\sum x_1 x_2 = 4896.50$$

$$\begin{aligned} \sum (x_1 - \bar{x}_1)^2 &= \sum (x_1)^2 - (\sum x_1)^2 / 11 \\ &= 1735017 - (2905)^2 / 11 \\ &= 967832.91 \end{aligned}$$

$$\begin{aligned} \sum (x_2 - \bar{x}_2)^2 &= \sum (x_2)^2 - (\sum x_2)^2 / 11 \\ &= 3405 - (18.9)^2 / 11 \\ &= 3372.53 \end{aligned}$$

$$\begin{aligned} \sum (x_1 - \bar{x}_1)(x_2 - \bar{x}_2) &= \sum (x_1 x_2) - (\sum x_1)(\sum x_2) / n \\ &= 4896.50 - (2905)(18.9) / 11 \\ &= -94.81 \end{aligned}$$

$$\begin{aligned} r &= \frac{\sum (x_1 - \bar{x}_1)(x_2 - \bar{x}_2)}{\sqrt{[\sum (x_1 - \bar{x}_1)^2][\sum (x_2 - \bar{x}_2)^2]}} \\ &= \frac{-94.81}{\sqrt{(967832.91)(3372.53)}} \\ &= -0.0017 \end{aligned}$$

Applying t test

$$\begin{aligned} t &= r \sqrt{(n-2)(1-r^2)} \\ &= 0.0017 \sqrt{(11-2)(1-(0.0017)^2)} \\ &= 0.0017 \times 3 = 0.0051 \end{aligned}$$

The t test is not significant so there is no correlation between the sugar beet root aphid infestation and the nitrogen content of the sugar beet root.

Correlation between Sugar Beet Root Aphid Infestation
and the Total Sugar Content of the Sugar Beet Root

$$\sum x_1 = 2905 \quad \sum (x_1)^2 = 1735017 \quad \sum x_2 = 139.6 \quad \sum (x_2)^2 = 1951.11$$

$$\sum x_1 x_2 = 38186.4$$

$$\begin{aligned} \sum (x_1 - \bar{x}_1) &= \sum (x_1)^2 - (\sum x_1)^2/n \\ &= 1735017 - (2905)^2/11 \\ &= 967832.91 \end{aligned}$$

$$\begin{aligned} \sum (x_2 - \bar{x}_2) &= \sum (x_2)^2 - (\sum x_2)^2/n \\ &= 1951.11 - (139.6)^2/11 \\ &= 179.47 \end{aligned}$$

$$\begin{aligned} \sum (x_1 - \bar{x}_1)(x_2 - \bar{x}_2) &= \sum x_1 x_2 - (\sum x_1)(\sum x_2)/n \\ &= 38186.4 - (2905)(139.6)/11 \\ &= 1319.31 \end{aligned}$$

$$\begin{aligned} r &= \frac{\sum (x_1 - \bar{x}_1)(x_2 - \bar{x}_2)}{\sqrt{[\sum (x_1 - \bar{x}_1)^2][\sum (x_2 - \bar{x}_2)^2]}} \\ &= \frac{1319.31}{(967832.91)(179.47)} \\ &= 0.01 \end{aligned}$$

Applying t test

$$\begin{aligned} t &= r \sqrt{(n-2)/(1-r^2)} \\ &= 0.01 \sqrt{(11-2)/1-(0.01)^2} \\ &= 0.01 \times 3 = 0.03 \end{aligned}$$

The t test is not significant so there is no correlation between infestation by the sugar beet root aphid and the total sugar content of the sugar beet root.

Figure 16

Fig. 16. Cage used in studies of poplar galls.

Fig. 17. Leaf cages on poplar twig.

Figure 17