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Title The Biology and Control of the Insect Vectors of Potato Viruses in Oregon

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1. Potato virus diseases are the limiting factor in the production of potatoes for seed in Oregon, and materially reduce yields in commercial potatoes. Insects are the only important agents by which these viruses are spread in the field.

2. Six species of aphids carry the 3 most important potato viruses, but only the green peach aphid, Myzus persicae (Sulz.), is important as a vector in this state. The aster leafhopper, Macrosteles divisus (Uhl.), may be a vector of one or more of the potato viruses.

3. The life history, food plants, distribution, and ecology of the vectors are discussed. The overwintering habits of the aphids are not known in Oregon, but are shown not to be those quoted elsewhere. The possibilities of the manner of overwintering are discussed. The correct systematic position of the vectors is established, and means for their identification provided.

4. Other insects common on potato have consistently failed to transmit potato viruses. Aphids have not transmitted the viruses causing green dwarf, witches' broom, late breaking virus disease, or calico dwarf. The vectors of these viruses are not known.

5. Killing the aphids with DDT formulations has not resulted in a cessation of the spread of potato viruses in the field. It is postulated that a quick-killing, long-lasting insecticide is needed. Dusting potatoes with aphicides, combined with other disease control methods, is shown to be of value and economically feasible.

THE BIOLOGY AND CONTROL OF THE INSECT VECTORS OF POTATO VIRUSES IN OREGON

by

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A THESIS

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INTRODUCTION

THE POTATO INDUSTRY IN OREGON

Importance and Value. With approximately fifty thousand acres grown yearly, potato culture is one of the major farming operations in Oregon. Only four other commodities grown in the state have a higher annual crop value; namely, pears, wheat, hops, and combined truck crops. In 1945 the potato crop had a value of $10,648,000, and the 3,443 acres of potatoes grown for seed had a value of $2,613,993 (62)[1]. Oregon ranks eleventh in the nation in number of bushels produced yearly. Table 1 summarizes the number of acres of potatoes grown for seed during the past few years.

Table 1

Oregon Certified Seed, Acreage by Years (37)

Year	Acres of Seed	Year	Acres of Seed
1920	55	1944	2867
1924	172	1945	3443
1929	822	1946	2878
1934	1250	1947	2987
1939	1620	1948	3149

[1] Numbers in parentheses refer to Literature Cited.

Certification of Seed. Since the conditions for the production of seed are excellent in many parts of the state, this phase of potato growing has long been stressed by Oregon farmers. As a means of assuring the highest quality of this seed, the Oregon State College Extension Service has been empowered to inspect and determine the quality of potatoes for seed. On the basis of field and bin inspections, fields entered for certification are classed as foundation or certified seed, or are rejected if the field contains more diseased plants than the standards allow. Fields, the seed of which is to be tagged as foundation, must have a sample of the potatoes collected and planted during the winter months, in order to be certain that there was not late season spread of diseases to appear in the next generation of plants. Table 2 summarizes the present requirements for certification.

The Problem. In 1948, 4,481 acres were entered for certification as seed. Of this, 1,332 acres, or 30 per cent of the total, were rejected during the field inspections because of disease. Of the acres rejected, 68.7 per cent were because of leafroll, 23 per cent were withdrawn from consideration, presumably because of late season disease spread, and 6.9 per cent were rejected because of mild mosaic. In the five principal potato producing

Table 2

Requirements for Certification of Seed Potatoes in Oregon
(From Seed Certification Service)

Factor	Foundation Seed 1st Field Inspection %	Foundation Seed 2nd Field Inspection %	Certified Seed 1st Insp. %	Certified Seed 2nd Insp. %
Leafroll--Netted Gem and Burbank	0.5	0.2*	0.5	0.25*
Leafroll--Other Varieties	0.5	0.2*	1.0	1.00**
Mosaic	1.0	0.2*	3.0	1.50**
Other Viruses	1.0	0.2	3.0	1.50
Total Virus Diseases	1.0	0.2	3.0	1.50

*Tuber Perpetuated 0.1 %
**Tuber Perpetuated 0.5 %

Requirements on Test Plot Reading:

Foundation Seed--1.0 % Total Virus Diseases
Certified Seed--10.0 % Total Virus Diseases

counties there was a great deal of variation in the acreage meeting certification standards. In Multnomah county, 9 per cent of the acreage entered was rejected, in Klamath county 12 per cent was rejected, in Crook county 30 per cent, in Deschutes county 27 per cent, while in Jefferson county 64 per cent of the acreage entered was rejected, primarily because of leafroll (27).

No such figures as these are available on a national scale, but the Agricultural Research Administration estimates (1) that in 1944 the potato losses from aphids, carriers of the potato viruses, amounted to some

$66,467,000 in the "northern states" alone.

Another measure of the importance of the viruses affecting the potato may be gained from the observation of Kunkel (45) that of the papers written in the past 25 years on plant pathology, 25 per cent have been on the viruses attacking potato.

According to Smith (98), the losses of potatoes in England due to virus diseases are estimated to be about 1.2 tons per acre of potatoes grown. In Wales in 1923, the loss due to leafroll alone was 52.6 per cent of the entire crop. It costs the growers of England $2,800,000 a year to buy seed in Scotland and Ireland to replace their own stocks which have become diseased (4). In Germany losses of 20 to 30 per cent are not at all uncommon.

McKay and Dykstra (52) reported that losses in Oregon in 1929 and 1930 from virus diseases amounted to 77 per cent from spindle tuber, 62 per cent from crinkle mosaic, 36 per cent from mild mosaic, and 19 per cent from interveinal mosaic. These figures are intended to show the amount lost when plants are infected with these respective diseases. Thus it can be seen that viruses cause great losses. The problem involves finding measures of insect control and cultural practices to reduce their spread from a source to other plants.

HISTORICAL

Potato Virus Diseases. There is abundant evidence that a potato disease known as "leaf curl" was recognized in England as early as 1757, and by 1770 it was abundant in fields of that country. The problem became so serious, and losses so great, that in 1776 growers commenced importing their seed from Scotland, because there was less "curl" in potatoes from that area.

In 1780 it was proved that the potato degeneration diseases are vegetatively transmitted, and Anderson (4) recommended roguing as a control measure. By 1886 Porter had reported the occurrence of a virus disease of potato in Minnesota. Then in 1905 Orton recognized potato leafroll in Europe, and in 1911 described mosaic as a separate disease. On his return to the United States, he found these diseases prevalent in this country (63). In 1913 Quanjer reported the occurrence of phloem necrosis associated with leafroll, and that same year Orton further divided potato virus diseases into leafroll, mosaic, and streak (63). The following year he suggested certification of seed as a valuable control measure (64). His field observations stimulated a great deal of work in the next 25 years with potato viruses.

The infectious nature of leafroll was first recognized by Quanjer, Lek, and Botjes in 1916 (74). In 1915

Worthley (112), working in Bermuda, had proved that potato mosaic was tuber borne from one generation to the next. Schultz, in 1917, found mosaic could be transmitted by grafting.

The first reported work in Oregon with potato virus diseases is that of McKay and Dykstra (52). In the course of their investigations they recognized the following diseases: mild mosaic, interveinal mosaic, rugose mosaic, crinkle mosaic, leaf-rolling mosaic, leaf roll, spindle tuber, calico, giant hill, and witches' broom. They experimented with various methods of transmission, described the symptoms of each disease, found some of their insect vectors, and suggested control measures for the farmer to use. This stands as a fine beginning for work of this type in the state.

In 1933 Dykstra published the results of his work on weeds as carriers of leafroll and rugose mosaic (18). This is still valuable, being the only publication of its type.

In 1933 McKay, Dykstra, and others issued "Virus and Virus-like Diseases of the Potato in the Northwest and Their Control" (53). This is an excellent summary of the characteristics of a number of diseases, and has explicit suggestions for their control. The control methods advocated are still probably the most valuable methods available today. They discussed mild mosaic, crinkle mosaic, rugose mosaic, leaf-rolling mosaic, other mosaics, calico, leafroll, witches' broom, psyllid yellows, spindle tuber, and giant hill.

Then in 1938 McKay and Dykstra published "Potato Diseases in Oregon and Their Control" (54). This contains a summary of the symptoms of mild mosaic, rugose mosaic, leafroll, spindle tuber, witches' broom, calico, and net necrosis. There is a brief summary on the means of transmission and suggestions for the control of these various diseases.

Insect Transmission. The first record of insects in relation to potato virus diseases was that of Smee of England, who wrote in 1846 of the abundance of *Aphis vastator* on potatoes affected with "leaf curl" (91). Schultz, Hildebrand, and Hawkins (84) showed in 1919 that the two aphids *Macrosiphum solanifolii* (Ashm.) and *Myzus persicae* (Sulz.) could transmit mild mosaic from diseased to healthy plants.

The transmission of leafroll by aphids was first reported by Oortwijn Botjes in 1920 (61), and independently by Schultz and Folsom in 1921 (85). In 1924 Murphy (58) successfully transferred leafroll from diseased to healthy potatoes by allowing the green peach aphid to feed first on diseased, and then on healthy, sprouts.

Murphy and McKay (59) presented evidence that *Calocoris norvegicus* (Gmelin)(Miridae) and *Typhlocyba ulmi* (L)(Cicadellidae) could also transmit leafroll. Elze (21), working with leafroll, mosaic, crinkle, stipple streak, interveinal mosaic, aucuba mosaic, and spindling sprout, obtained infections of healthy plants using the aphids *Myzus persicae*, *M. solani* (Kalt.), *Aphis rhamni* (Boy.), *Aphis fabae* Scop. (*rumicis* L.), a leafhopper *Eupteryz auratus* (L.), a plant bug, *Lygus pratensis* (L.), a beetle, *Psylliodes affinis* Payk., and a cutworm, *Mamestra brassicae* (L.). Elze claimed that each of these species was capable of transmitting one or more of these aforementioned diseases, except aucuba mosaic. Leafroll was the easiest to transmit, although infections were more difficult to accomplish with insects other than aphids. Of the aphids used, *Myzus persicae* always possessed the greatest infecting power. Later, Elze withdrew his claims of transmission by insects other than aphids, except for *Psylliodes affinis*.

Smith (95) secured uniformly negative results with all of the above insects, except the aphids, and a leafhopper, *Empoasca viridula* was also a negative carrier. Of the aphids tested, he was unable to get transmission using *Macrosiphum gei* (Koch), *Aphis rhamni*, or *Aphis* gossypii Glover.

Cleveland (11) reported that Myzus persicae and the potato leafhopper, Empoasca fabae (Harris), are the principal carriers of leafroll in Indiana, and he concluded that they were equally responsible for its spread in the field. He found that the potato flea beetle, Epitrix cucumeris Harris, Thrips tabaci Lind., blister beetles, Colorado potato beetles, grasshoppers, and white flies did not transmit the disease.

Schultz and Folsom (86) obtained mild mosaic transmission in experiments with Macrosiphum solanifolii and Aphis abbreviata Patch, but with flea beetles and Colorado potato beetles their results were negative.

The first work in Oregon concerned with the determination of the insect vectors of potato viruses was that of McKay and Dykstra. In the course of their studies they found (52) the following to be true: leafroll was consistently transmitted by Myzus persicae, M. pelargonii, and M. circumflexus, but only occasionally by Illinoia solanifolii. M. persicae and M. circumflexus occasionally transmitted rugose mosaic, while M. pelargonii and Illinoia solanifolii did not transmit these diseases. None of the four species transmitted mild mosaic. Crinkle mosaic was occasionally transmitted by M. persicae and M. circumflexus, but never by the other two species. Leaf-rolling mosaic was occasionally transmitted by I. solanifolii, M. persicae, and M. pelargonii. All these tests were carried out under field cages which enclosed one diseased and one healthy plant. The strange thing here involves the species designated Myzus pelargonii, presumably determined by Dr. P. W. Mason of the United States National Museum, an eminent aphid specialist. This aphid is rare in Oregon, only one specimen being found on the records of the Entomology Department. No record of its occurrence on potatoes has ever been found, nor further reference to its ability as a vector.

In 1938 Dykstra and Whitaker wrote an excellent paper on their work with aphids in the transmission of various potato viruses (19). Using Myzus persicae, M. circumflexus, M. solani, and Macrosiphum solanifolii, their results were as follows: all four species can serve as vectors of leafroll, rugose mosaic, crinkle mosaic, and mild mosaic. Macrosiphum solanifolii was not as effective a vector of leafroll as the other three species, and the authors conclude that this is because it feeds in the phloem only part of the time, whereas the three Myzus species fed consistently in the phloem. All of the aphids transmitted the mosaic group of viruses only intermittently, being the best vectors when they had access to both diseased and healthy plants. In addition to their work with aphids, they used insects commonly found on potato in attempts to transmit leafroll, rugose mosaic, crinkle mosaic, and mild mosaic. These were _Lygus pratensis_ L., _Epitrix subcrinata_ Lec., _Empoasca filamenta_ DeL., _Philaenus leucophthalmus_ (L.), and _Nabis alternatus_ (_annulatus_ Reut.?). All these failed to transmit any of the viruses used over a three year period. This is easy to understand for the _Nabis_ species, for members of this family are not plant feeders, but prey on other insects.

In regard to the control of the aphids known to carry potato viruses in the state, the Agricultural Experiment Station engaged Mr. J. Schuh, consulting entomologist, to initiate experiments in the Gresham and Klamath Falls areas in 1945 and 1946. In 1947 he assisted in the program in both areas, along with Mr. P. W. Mowry, and in 1948 Mr. Schuh directly supervised the work of a field aide at Klamath Falls.

DEFINITION OF TERMS USED

In the following pages a number of terms peculiar to studies of this type are used. The following definitions are presented for the reader's information.

Acquisition Threshold. The minimum time necessary for a vector to feed upon a disease source in order to obtain an infective charge of virus.

Actively Infective. A condition of an infective vector during which it will successfully inoculate a healthy susceptible host, if given a suitable test feeding upon it.

Current Season. Refers to potato virus disease symptoms which show during the season in which infection occurred.

Infective. The term commonly used to describe the condition of a vector which has virus present in its body and is potentially capable of transmitting that virus.

Infection Feeding. The time that a previously non-infective vector is fed on a virus source.

Inoculation Threshold. The minimum time necessary for a vector to feed upon a healthy plant in order to successfully inoculate that plant with a given virus. The term is equivalent to the "threshold" period of Storey.

Latent Period. The term in common usage which denotes the time that must elapse before a vector can be demonstrated to be infective, after surpassing the acquisition threshold. Also commonly referred to as the "waiting" or "incubation" period.

Passively Infective. A condition of infectivity when a vector will not inoculate a healthy susceptible host, even though given an adequate test feeding period upon that host.

Pre-penetration Time. A variable period of time elapsing between the time an insect is placed upon a plant and the time penetration begins. This corresponds to the "penetration time" of Watson.

Retention Period. The period of time, following an infection feeding, during which a vector is capable of producing infections if fed upon a succession of susceptible healthy plants.

Recipient Plant. A healthy plant, to which the virus is transferred by the insect vector.

Source Plant. A plant in which the virus is present and upon which vectors are fed, in order for them to become infective.

Test Feeding. The time that a vector is fed upon a healthy recipient host, or test plant.

Transmission Threshold. The entire minimum time required for an insect to pick up and transfer a non-persistent virus to a healthy host plant.

Tuber Perpetuated. Refers to a potato virus disease appearing soon after the plant emerges from the ground. Infection occurred the previous season.

Viruliferous. A term coined by Carsner, to designate an insect which is carrying a virus (10).

THE VIRUSES ATTACKING POTATOES IN OREGON

It may be said without fear of controversy that potato viruses are the limiting factor in potato production in this state. Since the largest acreage is devoted to the Netted Gem variety, this may be considered first. This variety is grown primarily east of the Cascade mountains, in Klamath county, and in the Central Oregon district, composed of Crook, Deschutes, and Jefferson counties. Leafroll, the most serious virus of all varieties, since it reduces the yield up to 75 per cent (75), causes an internal browning in Netted Gems, known as "net necrosis." This condition causes the rejection of commercial potatoes for U. S. No. 1 grade, and hence is of primary concern to even the commercial grower of this variety. Strangely, leafroll is by far the most prevalent virus in potatoes at Klamath Falls, others being present but seldom of importance. In Central Oregon, on the other hand, rugose mosaic is the most serious disease confronting growers, even though leafroll and other viruses are present. Leafroll appears to be on the increase in this area, but growers are still most conscious of their rugose problem. Both these diseases are easily seen in Netted Gem, so that they may be rogued from the field, and yet they persist as problems.

In the Multnomah county district, where White Rose is almost the only variety, and where no commercial potatoes are grown, mild mosaic is the primary problem. Leafroll does occur, and reduces the yield more than does mild mosaic. Mild mosaic is easily seen in White Rose, and leafroll difficult to detect. Why then, the problems are as they have been stated, is difficult to understand. In each area all diseases are present, yet the one most easily seen is the one causing trouble.

Starting in 1946, a new disease appeared on the scene. The growers mistook it for rhizoctonia or some similar disorder, and many failed to remove diseased plants from the field. As a result, many fields were rejected for certification in all major areas. The plant pathologists of the Experiment Station studied the disease in detail, and after comparing the symptoms with those of many other similar diseases, decided it was new, and published a description of it (57). It was soon a problem of major importance, although it did not spread rapidly in the field, and it was not so prevalent when growers began to watch for it.

A number of other viruses occur in the state, and while not major factors, cause constant concern to the grower, in that he must be able to recognize them and remove them from the field, if his potatoes are to be entered for certification.

All the viruses known to occur on potato in the state, or that are suspected of occurring, are listed in the following pages, along with detailed descriptions of the symptoms caused in potato. The methods of transmission of each are described.

An intimate knowledge of plant viruses is necessary in a study concerned with insect vectors. It is necessary that the worker be familiar with the virus under consideration in its common hosts, and that he be able to differentiate it from others causing similar symptoms in the host. It is because of this that such a detailed treatment of the viruses is included here.

THE VIRUSES AND THE SYMPTOMS CAUSED (111)

Leafroll Virus

(1) Technical Names: *Solanum* Virus 14 K. M. Smith, 1937

Corium solani Holmes, 1939

(2) Name of Disease: Leafroll

(3) Symptoms (111): Upward, longitudinal rolling of leaflets, evident first in the lower leaves of plants developing from tubers infected the previous season and then progressing upward until all leaves are affected (Fig. 1); in initially healthy plants which acquire infection during the season, rolling is first noted in the

Fig. 1. Symptoms of Leafroll Virus in Potato, Variety Burbank.

Top, Current Season Infection
Lower, Tuber Perpetuated Symptoms

upper leaves and then may progress downward until all leaves are involved. A pronounced change in leaf texture occurs, which is readily evident to the touch, owing to thickening and loss of succulence. Starch translocation from the leaves is notably reduced. General dwarfing, diffuse chlorosis, reddish or purplish discolorations of leaves, abbreviation of stolons and reduction in number and size of tubers also ensue. Necrosis of the primary phloem, most evident in the lower stem, is a reliable diagnostic feature. In some varieties, extensive phloem necrosis (net necrosis) develops in the tubers, but disappears in future tuber generations; affected tissue is said to be fluorescent under ultra violet light, but experiments in Oregon show this to be unreliable. Affected tubers sprout tardily and weakly; those showing net necrosis usually produce spindling sprouts (85). Plants tend to remain alive and green after normal plants have matured.

(4) Remarks: Dykstra (18) declares that tomato, _Datura_, _Solanum_ _dulcamara_, and _S_. _villosum_ are important carriers of this virus in Oregon.

Mild Mosaic Virus

(1) Technical Names: _Solanum_ Virus 3 K. M. Smith, 1937

Marmor _solani_ Holmes, 1939

(2) Name of Disease: Mild Mosaic, U. S.; Common Mosaic, Holland; Veinal Mosaic, England

(3) Symptoms: In tolerant potato varieties, as Green Mountain, this virus, freed of latent virus, causes a faint mottle involving both veinal and interveinal tissues. Together with the latent virus, it induces a strong mottle and more or less ruffling and crinkling, depending on the strains of both viruses that are involved. The most common manifestation of this virus complex in American commercial varieties is mild mosaic; the less prevalent crinkle mosaic is similar but leaf distortion is more marked. The strains of veinal mosaic virus occurring in European crinkle cause nearly identical symptoms. Symptom expression declines at high temperatures. In intolerant varieties, as British Queen, Bliss Triumph, and Up-To-Date, it causes a severe, often fatal, top necrosis in the aerial parts, together with superficial and interveinal necrosis of the tubers. Together with severe mosaic (Y) virus, it causes a pronounced yellow mosaic in certain potato varieties. It also accentuates the foliage symptoms of aucuba mosaic and tuber blotch viruses, and facilitates their transmission by aphids (12). No intracellular bodies have been found in potato or tobacco plants infected solely by this virus. Figure 2 shows the tuber perpetuated symptoms in the variety Burbank.

Fig. 2. Symptoms of Mild Mosaic Virus
in Potato, Variety Burbank.

Rugose (Severe) Mosaic Virus

(1) Technical Names: *Solanum* Virus 2 K. M. Smith, 1937
Marmor cucumeris var. *upsilon* Holmes, 1939
Murialba venatenia Valleau, 1940

(2) Names of Disease: Severe mosaic, rugose mosaic, stipple streak, leaf drop streak. These names are not synonymous, but include strain differences of the virus and varietal differences in the host.

(3) Symptoms: In different potato varieties the symptoms vary from complete masking (as the Dutch variety Zeeland Blue), through diffuse mottling with or without leaf distortion, to more or less severe veinal or sometimes interveinal necrosis. In plants grown from infected tubers the symptoms are accentuated, with marked leaf distortion, veinal necrosis, brittleness of stems and petioles; or by leaf and stem necrosis together, with partial abscission of basal leaves, which often remain attached by their vascular bundles. The typical syndrome of rugose mosaic usually results from the additional presence of latent (X) virus, or may be due to Y alone. The progression of necrotic symptoms is characteristically upward, except for the apical leaf necrosis resulting from initial

infection. Viruses of this group may occur also in combination with veinal mosaic (A) virus, with intensification of the symptoms of each, since there is no reciprocal protection. Symptom expression does not decline at high temperatures.

A few small intracellular bodies are produced in potato and tobacco plants infected with Y virus and related viruses; they are readily distinguishable from the characteristic inclusion bodies associated with X virus infection of various hosts.

Witches' Broom Virus

(1) Technical Names: *Solanum* Virus 15, K. M. Smith, 1937

Chlorogenus solani Holmes, 1939

Chlorophthora solani (Holmes) McKinney, 1944

(2) Name of Disease: Witches' Broom

(3) Symptoms: In primary (current season) infection, apical leaves become slightly rolled, upright, light green with reddish or yellowish margins; proliferation of axial buds, tendency to bloom and set fruit, production of aerial tubers and numerous small subterranean tubers, often in bead-like arrangement, which tend to sprout without a dormant period. Infected tubers produce thin,

branching sprouts (spindling sprout, hair sprout) from all or most of the eyes, giving rise to dwarfed, extremely bushy plants (Fig. 3) that have thin, smooth stems, and small, simple, rounded or heart-shaped leaves. Net necrosis occurs in tubers of some varieties. The marginal flavescence (chlorosis), with light green or yellowish margins of the leaves is prominent in our varieties.

Calico Virus

(1) Technical Names: *Solanum* Virus 10 K. M. Smith, 1937

Marmor medicaginis Holmes var. *solani* Black and Price, 1940

(2) Name of Disease: Potato Calico

(3) Symptoms: Large, irregular, yellow to yellowish white or gray spots and blotches on the leaves, covering veins and interveinal areas; because of chlorophyll deficiency plants infected when young are considerably reduced in size.

Green Dwarf Virus

(1) Technical Name: None

(2) Name of Disease: Green Dwarf

(3) Symptoms: Late emergence, extreme dwarfing of the plant (plants may be but six inches high when mature,

Fig. 3. Symptoms of Witches' Broom Virus
in Potato, Variety Burbank.

while adjacent healthy plants are two feet tall). Basal leaves normal, but close together in a basal rosette of four or five leaves. Remaining terminal growth dwarfed and malformed; the growing point pinched together into a cluster of small leaves. Leaflets on the young leaves cup upward, forming small boat-like structures. The plants are normal green, or sometimes even darker green than normal. The tubers are small, but exhibit no other symptoms. Often only one or two eyes of a tuber will be infected and the rest will be healthy. Or one branch of a plant may show distinct symptoms and the remainder of the plant remains normal (27).

Late Breaking Virus

(1) Technical Name: None

(2) Name of Disease: Late Breaking Virus

(3) Symptoms: Plants grow normally until late in the season and then they become off color, the stems stand erect, aerial tubers develop in nearly every leaf axil, and the leaves become yellowed and rolled. Plants affected with acute symptoms remain small, yellowed, and have thickened nodes and aerial tubers. It is tuber perpetuated for at least three generations; normal appearing plants from affected tubers develop symptoms late in the season as plants reach full size; tubers are reduced in

size, normal in number, and without internal symptoms; tubers from an infected hill may produce normal plants, weak plants, and plants with severe or mild symptoms; a single tuber cut into several pieces may produce plants which also show this variation symptom in development (57). Figure 4 shows the typical symptom picture in the greenhouse.

Latent (Mottle) Virus

(1) Technical Names: *Solanum* Virus 1 K. M. Smith, 1937

Marmor dubium vars. *vulgare*, *annulus*, *obscurum*, and *flavum* Holmes, 1939

(These varieties refer respectively to the mottle, ring-spot, masked, and yellow mottle strains; there is no formally published binomial applicable to the virus as a whole.)

(2) Names of Disease: Mottle (simple or mild mosaic), Denmark, England, Germany, Sweden; mosaic, Holland; latent mosaic, U. S.; in Europe these names usually refer to viruses caused by mottle virus alone; in the United States these viruses, when present alone, are nearly or completely masked in most commercial varieties.

(3) Symptoms: In different potato varieties,

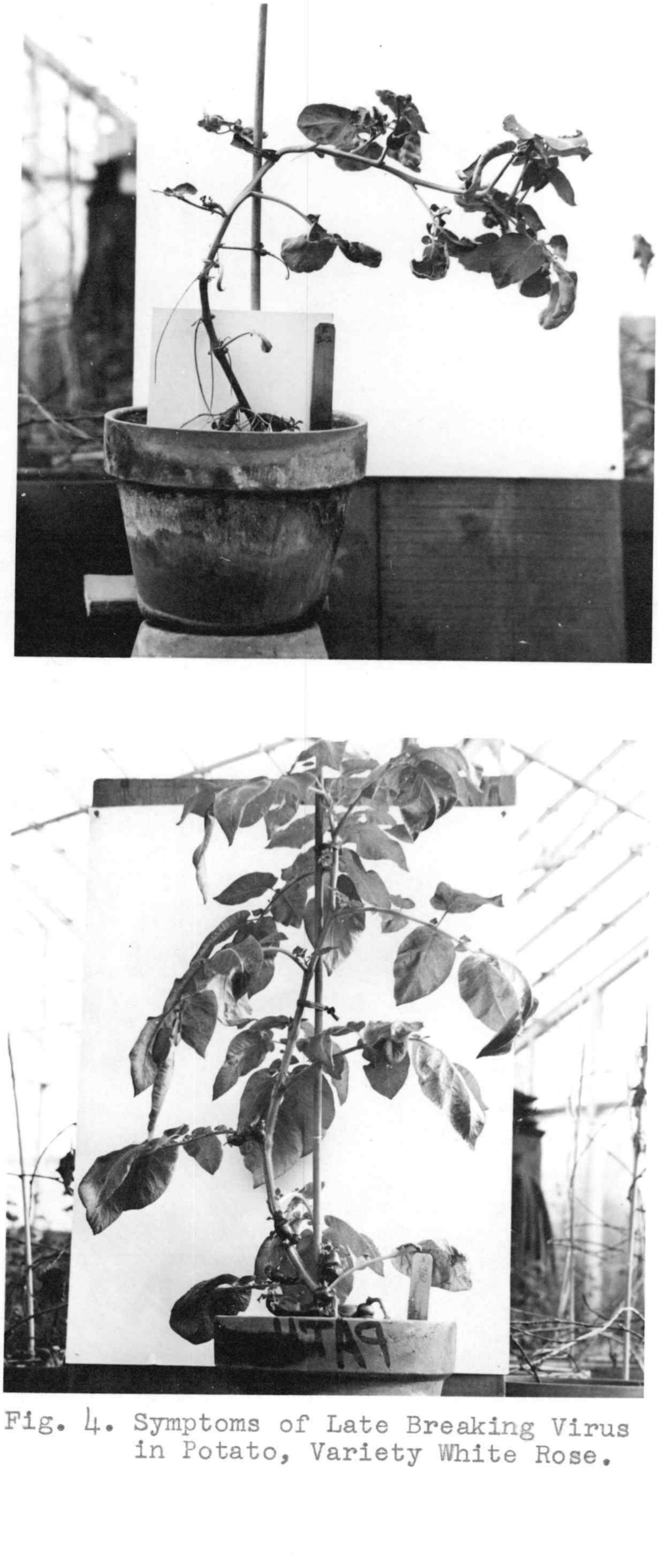


Fig. 4. Symptoms of Late Breaking Virus
in Potato, Variety White Rose.

depending also on the strain of virus, symptom expression may be practically nil or consist only of a faint, transient, interveinal mottle, which is systemic and detectable only under optimum environmental conditions; or there may be nonsystemic necrotic spotting of the foliage, or severe top necrosis which is often systemic, involving the eyes of tubers as well as the shoots. For practical purposes varieties showing more or less masked mottling may be classed as tolerant carriers, but those reacting with top necrosis are field immune, since infected plants are self eliminating (Arran Chief, Epicure, King Edward).

Intracellular bodies of the granular, vacuolate type are usually formed in association with all strains, especially those that induce a bright yellow mosaic in tobacco, and occur in potato, tobacco, tomato, and *Datura*. They are found mostly in the palisade and spongy parenchyma, and can be removed from the cells and even sectioned, without dissolution, by micro-manipulation.

Spindle Tuber Virus

(1) Technical Names: *Solanum* Virus 12 K. M. Smith, 1937

Acrogenus solani var. *vulgaris* Holmes, 1939

(2) Name of Disease: Spindle Tuber

(3) Symptoms: In general, affected plants are more erect, narrow, and tapering than normal plants, and appear to lack vigor; the stems are stiff and reduced in diameter, especially in the internodes; the leaves are dwarfed, erect, and darker green than normal; the petioles are slender and sometimes brittle; tubers elongated, tend to be pointed at both ends, especially the bud end; often irregular, eyes conspicuous, "staring." Round ended varieties show tuber elongation most conspicuously; in varieties with colored tubers, the color is duller, paler, and tends to be blotchy; russet tubered varieties tend to become smooth. These symptoms are accentuated by high soil moisture and temperature.

<u>Aster Yellows Virus</u>

(a) Eastern or New York Strain

(1) Technical Names: <u>Callistephus</u> Virus 1 K. M. Smith, 1937
<u>Chlorogenus</u> <u>callistephi</u> var. <u>vulgaris</u> Holmes, 1939

(2) Name of Disease: Purple Top Wilt

(3) Symptoms: Dwarfing of apical parts of plant, upward folding and narrowing of terminal leaflets, loss of green color and replacement by a purplish tinge in leaf margins (yellow in Green Mountain), progressive extension

of color changes to stems, with swelling of nodes and foreshortening of internodes; wilting first of apical parts, then becoming general; proliferation of axillary buds and development of shoots from tips of stolons; production of aerial tubers; roots reduced in size and length, becoming brittle. A general brownish discoloration occurs in the vascular system of roots, stolons, stems, and tubers, often followed by decay; net necrosis in stolon end of tubers; affected tubers produce spindling (hair) sprouts.

Potato infection is natural in many varieties, though differences in susceptibility have been noted; in some localities Rural New Yorker, Russet Rural, and Green Mountain are reported very susceptible; in others, Katahdin and Bliss Triumph; Sebago shows less tuber symptoms. All varieties tested have become infected.

In Maine, two types of disease having purple top symptoms occur, one of which does not affect the seed quality of the tubers, which grow normally, and the other materially affecting them. The effect is, however, a general weakening rather than a perpetuation of the disease. In New York purple top wilt is definitely associated with the eastern strain of aster yellows virus (113). Although doubt has been expressed at times that the disease first described as "blue stem" in West

Virginia and Pennsylvania is identical with purple top wilt, this conclusion is accepted (48) by Leach and Bishop, who find that potatoes become infected from viruliferous leafhoppers that have overwintered. The incubation period of the virus is no longer in potatoes than in asters. Differences in symptom expression are related to the stage of growth when infection occurs. In Minnesota and North Dakota anomalies have been noticed in the distribution of aster yellows virus in weeds and crops other than potatoes in relation to the occurrence of purple top wilt in potato, whence it is inferred that all instances classed as the latter disease may not be caused by this virus.

(b) California Strain

(1) Technical Names: *Callistephus* Virus 1A K. M. Smith, 1937
Chlorogenus callistephi var. *californicus* Holmes, 1939

(2) Name of Disease: California Aster Yellows

(3) Symptoms: Dwarfed, inrolled leaflets, petioles curving downward; leaves and stems brittle, turning yellow and dying prematurely; purple aerial tubers; slender purple sprouts produced by tubers from affected plants (89).

Natural infection of potatoes has been found in

California, but only rarely; transmitted experimentally to Bliss Triumph, White Rose, and seedlings.

Leaf-Rolling Mosaic Virus

(1) Technical Name: *Solanum* Virus 11 K. M. Smith, 1937

(2) Name of Disease: Leaf-Rolling Mosaic

(3) Symptoms: Primary symptoms consist of a slight dwarfing, diffuse mottling, wrinkling, slight ruffling and rolling of upper leaves only; secondary symptoms are similar, with the effects becoming general; the leaves remain flaccid.

(4) Remarks: This disease has been described in detail as occurring in Oregon (20), but neither the writer nor the plant pathologists of the Experiment Station have ever noted an instance of the disease in the state. Frequently plants are encountered which are infected with both leafroll and mild mosaic, however.

Curly Top Virus

(1) Technical Names: *Beta* Virus 1 K. M. Smith, 1937
Chlorogenus eutetticola Holmes, 1939
Ruga verrucosans Carsner and Bennett, 1943

(2) Name of Disease: Curly Top of Potato

(3) Symptoms: Apical parts stunted, flavescent; leaflets rolled inward, petioles curved downward; proliferation of axial buds; premature yellowing and reddening and death (88).

METHODS OF TRANSMISSION

Experimental Methods

(1) Leafroll Virus: By stem grafts (readily), and by tuber grafts (with difficulty); not by the inoculation of expressed juice. By true seed, rarely (58).

(2) Mild Mosaic Virus: By juice inoculations with the aid of carborundum, both between potatoes and to or from tobacco. By tuber and stem grafts, readily.

(3) Rugose Mosaic Virus: By juice transfer (leaf rubbing) (38, 53, 87), facilitated by the use of carborundum (94); not transmissible by the needle prick method (97) and therefore separable from the needle transmitted X virus. By stem and tuber grafts (76).

(4) Witches' Broom Virus: By tuber and stem grafts; by dodder, Cuscuta campestris Yuncker; not by juice or through true seed.

(5) Calico Virus: Readily transmitted by sap between various hosts; by tuber grafts in a small proportion of trials.

(6) Green Dwarf Virus: Readily transmitted by stem grafts; not by juice, even when aided with carborundum, nor by tuber core grafts.

(7) Late Breaking Virus: By stem grafts, readily; not by rubbing juice with the aid of carborundum. Tuber core grafts not tried.

(8) Latent Mosaic Virus: Transmitted readily by rubbing expressed juice of diseased plant on tolerant varieties of potato, from potato to other plants, and from other hosts to potato. Transmission to intolerant varieties is usually effected only by grafting, either by stems or tubers. The nearly universal occurrence of this virus in most commercial varieties in the United States is attributed to spread by contact of foliage in the field and of cut tubers used for seed (77). Not by true seed.

(9) Spindle Tuber Virus: Readily transmitted by sap (leaf rubbing, needle punctures, contact with macerated infected tissue, and between freshly cut tubers); by stem and tuber grafts.

(10) Aster Yellows Virus: By stem grafts between potato plants, and by tuber grafts, although not ordinarily tuber perpetuated.

(11) Leaf-Rolling Mosaic Virus: By inoculation of sap between infected and healthy plants (39); by grafting.

(12) Curly Top Virus: Transmission of this virus

between other host plants has been claimed by spreading infected juice over the crown of the plant and then repeatedly pricking the crown with a needle.

Insect Transmission

(1) Leafroll Virus: By the aphids *Macrosiphum solanifolii* (Ashm.) and *Myzus persicae* (Sulz.) (61, 85). Smith found (95, 96) only *Myzus persicae* among several species tested to be an efficient vector of this virus, and postulated the existence of a special relation between the virus and its vector; thus a feeding period of six hours or longer is required for the insect to acquire the virus, and a further period of 48 hours or more must elapse before the virus can be transmitted; thereafter the virus can be transmitted successively to as many as 10 plants without the insect again feeding on a virus source. Though agreeing that *M. persicae* is the principal vector of leafroll, other investigators have reported that different species of aphids possess this capacity, e.g. *Aphis abbreviata* Patch (21, 28); more effectively if the infection feeding period follows a period of non-feeding of four hours (50); *Aphis rumicis* L. (21); *Myzus circumflexus* (Buckt.) (19,95); *M. ornatus* Laing (49); *M. solani* (Kalt.) (19, 96).

Besides by aphids, leafroll transmission has been claimed for the following insects: Calocoris norvegicus (Gmelin), Miridae, and Typhlocyba ulmi (L.), Cicadellidae (9); Eupteryx auratus (L.), Cicadellidae, Lygus pratensis (L.), Miridae, Psylliodes affinis (Payk.), Chrysomelidae, and the larvae of Tipula paludosa, Tipulidae, and Mamestra (Barathra) brassicae (L.), Phalaenidae (21) (in subsequent reports transmission by Psylliodes was still claimed, but the claims for Eupteryx, Lygus, and Mamestra were dropped.)

Cleveland, in 1931 (11), claimed Empoasca fabae (Harris) was one of the principal carriers of the disease in Indiana.

Extensive tests by other investigators failed to demonstrate any vector capacity in insects other than aphids (19, 86, 95). It has been shown that certain leaf-hoppers may induce a leaf rolling symptom in potato foliage that is not tuber perpetuated.

In Oregon in 1929 it was reported that Myzus pelargonii, M. circumflexus, M. persicae, and Macrosiphum gei all transmitted leafroll, but inefficiently. In 1933-34 it was found that M. persicae, M. solani, and Macrosiphum gei all carried leafroll.

(2) Mild Mosaic Virus: By the aphids Aphis abbreviata, Macrosiphum solanifolii, Myzus circumflexus, M. persicae, M. solani (19, 86).

In Oregon in 1929 this virus was not transmitted by any of these species: Macrosiphum solanifolii, Myzus persicae, nor M. circumflexus. However, in 1933-34 M. persicae, M. solani, M. circumflexus and Macrosiphum solanifolii all did.

(3) Rugose Mosaic Virus: By the aphids Aphis abbreviata, Macrosiphum solanifolii, Myzus circumflexus, M. ornatus, and M. persicae, especially the latter (95, 109).

Belongs to the non-persistent group of viruses which become inactivated during insect feeding; the efficiency of the aphid as a vector is increased by a preliminary period of fasting (109).

In Oregon in 1929, M. persicae and M. circumflexus transmitted this virus, but Macrosiphum solanifolii did not. In 1933-34 the first and last named species did, and M. solani was also found to be a vector.

(4) Witches' Broom Virus: Insect Vector, if any, unknown.

(5) Calico Virus: By the potato aphid, Macrosiphum solanifolii (71). Not by Myzus persicae.

(6) Green Dwarf Virus: Insect vector, if any, unknown. Not by Myzus persicae nor Macrosiphum gei.

(7) Late Breaking Virus: Not by Myzus persicae, Macrosiphum gei, nor Aleyrodes spiraeoides Q. By Macrosteles divisus?

(8) Latent Mosaic Virus: Not transmitted by any of

the potato infesting aphids, not by any other insect, so far as is known, although Smith has suggested flower infesting thrips (99), but this has been dismissed by Cockerham (13) as being improbable. Smith presents a case, however, in that certain English varieties which seldom flower are comparatively free of the virus (King Edward, Great Scot, Epicure), whereas free-flowering varieties (Majestic, Up-To-Date, Golden Wonder) are almost universally infected.

(9) Spindle Tuber Virus: By many unrellated insects, including aphids, _Myzus persicae_, _Macrosiphum solanifolii_, flea beetles, _Epitrix cucumeris_ and _Systena taeniata_ (Say); leaf beetles, _Disonycha triangularis_ (Say) and larvae of _Leptinotarsa decemlineata_ (Say); tarnished plant bug, _Lygus oblineatus_ (Say); grasshoppers, _Melanoplus_ spp.

(10) Aster Yellows Virus--Eastern Strain: By the six-spotted, or aster, leafhopper, _Macrosteles divisus_ (Uhler). The vector is ordinarily unable to transmit the virus from potato plants, but transmission from potato to _Nicotiana rustica_ can be effected by grafting, and thence to other hosts by the vector.

--California Strain: By all of the following leafhoppers (90): _Macrosteles divisus_ (Uhler), _Colladonus montanus_ (V.D.), _Colladonus geminatus_

(V.D.), Acinopterus angulatus Lawson, Gyponana hasta DeL., Texananus Lathropi Baker, Texananus latipex DeL., Idiodonus kirkaldyi (Ball), Texananus denticulus O. & L., Cloanthus irroratus (V.D.), Phlepsius apertinus O. & L., Eusceles maculipennis DeL., Texananus spatulatus (V.D.), T. pergradus DeL., T. oregonus Ball. From potato to other plants only by the long-winged form of Macrosteles divisus (45).

(11) Leaf-Rolling Mosaic Virus: By the aphids Macrosiphum solanifolii, Myzus pelargonii, and M. persicae (52).

(12) Curly Top Virus: Only by means of the sugar beet leafhopper, Eutettix tenellus (Baker).

Field Methods of Spread

The only method of importance by which these viruses spread in the field is by the assistance of their insect vectors. Latent virus apparently can be spread from plant to plant, merely by the foliage of one touching the other (77), but all the remaining ones require a vector. Of course, this does not eliminate cutting of seed pieces, in which operation one diseased tuber may become four or more seed pieces to produce more diseased plants. The potatoes in a field are the source of a major part of the virus which spreads to healthy plants in that particular field. It has been found in Maine (7) that only one out of a thousand winged peach aphids flying into potato fields is already infected with leafroll. In the case of mild mosaic it is even more improbable that aphids flying into fields bring the virus with them, since this is a non-persistent virus, and the aphids lose infectivity soon after feeding on a diseased plant. Within a period of two to five minutes after the infection feeding, the ability of aphids to transmit mild mosaic virus to a healthy plant is lost.

THE INSECT VECTORS OF POTATO VIRUSES IN OREGON

SUSPECTED AND IMPLICATED INSECTS

By 1946, many growers had decided that aphids were not the only agents of spread of potato viruses in the state. Jones (40) also was of the opinion that insects other than aphids were vectors in the state of Washington. An examination of the literature reveals that there is considerable difference of opinion as to which insects are able to carry potato viruses (11, 21). Hence, at the onset of this study, it was necessary to collect all species of insects common on potato which might serve as carriers of the viruses from plant to plant. It appeared that the vectors must be rapid moving insects and that they must occur in large numbers on potato, particularly early in the season. The experiments with all these insects are summarized in Section IV.

Potato flea beetles were eliminated as suspects, primarily because DDT in any form is so effective against them, and because no claim had ever been made for their effectiveness in the past. Viruses spread all over a field, and generally flea beetles are found in small portions only. *Lygus* bugs filled all requirements, and were included as possibilities. DDT does kill *Lygus* readily, and they are common on potato only late in the season, unless alfalfa is cut near potato earlier. Their saliva kills the cells of potato stems, making it unlikely that a virus could survive in the resultant dead cells. But since they are deep feeders and do move about a great deal, they were possibilities. Empoasca filamenta DeL., a small, delicate, green leafhopper, is common on potato all over the state, and included in the experiments. This insect, like Lygus bugs, does some damage to potato, moves rapidly, feeds deeply in plant tissue, and occurs all over the fields. DDT is very effective against these leafhoppers, however, so that the possibility of their being important was questionable. Macrosteles divisus (Uhler), the aster leafhopper, is found on potato all over the state, sometimes in large numbers. It was included as a possible vector of leafroll and other common viruses, and was suspected of carrying late breaking virus. In 1946, for the first time, whiteflies (Aleyrodes spiraeoides Q.) appeared on potato in large numbers and still occur each season, particularly at Redmond. These were likely suspects as vectors of the common viruses, and particularly as vectors of the late breaking virus which came to the attention of all that year. Experiments with the collections here, and those of Klostermeyer at Prosser, Washington (44), proved these insects to be non-vectors of all the viruses with which they were tried.

Four years intensive study has yielded only negative results with the species of insects named. It is still possible that Macrosteles is the vector of some of the viruses for which the vector is unknown, but no new vector was found for any of the common viruses, while the known species consistently transferred them. Then other avenues of investigation were opened to explain why viruses were spreading in the field, when DDT was giving good entomological control of the aphid vectors. Small plot trials, summarized later, showed that DDT required 48 to 96 hours to kill the green peach aphid. In rearing experiments it was noted that apterous peach aphids crawled as much as 20 feet overnight, even when plenty of food was available. Observations in the control plots showed that the peach aphid, when flying into fields in the spring and early summer, alighted on plants, fed for about one minute, wandered about the plant for about another minute, and then flew on to another plant 10 or 20 feet away. Laboratory tests with insecticides showed that the aphids were impelled to move about a good deal after dusting. Why then search for another vector or vectors, when the green peach aphid alone can be shown to fill all the requirements for a vector of potato viruses. Moreover, when it is known (92) that peach and potato aphids produce normal young up to two or three days following DDT dusting.

The aphid, Myzus persicae, is, without question, the primary vector of potato viruses in this state. The potato aphid Macrosiphum gei is a vector of secondary importance, occurring in small numbers, except in isolated cases such as the great buildup at the Multnomah County Farm in the fall of 1947. The foxglove aphid Myzus solani is taken only occasionally on potato, and is thus not considered of economic importance. The lily aphid, M. circumflexus, while a good vector, is not taken out of doors in any numbers, so is only of academic interest. The buckthorn aphid, thought to occur at Klamath Falls, probably is not found in Oregon yet. The ornate aphid, M. ornatus, a good vector, does occur, but has not yet been taken on potato.

A good many other species of aphids other than those mentioned above have been taken on potato; some species many times. None which have been tested has ever transmitted a potato virus, but they cannot be eliminated as suspects without further work. It seems entirely possible that almost any aphid should be able to carry the virus of mild mosaic, since it is obviously carried somewhat mechanically within the mouthparts. Leafroll, on the other hand, is a persistent virus, and probably has few vector species.

The pea aphid is commonly taken on potato. Occasionally the cabbage aphid is found, and Hyalopterus atriplicis (L.), the species which forms pseudogalls on *Chenopodium*, is often found in number. *Aphis rumicis* has been found but rarely in the field, except that on the variety Teton they abound, and form large colonies.

The following are all the species of aphids taken on potato in Oregon: *Amphorophora arnicae* Glend., *Aphis cardui* L., *Aphis bakeri* Cowan, *A. rumicis* L., *Brevicoryne brassicae* (L.), *Hyalopterus atriplicis* (L.), *Macrosiphum gei* (Koch), *M. pisi* (Kalt.), *Mindarus abietinus* Koch, *Myzocallis annulatus* (Hartig), *Myzus hieracii* (Kalt.), *M. persicae* (Sulz.), *M. solani* (Kalt.), *Rhopalosiphum prunifoliae* (Fitch), and *Rhopalosiphoninus latysiphon* (Davidson).

THE KNOWN VECTORS

One of the most confusing aspects of the great volume which has been written about the aphids concerned here is the different terminology attached to the different species. It is impossible to be certain which species have been used in many experiments, and it is problematical whether several workers are referring to the same species. An attempt has been made, therefore, to name the species used here correctly. Original and later descriptions have been consulted; and the best aphid specialists have been asked for their opinions. The types of many of the species are lost, but specimens from several type localities and hosts have been available for examination, and have been compared with specimens of our Oregon species in some detail. It is felt that the following list of synonyms for each species is reasonably complete, that the names used are correct, and that they may be separated from related species with the aid of the information here.

Characters for separating the principal species in the field are given in Diagrams 1 and 2 in the Appendix.

These six species of aphids all transmit potato viruses. All but one occur in Oregon.

The Green Peach Aphid, *Myzus persicae* (Sulzer)

Aphis persicae Sulzer, Abgekurzte Geschichte der Insekten, p. 105, 1776.
Aphis dianthi Schrank, Fauna Boica, v. 2, p. 114, 1801.
Aphis vulgaris Kyber, Germar's Mag. En. 1(2):9, 1815.
Aphis furcipes Rafn., Amer. Month. Mag. & Crit. Rev. 1:361, 1817.
Aphis rapae Curtis, Roy. Agr. Soc. Eng. Jour. 3:53, 1842.
Aphis dubia Curtis, supra cit., p. 54, 1842.
Aphis persicae Kaltenbach, Monog. Pflanzenlause, p. 93, 1843.
Aphis vastator Smee, The Potato Plant, p. 63, 1846.
Aphis cynoglossi *Walker*, Zoologist 6:2217, 1848.
Aphis egressa Walker, Zoologist 7:xxxviii, 1849.
Aphis redundans Walker, Zoologist 7:xxxii, 1849.
Aphis aucta Walker, Zoologist 7:xxxiii, 1849.
Rhopalosiphum dianthi (Shrank) Koch, Die Pflan. Aphid., p. 42, 1854.
Aphis instituti Koch, supra cit., p. 58, 1857.
Myzus persicae (Sulz.) Passerini, Gli Afidi, p. 35, 1860.
Aphis persicaecola Boisduval, Essai sur l'Ent. Hort., p. 251, 1867.

Aphis convolvuli Kaltenbach, Monog. Pflanzen., p. 40, 1843. ?
Siphonophora achyrantes Monell, Bul. U.S. Geol. & Geogr. Surv. Ter. 5:18, 1879.
Rhopalosiphum tulipae Thomas, Ill. State Ent. Rep't 8:80, 1879.
Myzus malvae Oestlund, Minn. State Geol. Rep't 14:31, 1886.
Myzus achyrantes (Monell) Oestlund, Minn. Geol. & Nat. Hist. Surv. Bull. 4:74, 1887.
Myzus pergandei Sanderson, Canad. Ent. 33:72, 1901.
Phorodon cynoglossi Williams, Nebr. Univ. Studies 10:89, 1910.
Rhopalosiphum solani Theobald, Entomologist 45:165, 1912.
Myzoides persicae (Sulz.) van der Goot, Tijdschr. Ent. 56:84, 1913.
Rhopalosiphym betae Theobald, Jour. Bd. Agr. 19:918, 1913.
Macrosiphum betae (Theob.) Theobald, Jour. Econ. Biol. 8:153, 1913.
Rhopalosiphum lactucellum Theobald, Bull. Ent. Res. 6:115, 1915.
Macrosiphum achyrantes (Monell) Wilson & Vickerey, Wisc. Acad. Sci., Arts, and Letters Trans. 19:29, 1918.
Rhopalosiphum tuberosellae Theobald, Entomologist 52:161, 1919.
Amphorophora betae (Theobald) Mason, U.S. Nat'l Mus. Proc. 67:12, 1925.
Myzus persicae (Sulz.) Mason, USDA Misc. Pub. 371:15, 1940.

Sulzer's original description of this aphid was brief and incomplete. A translation is reproduced for historical interest:

> "The peach aphid, Aphis persicae. Living on the leaves of the peach tree; belonging to the large type, with honey tubes, of which most are winged. The peach aphid is green, the antennae are longer than the abdomen, the proboscis is short, head, episternum and knees black, the somites have a black dot on the sides, the wings are long, with a brown fleck on the lower margin, the legs are long."

Since this description is so inadequate, the following by Mason (55) is quoted here:

"Summer apterous form. Pale green or greenish yellow, with darker dorsal and subdorsal stripes. Antenna pale, apices of segments darker. Legs pale, tarsi dark. Cornicles pale dusky, tips darker. Cauda concolorous with body or pale dusky.

"Antenna shorter than body, distinctly imbricated; hairs short and inconspicuous; no secondary sensoria. Length of segments: III, 0.31 to 0.48 mm.; IV, 0.21 to 0.35 mm.; V, 0.16 to 0.29 mm.; VI, base 0.10 to 0.15 mm.; unguis 0.35 to 0.49 mm. Antennal tubercles large, conspicuously imbricated, strongly convergent; distance between them 0.04 to 0.08 mm. Head 0.34 to 0.43 mm. across eyes. Beak extending between the middle and posterior coxae. Cornicle 0.34 to 0.51 mm. in length; slender, cylindrical to slightly swollen, not conspicuously imbricated, tip darker, flange distinct; one or two cross imbrications near flange. Cauda 0.15 to 0.21 mm. long, broadly conical, and with two or three hairs on each side.

"Summer alate form and fall migrant. Head and thorax dusky to black, lighter parts of thorax often yellowish or reddish. Antenna dusky. Terminal half of femur dusky. Abdomen with a large, rather square, dusky area with lateral projections; dusky bands in front of patch, often somewhat broken; similar dusky bands caudad of dorsal area; large, black, lateral spots; cornicles and cauda dusky.

"Antenna slightly longer than body; hairs inconspicuous; III, 0.41 to 0.61 mm.; IV, 0.35 to 0.54 mm.; V, 0.26 to 0.36 mm.; VI, base 0.13 to 0.19 mm; unguis 0.40 to 0.71 mm. Antennal tubercles heavily imbricated, strongly convergent; distance between them 0.05 to 0.08 mm. Head 0.38 to 0.43 mm. across eyes. Cornicle 0.33 to 0.41 mm. in length; distinctly swollen, becoming more so as the season advances; distinct cross imbrications near flange. Cauda 0.15 to 0.21 mm. long, broad, somewhat constricted, and with three hairs on each side."

This species forms dense colonies on spinach and cruciferous plants in the greenhouse. It reproduces rapidly there, so that large numbers will soon be found swarming over the plants. It is negatively phototropic, preferring the undersides of mature leaves near the ground. It will occupy the tops of leaves if those are turned over. Pink, green, and yellow forms occur in the same colony. Individuals do not drop off the plant when disturbed, and remain in the same position on the plant for feeding, for long periods.

This species is rather easily separated from aphids on potato by the general shape, the lack of sensoria on antennal segment III, by the short antennae, and by the swollen cornicles of winged individuals.

This aphid carried 55 or more plant viruses. The fact that it is implicated as a vector so often is partly due to its wide host range, and to the fact that it is about the first insect used in all vector studies. However, where it is but one of several vectors of a virus, it is often the most efficient.

Life History. According to Patch (68) this species has the following life history in Maine: The fall generation is rather haphazard in its destination, so that eggs are laid on herbs, trees, and shrubs not known to be spring hosts. Its true primary host is peach, but north of the peach area it carries through on other species of *Prunus*, with the spring colonies on these hosts being small and weak. Also winters on household and greenhouse plants.

From each egg a stem mother is produced, which gives rise, in turn, to a wingless female, which produces winged females or spring migrants. These latter fly to a variety of hosts, including potato, and there produces young which become wingless females. These, in turn, produce numbers of young, some of which are wingless, and some winged. As fall approaches, winged fall migrants appear, which fly to overwintering hosts, and there give birth to young which become wingless egg laying females. Winged males then appear on the summer hosts, fly to the overwintering host, and there mate with the egg laying females, which then deposit eggs and die.

In Colorado (29) eggs are deposited on peach, and occasionally on other stone fruit trees in proximity to a bud or in rough spots on the bark. It is said to over-winter as adults on green vegetation, as well, but this statement is not enlarged upon. The eggs hatch in February or early March.

Taylor (106) observed in Colorado that the fall migrants fly to peach over a period of six weeks. The eggs are laid in October on peach and also on plum, nectarine, prune, cherry, chokecherry, sand cherry, and rarely on pear, apple, crabapple, willow, and rose. From February through early spring the eggs hatch, the stem mothers being dark green, appearing almost black, turning pink, living 23 to 29 days. From 15 to 17 days after the egg hatches young are produced, as many as 26 being produced by one stem mother. The second generation becomes winged in 11 to 16 days after birth.

In England eggs are laid in the axils of buds of peach, nectarine, *Daphne*, and *Brassica* sp., in October and November. Those eggs on *Daphne* hatch in January and the stem mothers are dark green. In May and June the winged spring migrants fly to vegetables. Some are said to winter as apterae on *Brassica* sp.

Burnham (9) reports that he found fall migrants feeding and rearing young on *Prunus pennsylvanica* and *P. virginiana* in early September in New Brunswick.

Huckett (35) found that this species overwintered on Long Island as eggs and nymphs on cruciferous plants.

In Pennsylvania (34) oviparous females and eggs were found on peach and chokecherry, and they are also believed to pass the winter on other *Prunus* species, and perhaps on some weeds. Stem mothers appear in the spring and produce a generation which remains wingless. These, in turn, produce living young, which become winged, and which migrate to other plants in April and May. A number of winged and wingless generations develop, and migrations to other hosts occur at irregular intervals. During October migrants from the summer hosts seek winter hosts and here give birth to young which develop into wingless oviparous females. In late October or early November, winged males develop on the summer hosts, fly to winter host trees, and mate with the oviparous females. Then the females deposit the small, elongate, green eggs in the bud axils and crevices of the bark. Shortly the eggs turn shining black.

According to Lambers (33) eggs are deposited on a number of _Prunus_ species in Holland. The eggs on hosts other than peach hatch, but the young do not survive.

Landis (47) finds that at Yakima, Washington, eggs are laid freely on apricot, and that young appear from these in the spring. In 1945 and 1946 they flew to apricot in mid-September. In 1948 the fall migrants flew to apricot from September to November, and egg laying females were taken as late as November 11. However, he now believes there are winter hosts in that area other than peach, for adults are taken on other hosts three weeks prior to the time eggs on peach have hatched.

Essig (26) has experienced difficulty finding eggs of this species in California. Dickson took sexuales at Riverside, California, on _Prunus pumila_ in December 1940.

In Oregon, the peach aphid is found in March and April on a large number of host plants, primarily the crucifers. As soon as potatoes emerge from the ground they are infested with winged aphids which produce young that continue, generation after generation, on the plants until frost kills the vines in the fall. At this time they disappear from potato. The adults have been taken as late as October 26 on *Brassica campestris*, after all potatoes in the area were dead. Whether this species overwinters on *Prunus* species in this state is not known. Examinations during October, November, December, January, and February in 1946, 1947, 1948, and 1949 have disclosed no eggs resembling those of this species on *Prunus emarginata*. Only two eggs have been found on peach at Corvallis in January and March, but none were found on this host at Klamath Falls or Redmond. No eggs have been found on apricot at Redmond. Only one large egg, probably not of this species, has been found on *Prunus subcordata* at Klamath Falls. Two large eggs, probably not of this species, were found on *Prunus demissa* at Klamath Falls, and 12 of the same type on this host at Redmond. A nymph from one of the Redmond eggs was carefully examined and appeared to be *Aphis pseudoavenae* Patch, but certainly was not *Myzus persicae*. No eggs have been found on willow or elderberry at Klamath Falls or Redmond.

While collecting in northern California in March 1949, many aphids of this species were taken on wild mustard. The possibility that these overwintering apterae fly north in the spring, aided by the wind was discussed with Essig, and he agreed that this is entirely within the realm of possibility. It is known that as many as 2,517 winged adults may be produced by one parent on mustard (105), so that the enormous numbers seen in many localities on this host make such a theory credible. At any rate, the winter habits of the green peach aphid in Oregon are not those classically quoted, and it is likely that they winter as eggs on some host other than those now known, or that they overwinter as adults in the south and fly north each year.

There are other possibilities: adults of this species may winter as apterous individuals on crucifers in the Willamette Valley, where the winters are usually not severe. Winter examinations have not disclosed any such individuals, but perhaps if the plants were brought into the greenhouse in winter the aphids might be found. Or perhaps they winter as eggs in the great peach growing districts of Medford and Salem, and are blown eastward over the Cascades each spring. Spring migrants fly into greenhouses at Corvallis about April first each year, and perhaps examinations of possible hosts in all areas at this time will disclose their winter host.

The question naturally arises: is it the green peach aphid which occurs here? Specimens from numerous hosts in the state have been examined by Mason and Essig with this question in mind, and both agree that our species is *Myzus persicae*. So the search for the over-wintering host or hosts will continue, so that eventually movements in the spring and numbers invading potato fields may be forecast with accuracy.

In North Wales (36) where the climate approaches that of the Willamette Valley, this species overwinters as apterae on *Brassica* and eggs are never deposited.

Essig (25) states, "in the northern limits of its range, it is maintained chiefly by migrations from more favorable and warmer areas where it has persisted and multiplied even during the winter. The migrations and dispersals northward begin early in February, March, April, and May, and may continue until winter approaches. The advance northward is regulated by the increasingly favorable seasonal weather conditions."

If the theory that aphids of this species are blown on the wing from northern California to central Oregon sounds untenable, the observations of Profft on this species in Europe make such a hypothesis sound much more reasonable. He (70) took winged adults of *Myzus persicae* on islands 36 miles from shore in the North Sea, and at Spitzenbergen also, which is hundreds of miles from their normal habitat.

Click (30) recovered one specimen of the green peach aphid in an airplane trap at 3,000 feet.

Davies and Whitehead (15) found that this species migrates only when the maximum temperature is about 65 F, the relative humidity is less than 75 per cent, and the wind velocity less than five miles per hour. These facts help explain why there is practically no spread of potato viruses along the Oregon coast, in the few places where potatoes are grown.

Essig's description of the various forms of this species are of value in identifying them on their various hosts, and are quoted here (25):

> Stem mother, a pink form that hatches from the overwintering egg and gives rise to succeeding generations.
>
> Apterous viviparous female, a pale yellow or green form born from the stem mother and living on the primary host. She gives birth to winged spring migrants.
>
> Spring migrants, greenish, yellowish, or reddish, black-marked winged viviparous females that migrate from the winter primary hosts and settle on spring and summer hosts of all kinds. These may also migrate great distances, especially if carried by favorable winds. The apterous females are usually greenish and have the apical portions of the antennae and legs, and tips of the cornicles dusky or black. The alates are yellowish or greenish, with the head, thorax, most of the antennae, apical portions of the leg segments, bases of the cornicles, lateral spots, and a large median dorsal spot on the abdomen black. The swollen cornicles and black dorsal spot on the abdomen serve to identify this aphid readily.

Summer alate and apterous viviparous females are not unlike the spring migrants. They are produced through many generations on the summer host plants and disperse freely over wide areas. The progeny of these may survive the winters in favorable areas.

Fall migrants, usually darker specimens that migrate to the primary host plants, where they mate (sic) and give rise to alate males and the apterous sexual females. The latter lay the overwintering eggs.

Males, small, very dark, almost wholly black.

Oviparous females, apterous, not greatly different from the apterous viviparous females.

Seasonal History in the Insectary. During the year 1947, the green peach aphid was reared from April 1 until November 1 in an outdoor insectary at the Entomology Farm, Corvallis. Attempts during the previous year had been confined to the greenhouse, where several difficulties presented themselves in rearing, and where data obtained would not give occurrences in the field a true picture. Winged spring migrants were caged on potato plants growing in 10-inch flower pots. The original females were kept until their death, and only their first born young retained. All records, then, are for first born generations, and except for the first females, are all for apterous ovoviviparous females. The series was terminated by the death of the last apterous female on November 1, sexual forms not being produced.

Sixteen generations were produced during the period of the rearing, including the spring migrants as the first generation. The young molt four times, passing through four nymphal instars before attaining the adult stage. The length of each instar, based on the first born of each generation (16 individuals) is as follows:

First instar--Average 1.8 days

Second instar--Average 2.0 days

Third instar--Average 2.5 days

Fourth instar--Average 1.9 days

An average of 1.6 days elapsed after the fourth molt until the time when young are produced. The average time after their own birth until females produced young was 11.2 days.

As other investigators have noted with aphids, the females became mature at an earlier age in summer than they did in the spring or fall. From April 1 to June 15, the average age at maturity was 11.8 days. From June 15 to September 1 it was 9.4 days, and from September 1 to November 1 it was 12.1 days. The reproductive period for 16 apterous females varied from six to 30 days, with an average period of 15.2 days. The number of young produced varied from six to 64, with an average of 29.0.

The maximum number of young produced by one female in one day was six, by an apterous female on July 27. The average production per day for all 16 individuals was 1.8 young.

No winged individuals appeared during the course of this experiment, but the spring migrants produced far fewer young, and lived a shorter time than did the apterae. Winged summer forms collected in the field at Corvallis displayed this same characteristic, but it was difficult to be certain of their ages or the number of young produced previously. For all individuals in the experiment, the average length of life was 26.6 days, with a range of from 10 to 58 days.

The lack of production of winged forms in the cages during the summer is not understood. In the field winged forms are produced at irregular intervals, without apparent cause. Plants need not be mature, nor crowded with individuals for this to occur. In fact, the species in question seems to prefer the older, mature, yellowing leaves at the base of the potato plant. It has been noted in the greenhouse during the winter that more winged individuals appear when colonies are reared on radish and turnip than when they are allowed to feed on sugar beet, and that more winged forms appear as the days grow shorter in the fall.

One surprising observation during the rearing was that apterous individuals, particularly adults, move about a great deal for no apparent reason. Even when an ample supply of food is available, aphids may walk 20 feet during the night and crawl onto other plants. This necessitated caging the individuals inside large, airy cages of transparent plastic, which was not desirable. It does help one understand how potato viruses spread in the field when wingless peach aphids are the only agent available, however.

Distribution. According to Essig (23) this species is found in the following countries: Egypt, Morocco, Nyassaland, Rhodesia, South Africa, Tanganyika, Ceylon, China, India, Japan, Palestine, Transcaucasia, Czechoslovakia, Denmark, France, Germany, Great Britain, Holland, Italy, Jugoslavia, Norway, Russia, Switzerland, Bermuda, Canada, Quatemala, West Indies, Argentina, Uruguay, Australia, East Indies, New Zealand, United States. It is found in every state of the United States, and probably occurs everywhere in the world.

In Oregon, this species has been taken in the following localities: Brooks, Seaside, Corvallis, Goble, Freewater, Klamath Falls, Albany, Portland, Troutdale, Corbett, Gresham, Redmond, Medford, Salem, Forest Grove.

Host Plants. Specimens in the collection of Oregon State College and of the writer have been recorded from the following hosts; this is probably only a partial list: Onion, *Narcissus*, Marigold, Pansy, Beet, Potato, Easter lily, Peach, Prune, Cabbage, *Solanum pseudo-capsicum*, Camellia, Solanum nigrum, S. dulcamara, Brassica campestris, Campe vulgaris, Raphanus sativus, Physalis sp., Datura stramonium, Chenopodium album, Amaranthus retroflexus, Spinach, Mustard, Cucumber.

Fig. 5. (From Essig, 1938)

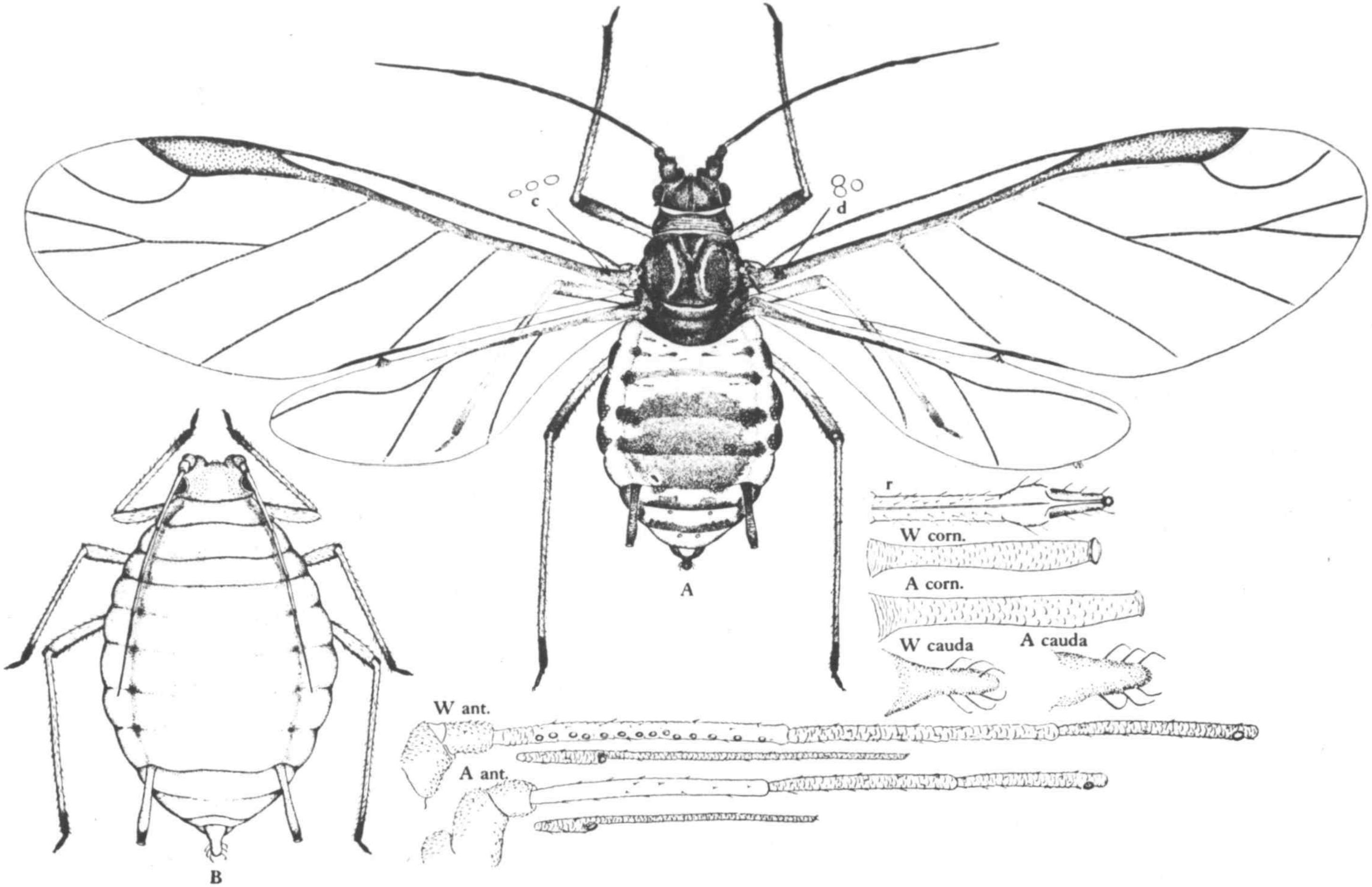


Fig. 11.—The green peach aphid, *Myzus persicae* (Sulzer). *A,* Adult winged female: *c* and *d,* fenestras on fore wings; *r,* rostrum; *W ant.,* antenna; *W corn.,* cornicle; *W cauda,* cauda. *B,* Adult apterous female: *A ant.,* antenna; *A cauda,* cauda. All greatly enlarged.

The Ornate Aphid, _Myzus_ _ornatus_ Laing

Myzus _ornatus_ Laing, Ent. Month. Mag. 68:52, 1932; Essig, Pan-Pac Ent. 14:92, 1938; Mason, USDA Misc. Pub. 371:14, 1940.

The original description of this aphid by Laing (46) is quoted here in its entirety:

"_Apterous viviparous female_. Green, with fuscous markings on the body as follows: A small spot towards the posterior angle, and two very narrow linear streaks on the posterior margin of the prothorax, two linear, transverse, submedian stripes on the posterior margin of mesothorax; metathorax usually with four transverse spots lying adjacent to the posterior border, a submedian linear pair, and a subcircular lateral pair; each of the next three segments with a broken transverse, narrow bar, forming a series of spots, two submedian, broken, transverse bars between the cornicles, and another shorter pair at the base of the cauda. The distal part of segment v of the antennae, the whole of vi, the tarsi, the tips of the cornicles, and the cauda, dark; eyes red, several non-pigmentary, reddish spots on body.

"Cuticle irregularly rugose; setae rare, small, inconspicuous, capitate; antennal tubercles fairly strongly developed, moderately porrected on inner side, setulose on surface; segments iii and vi (including spur) of antennae subequal, and shorter than cornicles, v very slightly longer than vi, the spur of vi twice the length of its base; cornicles rather broad, cylindrical, gradually contracted before the mouth, with two or three apical striae; cauda half the length of the cornicles, with two to three lateral and a pair of subdorsal, subapical, setae. Length 1.15 mm.

"_Alate viviparous female_. Head and thoracic segments black or blackish-brown; antennae pale brown, basal area of third segment yellowish-green; veins of wings fuscous brown; legs pale green, the distal areas of the femora and tibiae, and the whole of the tarsi, fuscous, most of the hind femora dark; abdomen green, with black ornamentation--four precornicular and one smaller postcornicular, lateral spots; two or three basal, narrow, broken, transverse bars; a large squarish dorsal, non-solid patch, with lateral prolongations anteriorly, in front of, and a broken transverse bar behind, cornicles; a dark area in front of cauda; cornicles and cauda brown, the former darker than the latter.

"Antennae with a row of about ten sensoria on segment iii; proportion of segments: (1)5; (2)5; (3)30; (4)21; (5)16; (6)10 & 19; total length 1.22 mm; all segments striated or imbricated; antennal tubercles moderately developed; with a few, short, sharp-pointed setae; rostrum reaching midway between fore and mid coxae; prothorax with a small posterior lateral tubercle; nervures of forewings with a slight tendency toward brown bordering; most of the abdominal black areas hispid; cornicles cylindrical, contracted a little apically (in one specimen swelling out apically), subimbricated, subequal in length to antennal spur; cauda half the length of the cornicle, with a pair of lateral setae, and one sub-apical, dorsal. Average length 1.6 mm.

"Devon: near Dawlish, ii, 1932, on Viola (L. N. Staniland).

* * * * * * * * * * * * * * * * *

"The antennal tubercles are developed in the apterous female as strongly as in some species assigned to the genus Phorodon; in the alate female, however, they are much less porrected, and are more typical of Myzus."

Life History. The fact that this aphid has been taken in two localities in Oregon exhausts our knowledge of it. The life history is not described by Laing or Essig. It has not been taken on potato in Oregon, but is known to be a vector of potato viruses in England and Ireland.

Distribution. England, Scotland, Ireland, Netherlands, Australia, Hawaii, Northern Europe, United States (California, Oregon).

In Oregon this species has been taken at Yachats and Portland.

Host Plants. The only recorded host in this state is *Erechites prenanthoides* DC.

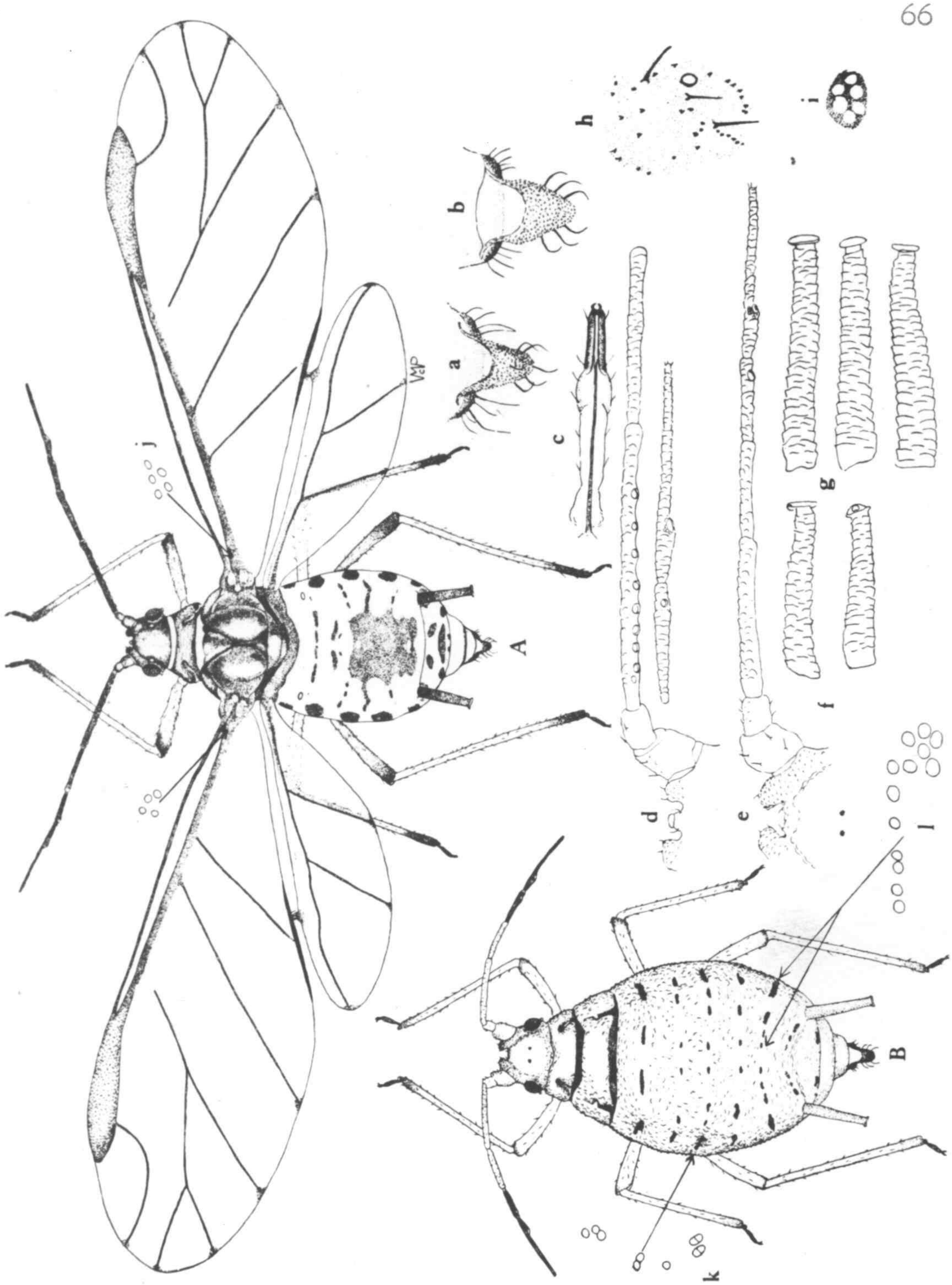


Fig. 6.—The ornate aphid, *Myzus ornatus* Laing: *A*, adult alate female; *a*, cauda; *c*, rostrum; *d*, front of head and antenna; *f*, cornicles; *h*, lateral abdominal dusky area; *i*, group of abdominal gland pores; *j*, fenestras near base of subcostal vein; *B*, adult apterous female; *b*, cauda; *e*, front of head and antenna; *g*, cornicles; *l*, gland pores arranged in dark broken bands on abdomen; *k*, lateral gland pores. (All greatly enlarged.) (*From* Pan-Pacific Entomologist **14**:94, 1938.)

Fig. 6. (From Essig, 1947)

The Potato Aphid, *Macrosiphum gei* (Koch)

Siphonophora gei Koch, Die Pflanzenlause Aphiden, p. 171, 1857.
Siphonophora euphorbiae Thomas, Bull. Ill. State Lab. Nat. Hist. I(2):6, 1878.
Siphonophora euphorbicola Thomas, supra cit., p. 6.
Siphonophora solanifolii Ashmead, Canad. Ent. 14:92, 1882.

The determination that the Oregon potato aphid is identical with the European *gei* was made too late to obtain the original description of this latter species. Because of this, the original description of *solanifolii* (3) is included here:

> "34. *Siphonophora solanifolii* n. sp.
> Wingless female--length 0.12 inch. Elongate ovate and of a pale yellowish green color; beak short, not reaching middle coxae, pale, tip black; antennae 7-jointed, slightly reaching beyond abdomen, situated on large tubercles, pale greenish, joints infuscated, 6th joint shortest, dark, 7th longest, brown; eyes red; honey tubes very long, reaching considerably beyond adbomen, slightly thickened at base, infuscated at tip; style short, conical, greenish; coxae shining and yellowish, feet black.
>
> "Male. Length 0.05 inch. Black. Beak reaching to middle coxae, apical half black; antennae black, hardly reaching to middle of abdomen; honey tubes rather short, black; all coxae black, anterior and middle legs pale greenish, tips of tibiae and feet black, posterior pair, excepting apical half of femora, which is greenish, brown.
>
> "Only two males were secured out of hundreds of apterous individuals, and these are remarkable for being so much smaller than the females.
>
> "Found feeding on the pepper vine, *Solanum jasminoides*."

Reproduces rapidly, and often damages potato by direct attack. These are large aphids, preferring the succulent tissues of the apical portion of the plant. Drop from the plant when disturbed, and "play possum" on the ground. Pink and green forms occur together on the same host. Impossible to differentiate from the pea aphid without a microscopic examination of the tips of the cornicles, which are reticulated in this species.

Attacks many host plants, and is known to carry at least 30 plant viruses.

Life History. According to Patch (68) this species has the following life history in Maine: Overwintering eggs on rose give rise to wingless stem mothers in the spring. These give birth to young which become winged spring migrants, and also to wingless females which, in turn, produce winged spring migrants. These fly from rose to tobacco, tomato, and particularly potato, where they produce several generations of winged and wingless females. In the fall, winged fall migrants are produced, which fly back to rose and give birth to young which become wingless egg laying females. Also produced on potato at this time are winged males, which fly to rose and mate with the sexual females, which then deposit eggs on the rose.

In Virginia (93) there is year round ovoviviparous reproduction and the production of eggs. When eggs are laid, they are rare, and difficult to find. Smith has collected them but once on rambler rose.

About the first of March the aphids leave the winter host plants, over a period of six weeks, and move to a great variety of weed hosts. They are abundant until late July and August, when their natural enemies reduce them to scarcity. The population builds up again in September and then the aphids move to their overwintering hosts. Hard rains and sleet effect a large reduction of the population at this time.

In Oregon, the overwintering host for this species is not known, but is not believed to be rose. If rose is the host on which eggs are deposited, they are rare and hard to find. Three seasons' examinations of wild and cultivated roses in proximity to potatoes has failed to disclose a single aphid egg. Scattered individuals of this species are taken in all potato producing areas, but only once has the population built up to numbers that would be a factor in virus transmission.

Seasonal History in the Insectary. During the spring and summer of 1947, a few individuals of the potato aphid were reared in the outdoor insectary at the Entomology Farm, under the same conditions used for the peach aphid. The original individuals (five apterous ovoviviparous females from potato in the greenhouse) were caged on potato plants, and their first born young recorded for the succeeding generations.

The total number of generations produced in a year by this aphid cannot be determined as yet, but 24 generations were produced from April 1 up to September 7, when the last female died. This would lead one to believe that at least 30 generations occur normally outdoors, since the population increased in Multnomah County in September.

This species, like the green peach aphid, molts four times, and has four nymphal instars. The average time for each nymphal stage is as follows:

1st instar--Average 2.2 days
2nd instar--Average 2.5 days
3rd instar--Average 2.8 days
4th instar--Average 2.5 days

Adult females lived an average of 30.5 days, and produced young for an average period of 18.2 days. They gave birth to first young an average of 11.0 days after their own birth. They, like the peach aphid, matured sooner in summer than in fall or spring, but accurate record of this was not kept.

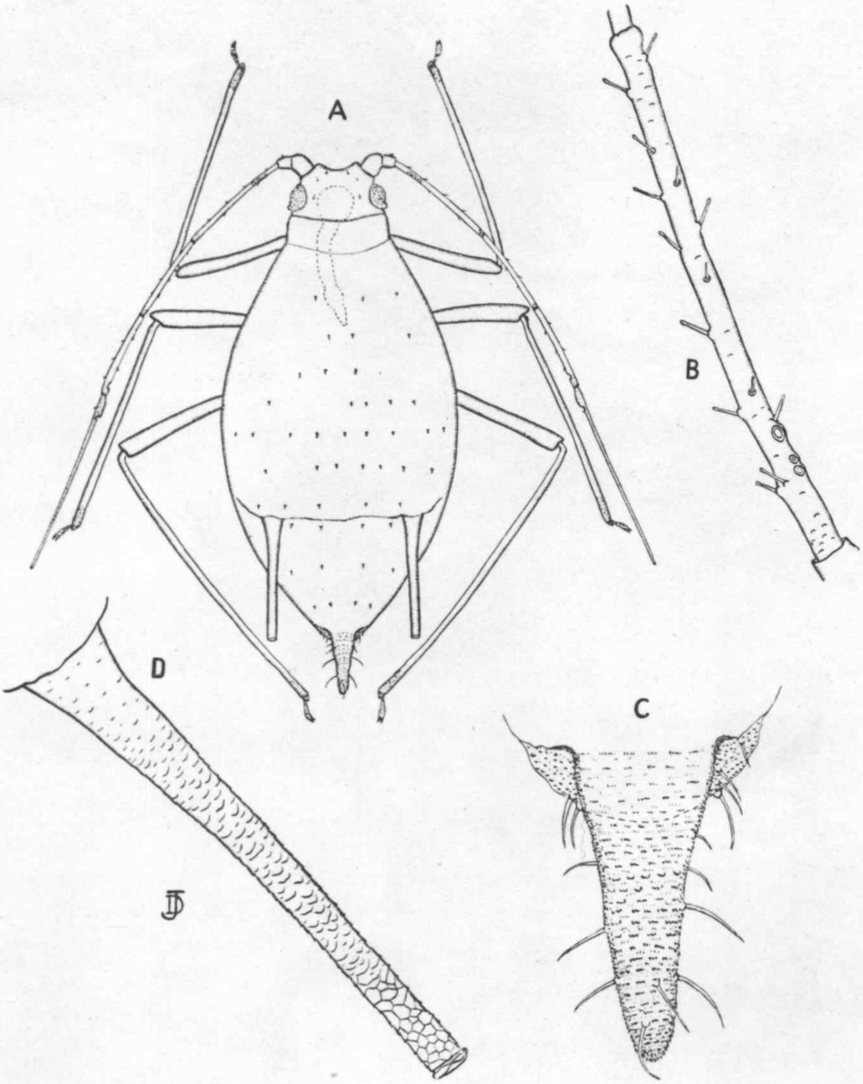
An average of 6.3 young were produced by each female per day. One female produced 82 young, but the average total for all was 42.6 young. The reproductive powers of this species is seen in the case where one female was isolated for 23 days on a caged potato plant. At the end of this period, 15 adult females and 25 nymphs were found.

No winged individuals appeared during the course of this study. This aphid, in the one instance when it became abundant in our plots, produced many winged young at one time, and they left the field in a short time.

Distribution. Holland, England, United States (Florida, Ohio, Maine, California, Washington, Oregon).

In Oregon, this aphid has been taken at the following localities: McMinnville, Corvallis, Forest Grove, Philomath, Eugene, Redmond, Gresham, Brooks, Alsea, Heceta Head, Portland, Waldport, Yachats, Salem, Ochoco Ranger Station, Summit.

Host Plants. The potato aphid has been recorded from the following plants in Oregon: Strawberry, onion, Gladiolus, Hypochaeris radicata, Hieracium sp., Sonchus asper, Sorbus aucuparia, Comarum palustre, Tulipa, Taraxacum officinale, Urtica holosericea, Helenium sp., columbine, Sisyrinchium idahoense, wild rose, Capsella bursa-pastoris, beet, potato, hops, squash, Solanum nigrum, S. dulcamara, Lactuca scariola, Brassica nigra, Rumex obtusifolius, Brassica campestris, Amaranthus retroflexus, Nicotiana quadrivalvis, Mentzelia albicaulis, Iris sp., Phaseolus vulgaris.



Macrosiphum gei Koch., from tulips: *A*, apterous viviparous female; *B*, segment 3 of antenna; *C*, cauda and anal plate (dorsal view); *D*, cornicle, greatly enlarged. (After Davidson.)

Figure 7

The Lily Aphid, _Myzus_ _circumflexus_ (Buckton)

Siphonophora _circumflexa_ Buckton, Monog. British Aphides 1:130, 1876.
Nectarophora _circumflexa_ (Buckt.) Hunter, Ia. Agr. Exp. Sta. Bull. 60:113, 1901.
Macrosiphum _circumflexum_ (Buckt.) Schoutenden, Mem. Soc. Ent. Belg. 12:238, 1906.
Myzus _vincae_ Gillette, Canad. Ent. 40:19, 1908.
Siphonophora _callae_ Henrich, Verhandl. u. Mitt. Siebenburg. Ver. Naturw. Hermannstadt 59:26, 1909.
Myzus _circumflexum_ (Buckt.) Davis, Canad. Ent. 46:121, 1914.
Neomyzus _circumflexum_ (Buckt.) van der Goot, Inst. Sci. Buitenzorg, Contrib. Faune Indes Neerland 1:50, 1917.
Aulacorthum _circumflexus_ (Buckt.) Hille Ris Lambers, Stylops 2:174, 1933.
Myzus _circumflexus_ (Buckt.) Mason, USDA Misc. Pub. 371:7, 1940.

A small ahpid, occurring in sparse colonies on lily and many other greenhouse plants. Very easily recognized by the dark green horseshoe on the dorsum of the abdomen, and the short, smooth, black tipped cornicles.

Known to transmit at least 16 plant viruses experimentally.

The original description of Buckton is quoted below:

"_Siphonophora_ _circumflexa_, Buckton

Apterous Viviparous Female

	Inches	Millimetres
Size of body	0.070 x 0.030	1.77 x 0.76
Length of antennae	0.075	1.89
Length of cornicles	0.015	0.38

"Oblong oval, smooth, shining. Bright green. Head broad, vertex flat. Antennae dark at their tips and placed on large frontal tubercles. Thorax deeply pitted, with two black or olive spots on each side. Rostrum rather long, reaching to nearly the third coxae. Abdomen broad between the cornicles. A dark patch on each side of the first abdominal ring, which is followed by a black characteristic horse-shoe-like mark with an irregular outline. Cornicles green, long and cylindrical. Last abdominal ring dilated. Legs and tail yellow. The last of moderate length. The young aphides are entirely green.

Pupa

"Wholly green, dull. Two red spots appear behind the eyes, the seats of the future ocelli. Antennae on large gibbous tubercles. In this respect this species approximates to the genus Myzus. Abdomen much ringed.

Winged Viviparous Female

	Inches	Millimetres
Expanse of wings	0.320	8.12
Size of body	0.070 x 0.030	1.77 x 0.76
Length of antennae	0.100	2.54
Length of cornicles	0.010	0.25

"Pale green. Head broad. Vertex pointed. Ocelli black. Thorax and prothorax black. Eyes and antennae black. The gibbous character of the frontal tubercles is less pronounced than in the larva. Abdomen oval, anal rings more and more pointed, ending in a black cauda. A small semicircular patch below the scutellum, followed by a row of dots. Below them, a large somewhat triangular patch of black, with its obtuse angle pointed backwards. Two last abdominal rings black. Legs fine, with black femora and yellow tibiae. Cornicles cylindrical and black. Wings very long, with dark gray cubitus and stigmata.

"This pretty insect was first noticed in my greenhouse from February to June, on the Cineraria, the Cyclamen, and the Spiraxis. Afterwards in a similar locality it was found plentifully at Chichester. It appears to be a spring species only, and the early winged forms do not develop such long antennae, as those which emerge later in June."

This aphid has never been taken out of doors, and the sexual forms are not known. Apparently it breeds indefinitely as ovoviviparous females in greenhouses and on plants in homes. It is common all over Oregon, but is not of economic importance as a vector of potato viruses, the fact of its ability to transmit them being of scientific interest only.

It is possible that the sexual forms of this species are being overlooked, or that they are being called by some other name. If a colony in the greenhouse is eradicated, plants may soon be reinfested from outside sources.

Distribution. This aphid is recorded (23) from the following countries: Belgium, Great Britain, Ireland, Latvia, Sweden, Switzerland, Northern Europe, Japan, Russia, Canada, Java, Hawaii, Argentina, Morrocco, Sumatra, United States (California, Colorado, Connecticut, Illinois, Kansas, New York, South Dakota, Indiana, Maine, Michigan, Utah, Wisconsin, Oregon).

In Oregon, this species is recorded from Corvallis and Portland, in greenhouses.

Host Plants. This aphid has been taken only on *Hesperis matronalis*, calla lily, in Oregon.

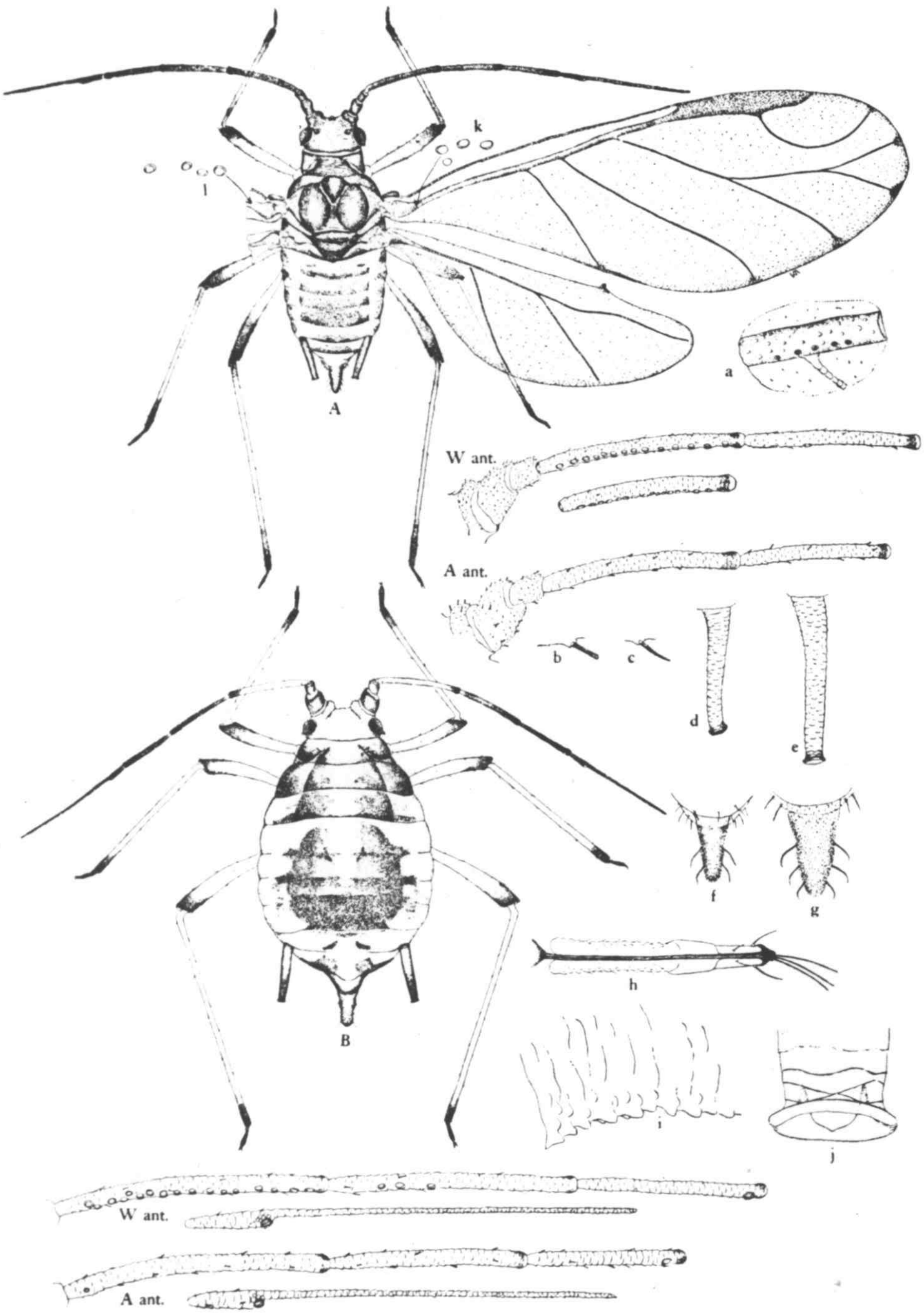


Fig. 8.—The lily aphid, *Myzus circumflexus* (Buckton). *A,* Adult winged female: *a,* section of the costal vein showing fenestralike areas; *d,* cornicle; *f,* cauda; *k* and *l,* fenestras near the base of the subcostal vein; *W ant.,* antennae. *B,* Adult apterous female: *A ant.,* antennae; *b* and *c,* setas on segments I and III of antenna; *e,* cornicle; *g,* cauda; *h,* rostrum; *i,* basal margin of cornicle; *j,* tip of cornicle. All greatly enlarged.

Fig. 8. (From Essig, 1938)

The Foxglove Aphid, Myzus solani (Kaltenbach)

Aphis solani Kaltenbach, Monog. der Fam. der Pflanzenlause, p. 15, 1843.
Aphis convolvuli Kaltenbach, supra cit., p. 40?
Aphis vincae Walker, Ann. & Mag. Nat. Hist. 2:429, 1848.
Siphonophora convolvuli (Kalt.) del Guercio, Nuove Rel. R. Staz. Ent. Agr. Firenze, 1(2):159, 1900.
Macrosiphum veronicae Theobald, Jour. Econ., Biol., 8:93, 1913.
Macrosiphum solani Theobald, supra cit., p. 127.
Macrosiphum picaella Theobald, Entomologist 49:146, 1916.
Macrosiphum primulana Matsumura, Jour. Col. Agr. Tohoku Imp. Univ. 7:400, 1917.
Macrosiphum vincae (Walk.) Wilson & Vickerey, Wisc. Acad. Arts, Sci., and Letters, Trans., 19: 177, 1918.
Myzus solani Theobald, Entomologist 52:161, 1919.
Myzus gei Theobald, supra cit., p. 157.
Myzus mercurialis Theobald, supra cit., p. 158.
Amphorophora convolvuli (Kalt.) Baker, USDA Bull. 826:55, 1920.
Myzus pseudosolani Theobald, So. East Agr. Col., Wye, Advisory and Res. Dep't Bull. 1:8, 1922.
Myzus glaucii Theobald, Ent. Month. Mag. 59:103, 1923.
Myzus hydrocotylae Theobald, Ent. Month. Mag. 61:73, 1925.
Myzus convolvuli (Kalt.) Davidson, List of Brit. Aphides, p. 22, 1925.
Myzus picaellus (Theob.) Theobald, Aphididae of Gr. Brit. 1:315, 1926.
Myzus polyanthi Theobald, supra cit., p. 341, 1926.
Myzus veronicellus Theobald, supra cit., p. 341.
Macrosiphum matsumuraeanum Hori, Hokkaido Agr. Exp. Sta. Rep't 17:51, 1926.
Macrosiphum aucubae Bartholomew, Ann. Ent. Soc. Amer. 25:713, 1932.
Myzus convolvuli (Kalt.) Mason, USDA Misc. Pub. 371:8, 1940.
Myzus solani (Kalt.) Essig, Hilgardia 17:607, 1947.

The original description of this species (41) is translated below:

> "Wingless: Egg shaped, arched, wrinkled, grass green, dorsum of the abdomen paler; proboscis long, proximal and distal portions of

> equal thickness, yellowish, black on the tip; cauda yellow, blunt, clublike, 1/3 the length of the proboscis. Length 1 mm.
>
> "They are found in small colonies under the leaves and on the stems of the potato plant (_Solanum tuberosum_ L.)--July and August.
>
> "_Wingless_: Antennae longer than the body, pale brownish, the segmental rings and tip of the flagellum brown, the two basal segments yellowish green, the second considerably smaller than the first; neck, head and front yellowish green, the latter produced in front into an acute protuberance; eyes reddish brown; beak yellow, third segment brown, reaching to the third pair of legs. Dorsum mixed green and yellowish, slightly shiny, wrinkled, leathery; beak long, equally thick proximally and distally, yellow, the tip of the same black; cauda yellow, bent upward, blunt, scarcely 1/3 the length of the beak; anal flap yellowish green, as is the whole venter of the body; legs brownish yellow, knee, tip of the tibiae and tarsi black, coxae green.
>
> "This species varies in the shape of the body somewhat from the rest of this group; the long beak and the head structure indicate however they belong here."

This species has long been called _Myzus convolvuli_ and _M. pseudosolani_. An examination of the description of _pseudosolani_ suffices to show that it is a synonym of this species. From Kaltenbach's description of _convolvuli_, however, one gains the impression he is discussing another species. Lambers considers that _convolvuli_ is a synonym of _persicae_.

Forms dense colonies on potato in the greenhouse, the individuals of which are easily recognized by the glistening sheen of the body, the granular green areas at the bases of the cornicles, and by the typical body shape

(Diagrams 1 and 2, Appendix). Individuals have the general appearance of species belonging to the genus Macrosiphum,[1] walk with the upraised, rapid gait of members of this genus, and drop from the plant when disturbed, like typical Macrosiphum. The antennal tubercles are not so prominent as in most members of the genus Myzus. It is questionable whether it belongs in one genus or the other.

Rather easily separated from other aphids on potato by the long antennae, cylindrical and definitely flanged cornicles, the presence of sensoria of antennal segment III, and the green areas at the bases of the cornicles.

Known to carry at least eleven plant viruses.

Life History. In Maine (69) the overwintering eggs on foxglove give rise to wingless stem mothers, which in turn produce young which become wingless females on this host. These give birth to females which develop into winged early spring migrants, and to wingless females which produce young that become winged later spring migrants. These migrants fly to secondary food plants, where a number of winged and wingless generations are produced. In the fall, winged migrants appear, fly to foxglove and deposit young which become wingless females. These, contrary to most aphids, produce wingless males and wingless oviparous females in September and October which

[1]The Imperial Institute of Entomology denotes this species as Macrosiphum solani.

mate and the females then lay the overwintering eggs in late September through October.

In Oregon this species may be found on the foxglove at almost any time of the year. It causes rather severe damage to this and other hosts, because its saliva is toxic to plant cells.

The foxglove aphid is rare on potato in this state, and is probably of no great economic importance as a vector of potato viruses. It has been taken during these studies but rarely, only six specimens were collected in three seasons.

Distribution. This aphid has been found in Great Britain, Germany, Canada, Alaska, and the United States (California, Colorado, Maine, Washington, Oregon).

In Oregon it has been collected at Corvallis, Hood River, Alsea, Waldport, Yachats, Multnomah, Portland, Salem, Trail, Gresham, Seaside, and McMinnville.

Host Plants. In Oregon, this species has been taken on Strawberry, *Sambucus racemosa*, *Ranunculus repens*, *Erechites prenanthoides*, *Chrysanthemum leucanthemum*, *Cerastium arvense*, *Convolvulus arvensis*, *Magnolia* sp., *Digitalis purpurea*, holly, *Tulipa* sp., *Vinca minor*, *Arctostaphylos viscida*, potato, begonia, celery, *Primula*, parsnip.

Fig. 9. (From Essig, 1938)

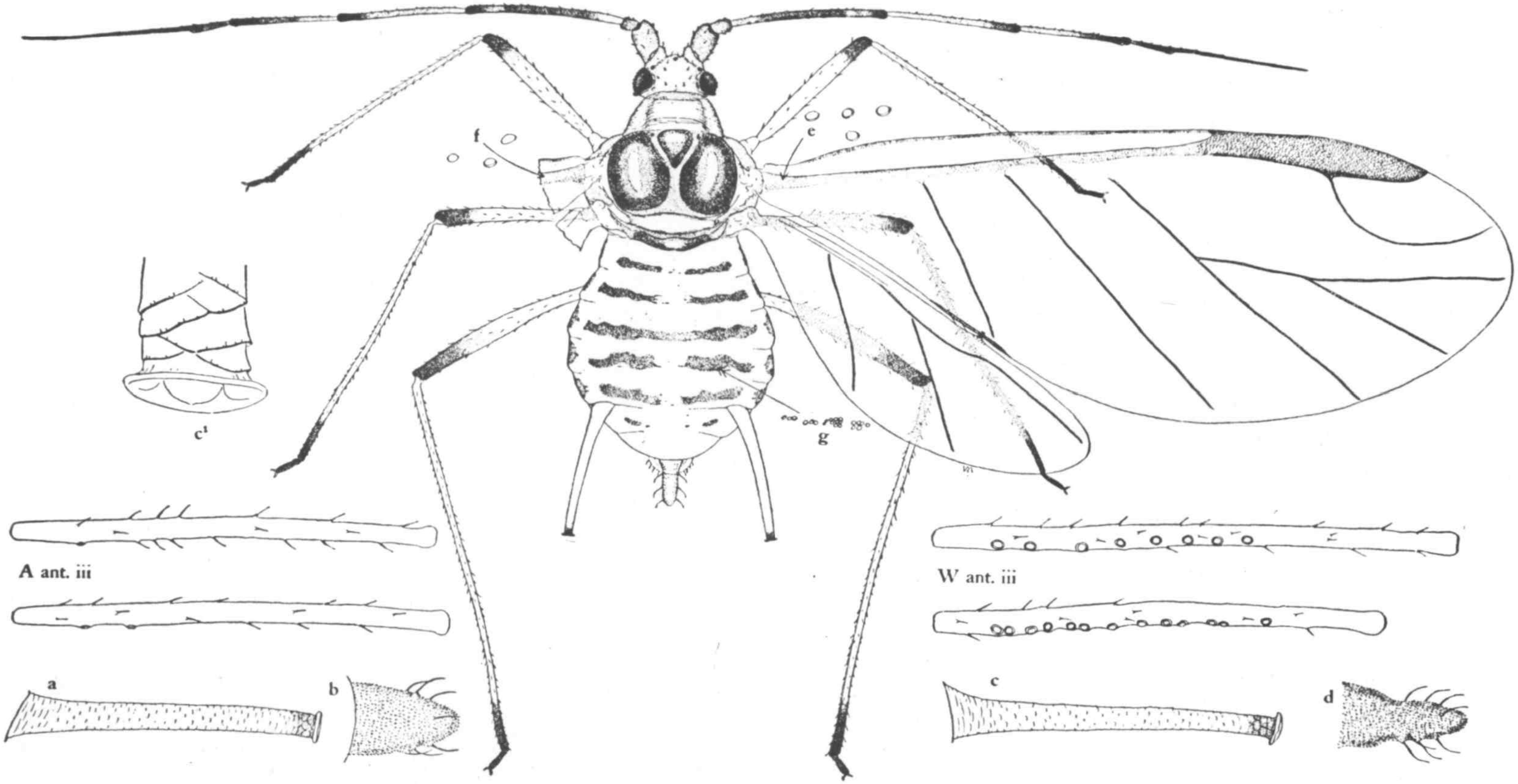


Fig. 9.—The foxglove aphid, *Myzus convolvuli* (Kaltenbach), adult winged female: *W ant.*, antennal segment III; *c*, cornicle, c^1, tip of cornicle; *d*, cauda; *e* and *f*, fenestras; *g*, gland pores as arranged in the dark transverse bands on the dorsum of the abdomen. *A ant.*, antennal segment III of apterous female; *a*, cornicle of apterous female; *b*, cauda of apterous female.

The Buckthorn Aphid, _Aphis_ _abbreviata_ Patch

Aphis _abbreviata_ Patch, Maine Agr. Exp. Sta. Bull. 202:170, 1912.
Aphis _frangulae_ Kaltenbach, Monog. der Fam. der Pflanzenlause, 1843 ?
Aphis _rhamni_ Kaltenbach, supra cit., p. 64 ?
Aphis _solanina_ Passerini, Gli Afidi, 1863 ?
Aphis _rhamni_ Boyer, Descr. des Pucerons qui se Trovent aux Environs d'Aix. Soc. Ent. de France Ann. 10:157, 1841 ?

The original description of this species is quoted below from Patch (66):

> "_Aphis_ _abbreviata_ n. sp. Some leaves of water plantain which were brought in for the sake of a large colony of _Rhopalosiphum_ _nymphae_ proved to be colonized also by a little pale green _Aphis_.
>
> "_Alate viviparous female_. Head and thorax black. Abdomen green. Antennae imbricated; III with from 8 to 12 large circular sensoria extending along the whole length, IV with 3 to 6 sensoria in a row, V with 2 or fewer sensoria besides the terminal one. Antennal total length about 1 mm.; III, 0.22; IV, 0.175 mm.; V, 0.125; Vi, base, 0.1 mm.; spur, 0.25 mm. Prothoracic tubercles present. Wing about 20 mm. long. Cornicle imbricated, 0.2 mm.; tarsus, 0.075 mm.; cauda, 0.19 mm. Total body length about 1.25 mm.
>
> "_Apterous viviparous female_. A pale green form. Antennae imbricated. No sensoria except usual terminal ones of V and VI. Total antennal length about 1 mm. III, 0.2 mm.; IV, 0.15 mm.; V, 0.15 mm.; VI, base, 0.1 mm.; spur, 0.26 mm.
>
> "The pupae of this collection were pale green with pale brown wing pads. The nymphs were pale green.
>
> "Cotypes collected on _Alisma_ _plantago-aquatica_ Sept. 14, 1910, at Orono, Maine, by W. C. Woods. No. 123-10."

According to Patch (68) this species deposits eggs on _Rhamnus_ _alnifolia_ and _R._ _cathartica_ in Maine. Stem mothers appear on these hosts when the eggs hatch in the spring, give birth to young which become winged spring migrants. These fly to a great many hosts, of which nasturtium seems to be a favorite, and potato one which they will accept. There several generations of winged and wingless forms are produced up to the advent of the fall. Then winged fall migrants appear, fly back to buckthorn, and produce wingless sexual females. Winged males then appear on potato, fly to buckthorn, and mate with the oviparous females. These then deposit the winter eggs about the buds and in rough places on the bark of this host.

Since this aphid is not now known in Oregon, its life history cannot be known. A few specimens from Klamath Falls were questionably determined by Essig as this species. This year, however, a careful examination revealed that they were not *aphis abbreviata*.

Distribution. This species is known only from California and Maine. As *Aphis rhamni*, it is recorded from Belgium and Great Britain. As *A. solanina*, it has been taken in Italy.

Host Plants. There are a great many host plants recorded for the species in Maine. In Oregon, the specimens first thought to be this species were taken on potato.

The Aster Leafhopper, *Macrosteles* *divisus* (Uhler)

In addition to the aphids previously discussed, there is one leafhopper which should be included in a list of possible vectors. It has not yet been proved that this leafhopper is a vector of any potato virus in Oregon. It is included here since greenhouse experiments indicate it can transmit aster yellows to potato, and that late breaking virus may be aster yellows. This taxonomic discussion is taken from Dorst (17) who has published the most comprehensive recent treatment of the genus.

"*Macrosteles* *divisus* (Uhler)

Jassus *divisus* Uhler, USDI Geol and Geogr. Surv. Bull. 3:472, 1877.
Cicada *sexnotata* Fallen, K. Svenska Cetensk. Akad. Nya Handl. 27:34, 1806.
Cicadula *quadrilineatus* Forbes, 14th Rep't State Ent. Ill., p. 68, 1884.

"Resembling *variatus*, but smaller. Length 3.5 to 4.5 mm., width 1 to 1.2 mm.

"A yellowish green species with six spots on vertex.

"Vertex produced, broadly rounding in front. Pronotum with lateral margins very short.

"Vertex with three pairs of black spots, one near the posterior margin, one on anterior margin, and one pair between the other pairs; black spot on margin of each eye. Elytra smoky on apical third.

"Male valve large, obtusely rounding at apex. Female last ventral segment truncate on posterior margin.

"Internal male genetalia with somewhat blunt toe on foot of style, with large aedeagus terminating in two fingerlike processes which are compressed dorsoventrally, gradually widening first two-thirds of distance, and then narrowing to a point.

"Macrosteles divisus is variable in intensity of color markings on the vertex and in size. In some specimens the spots on the vertex are prominent and in others the markings are very faint. The examination of a large series did not show a clear line for specific or varietal separation.

"This appears to be the most important species of the genus in that it transmits the disease of yellows to celery, lettuce, and aster.

"Cicadula quadrilineatus Forbes appears to be identical with divisus. H. H. Severin, of the University of California, sent a series of specimens the elytra of which were exceedingly long compared to those of other specimens, but no internal genetalic differences could be found.[1]"

[1] Severin has expressed the intention of describing the long winged form of this species as a new species, or a variety, and naming it M. divisus vectus.

Life History. The life history and habits of this leafhopper have not been studied in Oregon, since it has not been conclusively proved that they are vectors of Late Breaking Virus. The extracts from the work of Osborn (65) may be appropriate, however:

"There is little separation into distinct broods, and adults are found throughout the season, probably because of the short period of development of the young. In Texas adults have been abundant as early as March 22. Webster gives a record of adults, confined on wheat kept indoors, which deposited eggs on November 11. These hatched November 27. A further note on the last stage nymph on December 24 would indicate the passing nearly to adult stage within a period of about six weeks under indoor conditions. With present data, it seems impossible to determine definitely the number of generations during a season for individual localities.

* * * * * * * * * * * * * * * *

"The life history was studied in Maine some years ago. There seemed to be a fairly distinct migration from grasslands to oats at the time oats were in a succulent condition of growth.

"The nymphs are easily distinguished by the markings on the head, which are usually very similar to those of the adult. The color is usually darker green, the head is more rounded, and the abdomen is slender. The successive instars have not been differentiated.

* * * * * * * * * * * * * * * *

"The ready migration may lessen the efficiency of rotation and clean culture; yet it was noticeable that very few were found in fields where recent planting or clean culture was the rule. The hopperdozer treatment would probably serve in places where it can be used."

Distribution. Alaska, Canada, United States (Maine to California, and Minnesota to Texas) (17).

Host Plants. Oats, timothy, corn, potato, and grasses (17).

TRANSMISSION EXPERIMENTS

Before studies on the life history and control of insect vectors can proceed, it must be ascertained which of the insects common on the host in question are able to transmit the disease under consideration. In addition to learning these basic facts, it is well to determine the relations of the insect with the virus, such as the length of time necessary for the vector to acquire the virus, the time of feeding necessary for it to transmit the virus to a healthy plant, and the number of plants one vector can successfully infect after one feeding on a diseased plant. These facts are useful in the field in determining the source of infection of the insects, and determines the type measures to be used in insect control.

Plant viruses are divisible into two general groups on the basis of their insect vector relationships. They are: (a) Non-persistent viruses; (b) Persistent viruses (38). Non-persistent viruses are characterized by the following qualities: (1) They usually undergo no latent period in the vector; (2) They are not retained for long periods by the vector after the insect leaves a diseased plant and feeds on healthy plants; (3) A preliminary fast by the vector before feeding on a diseased plant usually increases transmitting efficiency, if the time of acquisition feeding is very short; (4) There is usually a low degree of specificity between virus and vectors.

Mild mosaic virus and rugose mosaic virus are examples of this first type. Aphids are usually vectors of these viruses. If we determine the virus to be of this type, it is then known that the vector acquires the virus in the field in which spread occurs, since the vector loses infecting ability within a short time of feeding on a diseased plant.

Persistent viruses usually have the following characteristics: (1) They undergo a latent period in the vector before transmission to healthy plants can be accomplished; (2) They are retained by vectors for extended periods of time; (3) Preliminary fasting of the vector prior to infection feeding does not increase efficiency; (4) They are often not transmissible from plant to plant by mechanical means; (5) There is usually a degree of specificity between virus and vector.

Leafroll virus, and possibly others attacking potato, are of the persistent type. Consequently, it is possible that aphids flying into the fields may be viruliferous, and that all of the spread in a given field may not be due to source plants within that field. Leafhoppers are typical vectors of this group, but a number are aphid transmitted.

GREENHOUSE EXPERIMENTS

Procedure. Colonies of aphids and leafhoppers have been maintained in the greenhouse for three years. The house is held at as close to 75 F and 35 per cent relative humidity as is possible. The insects are either reared on plants growing in pots on benches caged with 36 by 36 mesh plastic screen cloth, or within small cages covered with this material (Fig. 10).

The peach aphid has been maintained on sugar beet principally, since this plant will provide food for large numbers for long periods. Turnip and spinach are good hosts on which to allow the colony to build up rapidly, but do not survive when heavily infested. Plants grown in six-inch flower pots and fertilized from time to time will carry colonies for months. Plants survive best in winter within the caged benches, and grow more luxuriantly if given light from electric bulbs at night.

The potato aphid is difficult to rear in the greenhouse in winter. It has been carried on eggplant and potato successfully, but not on sugar beet. These first two plants being solanaceous, it is difficult to be certain the insects are non-viruliferous when a test feeding is begun.

The foxglove aphid has been reared only on potato, and no other host. This is unsatisfactory, since it is

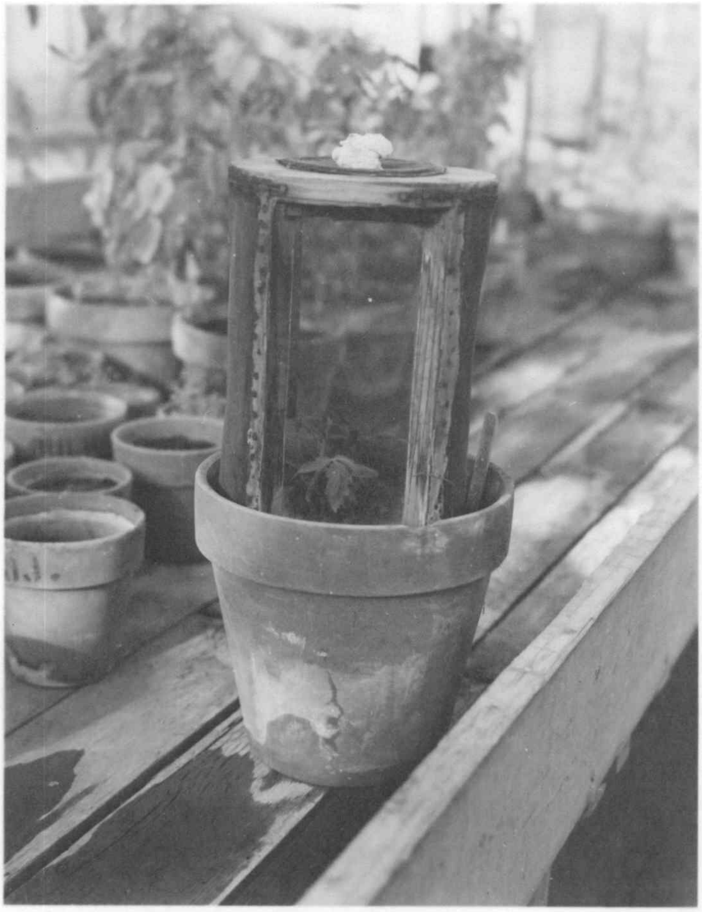


Fig. 10. Type of Cage Used in Greenhouse Transmission Experiments.

difficult to obtain virus-free potato.

The lily aphid has been successfully carried for long periods on Easter lily or on celery.

The aster leafhopper lives and multiplies rapidly on barley, but mildew is a problem in small screened cages when the humidity is high. Sacramento barley is mildew resistant, and provides rapid, succulent growth for feeding.

Thamnotettix montanus and *T. geminatus* increase rapidly on celery, and this plant will survive for extended periods under a cage.

Potato as a receiving plant for potato viruses is not satisfactory in the greenhouse. It grows tall and spindly in poor light, and requires ten to twelve-inch pots in order to produce tubers. It is almost impossible to obtain clean seed, and even taking portions of each tuber used as a check is not reliable, since some potato viruses attack but one or a few of the eyes of a tuber. In addition, the progeny of plants on which viruliferous insects have fed must be grown back the following season (Fig. 11, 12) in order to ascertain whether infection of the plants was accomplished.

As a result of these drawbacks, *Datura stramonium*, *Physalis angulata* and *P. floridana* have been substituted for potato as receivers for potato viruses. From 50 to 70

Fig. 11. Potatoes Growing in the Greenhouse.

Fig. 12. Progeny of Insect Inoculated Plants Growing in the Greenhouse.

per cent of the Datura plants a single viruliferous peach aphid feeds on become infected, from 20 to 40 per cent of P. angulata become infected, and from 70 to 90 per cent of P. floridana become infected, when the aphid has had a suitable acquisition feeding period on a plant infected with Leafroll (95). These plants are grown from seed, and hence are not infected originally. They can be grown in three or four-inch flower pots, effecting a great saving in bench space and amount of sterilized soil used.

Three years' trials with diseases for which no vector is known, and with insects not known to be vectors of potato viruses, are summarized in Tables 3, 4, 5, 6, and 7.

Table 3

Results of Attempts to Transmit Potato Leafroll Virus With Insects Not Known to Be Vectors

Insect Used	No. of Trials *	No. Used per Plant	Plants Infected Initial Season	Plants Infected Following Season
Aleyrodes spiraeoides	5	5	0/5	0/5[a]
Macrosiphum pisi	2	5-30	0/2	0/2
Aphis rumicis	5	5-50	0/18	0/18
Brevicoryne brassicae	3	5-50	0/11	0/11
Lygus spp.	10	5-25	0/10	0/10
Macrosteles divisus	8	5-50	0/11	0/11
Empoasca filamenta	5	5-25	0/5	0/5
Hyalopterus atriplicis	1	50	0/1	0/1

*In some of these trials the insects were starved 24-48 hours prior to test feeding.

[a]The numerator of the fraction represents the number of plants showing disease symptoms; the denominator, number of plants used.

Table 4

Results of Attempts to Transmit Potato Mild Mosaic Virus With Insects Not Known to Be Vectors

Insect Used	No. of Trials *	No. Used per Plant	Plants Infected Initial Season	Plants Infected Following Season
Lygus spp.	2	20	0/2	0/2
Macrosteles divisus	2	10-40	0/2	0/2
Empoasca filamenta	2	5-15	0/2	0/2
Aphis rumicis	3	10-25	0/16	0/16.

*In all of these trials the insects were starved 24-48 hours prior to the infection feeding.

Table 5

Results of Attempts to Transmit Potato Rugose Mosaic Virus With Insects Not Known to Be Vectors

Insect Used	No. of Trials	No. Used per Plant	Plants Infected Initial Season	Plants Infected Following Season
Aleyrodes spiraeoides	2	1-10*	0/2	0/2

*Immature forms on source plant 7 days.

Table 7

Results of Attempts to Transmit Aster Yellows Virus From Carrot to Potato by Means of _Macrosteles divisus_

Virus Used	No. of Trials	No. Used per Plant	Plants Infected Initial Season	Plants Infected Following Season
Aster yellows	1	5	0/14	3/14?
" "	1	1	0/5	2/5?
" "	1	1	0/10	3/10?
" "	1	2	0/10	7/10?*[a]

*Pictures of these plants and others infected with Late Breaking Virus were shown to H. H. P. Severin of the University of California; he believed both to be identical with the disease he produced in potato with aster yellows virus in California.

[a]Checks cut from the same seed tubers remained healthy.

Table 6

Results of Attempts to Transmit Potato Viruses for Which No Vector Is Known

Disease	Insect Used	No. of Trials *	No. of Insects per Plant	Plants Infected: Initial Season	Plants Infected: Following Season
Late Breaking Virus Disease	*Myzus persicae*	43	1-50	0/121	0/121
Late Breaking Virus Disease	*Macrosiphum gei*	3	5-25	0/4	0/4
Aucuba Mosaic	*Myzus persicae*	4	5-10	0/4	0/4
Aucuba Mosaic	*Macrosiphum gei*	3	10	0/3	0/3
Aucuba Mosaic	*Aphis rumicis*	2	2-10	0/2	0/2
Green Dwarf	*Myzus persicae*	13	1-50	0/41	0/41
Green Dwarf	*Macrosiphum gei*	1	6	0/1	0/1
Weak Plants	*Myzus persicae*	2	10	0/8	0/8
Witches' Broom	*Myzus persicae*	4	5-50	0/34	0/34
Calico Dwarf	*Myzus persicae*	3	1-50	0/35	0/35
Green Dwarf	*Myzus solani*	1	10	0/3	0/3
Late Breaking Virus Disease	*Macrosteles divisus*	2	2-3	0/22	5/14?

*In a few of these trials the insects starved 1-24 hours prior to infection feeding.

The results of transfers of leafroll virus, mild mosaic virus, and rugose mosaic virus are not summarized in the tables preceding. All three viruses have been so consistently transmitted by the peach and potato aphids as to be unworthy of detailed listing.

Insect-Virus Relationships. A series of experiments were made in 1948 to determine the retention of leafroll and mild mosaic viruses by the peach aphid. It was found that a single aptera was able to transmit leafroll to from five to ten plants in a row after a single feeding on a diseased plant. On the other hand, even after being starved for four hours prior to infection feeding, a procedure which increases its efficiency with viruses of this type, the peach aphid transmitted mild mosaic virus to a maximum of two plants.

The retention period of both viruses differs also. Leafroll is retained for at least six days, whereas mild mosaic virus is not transmitted later than four minutes after infection feeding.

These relationships assume importance in connection with control methods in the field. As has been discussed previously, this shows that mild mosaic virus is picked up in the field where spread occurs. Leafroll may be brought into the field where spread occurs in the aphid vector.

FIELD EXPERIMENTS

Cage Experiments. In 1946, 34 cages were erected at the Klamath Branch Experiment Station. In some of these cages insects were allowed to feed on a diseased plant, then a partition was removed and they were allowed to feed on an adjacent healthy plant. In others, insects collected on diseased plants were placed on healthy plants in the cage. The progeny of all originally healthy plants were collected and grown back in the greenhouse at Corvallis.

The results of these experiments were not unexpected. The peach aphid transmitted leafroll in seven cages; it transmitted mild mosaic in three cages; and the potato aphid transmitted mild mosaic in one cage. Several unnamed species of leafhoppers failed to transmit leafroll; several species of *Lygus* failed to transmit leafroll; and *Empoasca filamenta* failed to transmit mild mosaic.

At Corvallis in 1948 these experiments were continued. One diseased and one healthy plant were caged together, and various non-vectors introduced. These were allowed to feed for the remainder of the season, and then the tubers from the originally healthy plants dug and grown back in the greenhouse. The cage type used is shown in Figure 13.

In these trials, leafroll was not transmitted by

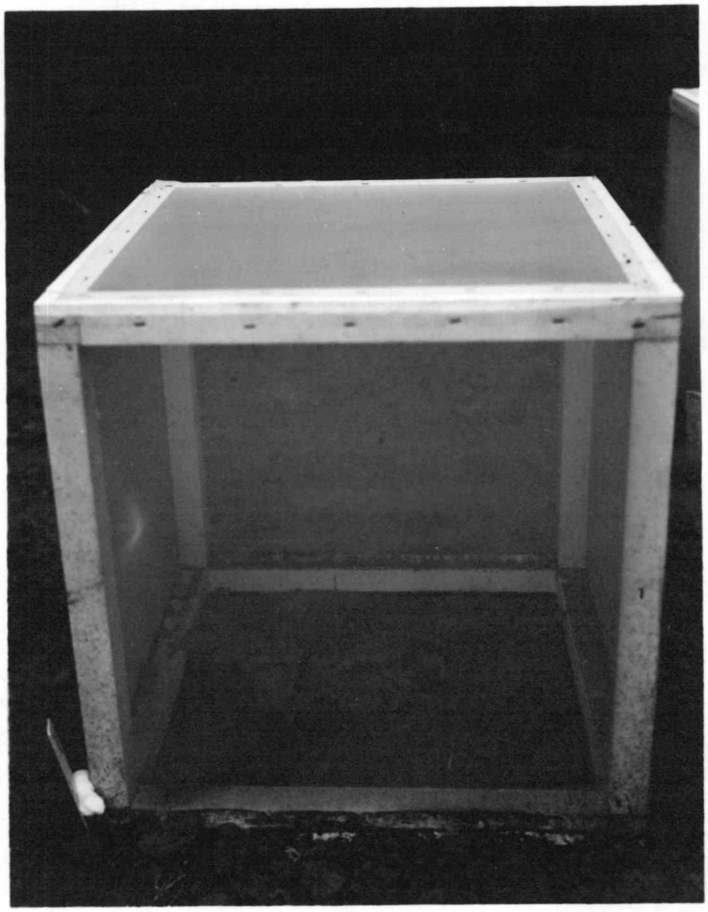


Fig. 13. Type of Cage Used in Field Transmission Experiments.

Empoasca filamenta nor by *Lygus* sp. Late breaking virus was not transmitted by either of these two species. Rugose mosaic was not transmitted by *Lygus* sp., and potato calico was not transmitted by *Empoasca filamenta*.

Observations in Field Plots. The relative numbers of different insects are learned during sampling in field plots. It is soon seen that fields may have abundant numbers of many different insects, but unless peach and/or potato aphids are present, there is no spread of the viruses.

About three weeks after infection occurs, the symptoms of the disease show in the plant, so that an estimate of the time infection occurred can be made. These observations can then be correlated with insect counts made at the time of infection, and the vector identified from a great many such observations.

POTATO VIRUS DISEASE CONTROL

MEASURES DIRECTED AGAINST THE INSECT VECTORS

Destruction of Eggs. If the green peach aphid were known to deposit eggs only on peach in a few localities in the state, it would doubtless be economically feasible to kill these eggs with insecticides during the winter or spring months. If, on the other hand, this species lays eggs on wild *Prunus* hosts, it would be out of the question to attempt to treat all the trees in any given area.

Destruction of Weed Hosts. In Maine (100) there is a large scale program in progress to control aphid vectors in this manner. Overwintering hosts, and such secondary weed hosts as can be killed, are treated with herbicides to eradicate plants on which the aphids can multiply. The value of this type program is questionable if the aphids move great distances on the upper winds, as theorized in a previous section. This is not intended to minimize the value of the destruction of weeds bordering potato fields, however, since these provide food for numerous aphids, and huge numbers are able to develop in wild mustard, for instance.

Timing of Planting. The season is so short in the Klamath and Central Oregon districts that planting dates cannot be altered greatly. In Multnomah county, however, it has been noted that fields planted late have potatoes emerging after the great movements of aphids are over, and hence avoid severe infestation. This is a factor that may vary from year to year, and to succeed a knowledge of the behavior of the aphids that season would be essential. It would be necessary that a qualified observer note the time of egg hatching or migration into the area, and that he make an estimate of the desirable time to plant.

Natural Enemies. Thompson (108) lists only a few parasites of the aphids concerned in this study. Of these a small number occur in the United States. With the country in which they are found, the following are listed:

(1) *Myzus persicae*:

Alloxysta sp. (Cynipidae), Australia
Aphelinus mali Hald. (Aphelinidae), Argentina
Aphelinus semiflavus (Harv.) (Aphelinidae), U. S.
Aphidius sp. (Aphidiidae), Italy
Aphidius matricariae Hal. (Aphidiidae), England
Aphidius persicae Froggat (Aphidiidae), Australia
Aphidius phorodontis Ashm. (Aphidiidae), Canada
Charips aphidae Froggat (Cynipidae), Australia
Diaeretus chenopodiaphidis Ashm. (Aphidiidae), Hawaii
Diaeretus rapae Curt. (Aphidiidae), Hawaii
Ephedrus incompletus Prov. (Aphidiidae, U. S.
Lygocerus niger How. (Calliceratidae), Australia
Praon simulans Prov. (Aphidiidae), U. S.

(2) *Macrosiphum gei*:

Aphelinus jucundus Gahan (Aphelinidae), U. S.

Aphidius matricariae Hal. (Aphidiidae), England
Aphidius polygonaphis Fitch (Aphidiidae), U. S.
Aphidius rosae Hal. (Aphidiidae), U. S.
Diaeretus rapae Curt. (Aphidiidae), U. S.
Lygocerus sp. (Calliceratidae), U. S.
Pachyneuron siphonophorae Ashm. (Pteromalidae), U. S.

(3) Myzus solani:

Aphelinus dubia Forst (Aphelinidae), ?
Aphelinus jucundus (Brulle) (Aphelinidae), U. S.

(4) Myzus circumflexus:

Aphelinus semiflavus How. (Aphelinidae), Hawaii

In all of the aphid counting which has been done during the course of the control studies, very few parasites, and not a great many predators, have been seen. In caged colonies in the greenhouse, a few parasites in the original colony may increase so rapidly as to wipe out the entire colony of aphids. In the summer of 1948, approximately one per cent of the peach aphids at the Multnomah County Farm were parasitized, and four species of Braconidae and Pteromalidae were reared from them.

A few species of parasites have been reared, and a few predators collected, and determined. These are:

(1) Parasites:

(a) Myzus persicae:

Aphidius nigriteleus Smith (Braconidae) hyperparasitized by Charips sp.

(Cynipidae)
Aphidius pisivorus Smith (Braconidae)
Asaphes californicus Gir. (Pteromalidae)
Diaeretus rapae (Curt.) (Braconidae)
Praon occidentalis Baker (Braconidae)

(b) _Macrosiphum gei_:

Pachyneuron siphonophorae (Ashm.) (Pteromalidae)

(2) Predators:

Coccinella trifasciata subversa Lec. (Coccinellidae)
Coccinella transversoguttata Fald. (Coccinellidae)
Hippodamia 5-signata ambigua Lec. (Coccinellidae)
Hippodamia convergens Guerin (Coccinellidae)
Cycloneda polita Cay. (Coccinellidae)
Scaeva prrastri Linn. (Syrphidae)
Syrphus opinator O. S. (Syrphidae)
Sphaerophoria sulphuripes Thomp. (Syrphidae)
Chrysopa californica Coq. (Chrysopidae)
Orius tristicolor (White) (Anthocoridae)

In the summer of 1947 it appeared at Klamath Falls that frost was of value in reducing the number of aphids in fields. It also appeared on observation that there was less leafroll spread in frosted portions of fields there. In the early summer of 1948, however, careful counts of aphids on frosted and unfrosted plants in a field at Culver were made, and no difference could be seen in the numbers on frosted or unfrosted plants.

Fields counted before and after heavy rains or even hail storms showed no reduction in numbers of aphids. It is believed that these factors are of no great importance in reducing aphid populations.

During three years' observations over the state, no aphids have been noted that were affected with a fungus disease. This is not as one would expect, since the peach aphid lives on the lower, older leaves, near the ground, where the humidity is high, and air movement reduced to a minimum.

Destruction of Aphids With Insecticides. The problem of attempting to control the spread of important plant diseases by killing the insect vectors presents many difficulties. In Maine (2) very good aphid control has been obtained with several insecticides, but with no reduction in the spread of leafroll or mild mosaic. A complete understanding of the habits of the vectors, their life history and ecology, is necessary before investigations on their control can be successful, other than by the lucky accident of accomplishing control in one season.

The control investigations in Oregon began in 1945, when Schuh (79) was employed at Gresham by the Entomology Department of the Experiment Station. He recorded the number of aphids per sweep sample in various field plots for the season, and then tuber samples were dug from the plots, and grown back at Corvallis the following spring to determine the best insecticide treatments. Beginning in 1946, lower leaf samples in units of 50 were picked and examined for aphids. This procedure has been followed up to the present.

(1) Field Experiments, 1945:

In the Aylsworth-Mohler plots, one was dusted once with 70 per cent Cryolite, and 592 aphids were found during the season. The second plot was dusted once with three per cent DDT, and only 130 aphids were taken during the season.

In the Aylsworth-Ruby field, one plot was treated with three per cent DDT plus three per cent Lethane 70, and 296 aphids were found during the season. The second plot, treated with 0.5 per cent rotenone and 20 per cent calcium arsenate, yielded 2930 aphids. Tuber samples were not collected from these two fields, but the reduction in aphids in the DDT plots was very encouraging.

The McKay field was divided into four plots. Plot I was dusted three times with rotenone and calcium arsenate, and had 444 aphids during the season (Fig. 14). Tubers grown at Corvallis showed 19.8 per cent mild mosaic and 3.4 per cent leafroll (Table 8). Plot II, dusted three times with three per cent DDT, had 109 aphids during the season, and the tuber sample showed 7.9 per cent mild mosaic and 0.53 per cent leafroll. Plot III received

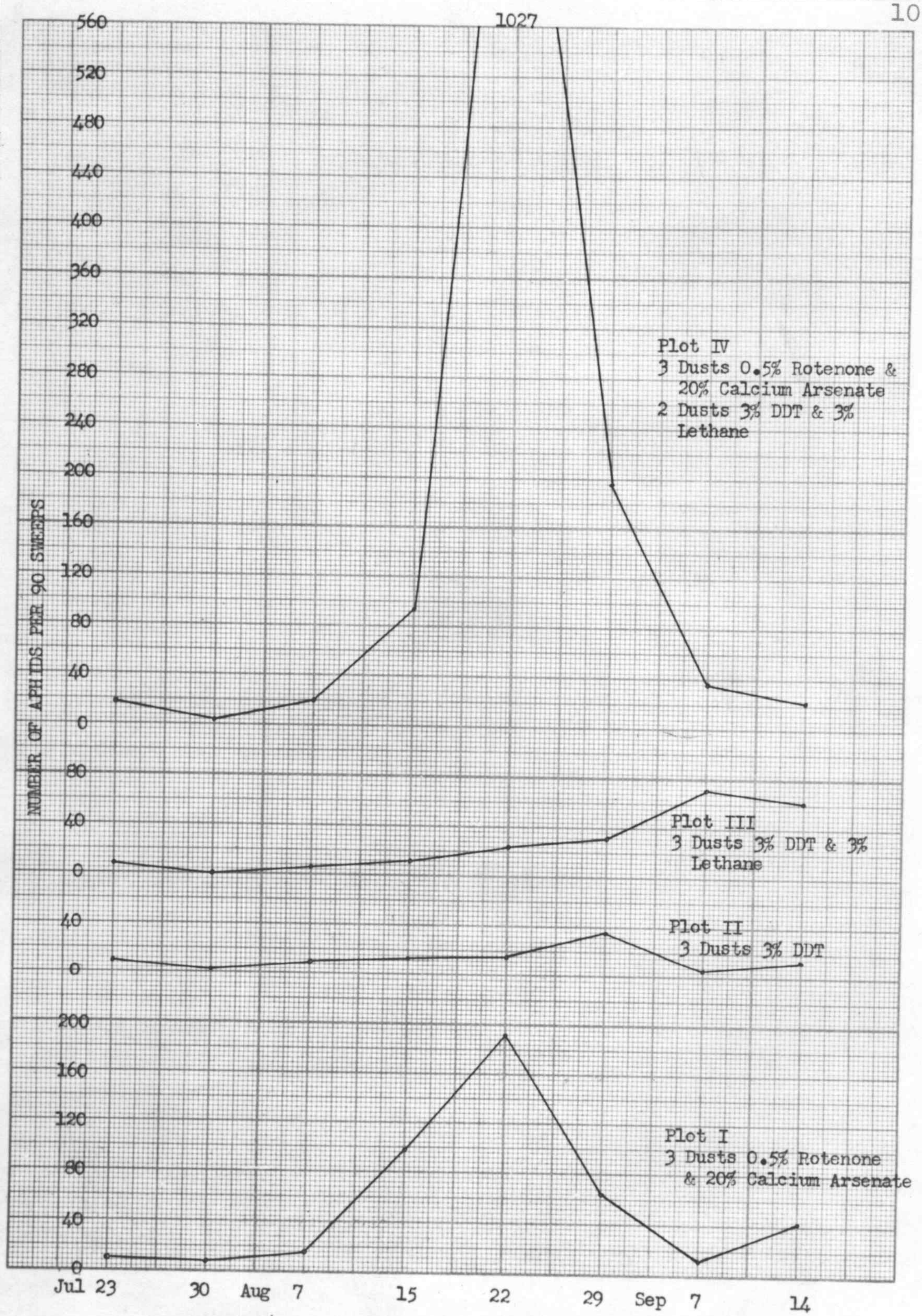


Fig. 14 Numbers of Aphids in McKay Plots, 1945.

Table 8

Amounts of Potato Virus Diseases in Tuber Samples From 1945-46 Insecticide Plots

Year	Grower	Plot No.	Treatment	Total Aphids	Total Disease in Sample in %		
1945	McKay	I	Rotenone-calcium arsenate	444	19.8 MM	3.4 LR	
1945	McKay	II	DDT	109	7.9 MM	0.53 LR	
1945	McKay	III	DDT-Lethane	217	5.1 MM	0.26 LR	
1945	McKay	IV	Rotenone-calcium arsenate	1326	9.0 MM	1.5 LR	
1946	McKay	I	DDT-8X	92	1.8 MM	0.2 LR	1.6 LBV
1946	McKay	II	DDT-4X	533	4.3 MM	0.0 LR	3.0 LBV
1946	McKay	III	BHC-4X	885	2.8 MM	0.4 LR	3.8 LBV
1946	Warren	I	DDT-3X	252	1.3 MM	0.0 LR	
1946	Warren	II	Check	419	2.5 MM	0.5 LR	
1946	Warren	III	PCH-2X and DDT-1X	274	1.6 MM	0.7 LR	
1946	Warren	IV	DDT-3X	93	1.6 MM	0.0 LR	
1946	Warren	IV	DDT-3X	93	0.9 MM	0.0 LR	
1946	Warren	V	DDT-3X	74	0.9 MM	0.0 LR	
1946	Warren	VI	DDT-4X	319	2.4 MM	0.5 LR	
1946	Warren	VI	DDT-4X	319	1.2 MM	0.0 LR	
1946	Warren	VI	DDT-4X	319	3.2 MM	0.0 LR	
1946	Warren	VI	DDT-4X	319	0.0 MM	0.0 LR	
1946	Warren	VIa	HETP spray-1X	574	0.0 MM	0.0 LR	
1946	Warren	VII	BHC-3X and DDT-1X	307	1.1 MM	0.0 LR	
1946	Cheyne	I	DDT-5X, Not rogued	108	38.6 MM	0.0 LR	
1946	Cheyne	II	No Dust. Not rogued	117	25.8 MM	0.7 LR	
1946	Cheyne	III	DDT-3X, Rogued	94	24.8 MM	0.0 LR	
1946	Short	I	No Dust. Not rogued	0	39.0 MM	0.0 LR	
1946	Short	II	DDT-3X, Not rogued	45	46.4 MM	0.0 LR	
1946	Short	III	DDT-3X, Rogued	16	46.8 MM	0.3 LR	

three applications of three per cent DDT plus three per cent Lethane 70, and yielded 217 aphids during the season. The sample from this plot contained 5.1 per cent mild mosaic, and 0.26 per cent leafroll. Plot IV, which received three applications of rotenone and calcium arsenate and two applications of DDT-Lethane, had 1326 aphids, and the tuber sample showed nine per cent mild mosaic and 1.5 per cent leafroll. While the amount of disease in the samples and the aphid numbers are not closely correlated, the trend in that direction will be seen.

Similar trials were made at the Sester field in 1945, in which Plot I received three applications of DDT-Lethane, Plot II was given three applications of rotenone-calcium arsenate, Plot III was dusted three times with three per cent DDT, and Plot IV received one application of rotenone-calcium arsenate and two applications of 0.75 per cent rotenone plus three per cent Lethane 70. Plot I had 245 aphids, Plot II had 761, Plot III 220, and Plot IV had 299. While the two DDT plots had fewer aphids than the other plots, control was not as good as was expected from three applications of materials. However, it was apparent that DDT with or without Lethane was far superior to rotenone as an aphicide. It was also seen in the McKay samples that there was less disease in the DDT plots.

(2) Field Experiments, 1946:

With these findings in mind, five per cent DDT was used in a few plots at Corbett (80). In the Seidl field, Plot I was dusted four times with five per cent DDT, and showed 450 aphids during the season. Plot II received four applications of 0.5 per cent rotenone plus 20 per cent calcium arsenate, and only 341 aphids were found during the season. This pointed out the need for replicated plots within fields, since the aphids were apparently concentrated on the side of the field receiving the DDT dust.

At the McKay field in 1946, Plot I was dusted eight times with three DDT formulations, and only 92 aphids were found on the 400 leaves examined. Plot II received four applications of 0.75 per cent gamma isomer of benzene hexachloride and 533 aphids were taken. Plot III was dusted four times with three formulations of DDT, and yielded 885 aphids (Fig. 15). Tuber samples from this field (Table 8) showed that the amount of disease in the tubers was directly correlated with number of aphids taken during the season, and that frequent DDT applications aided in controlling the spread of the viruses.

A large field of Warren's at Klamath Falls was made available in 1946, and eight plots were arranged here. The materials applied and numbers of aphids found are summarized in Figure 16. The proportion of diseases in

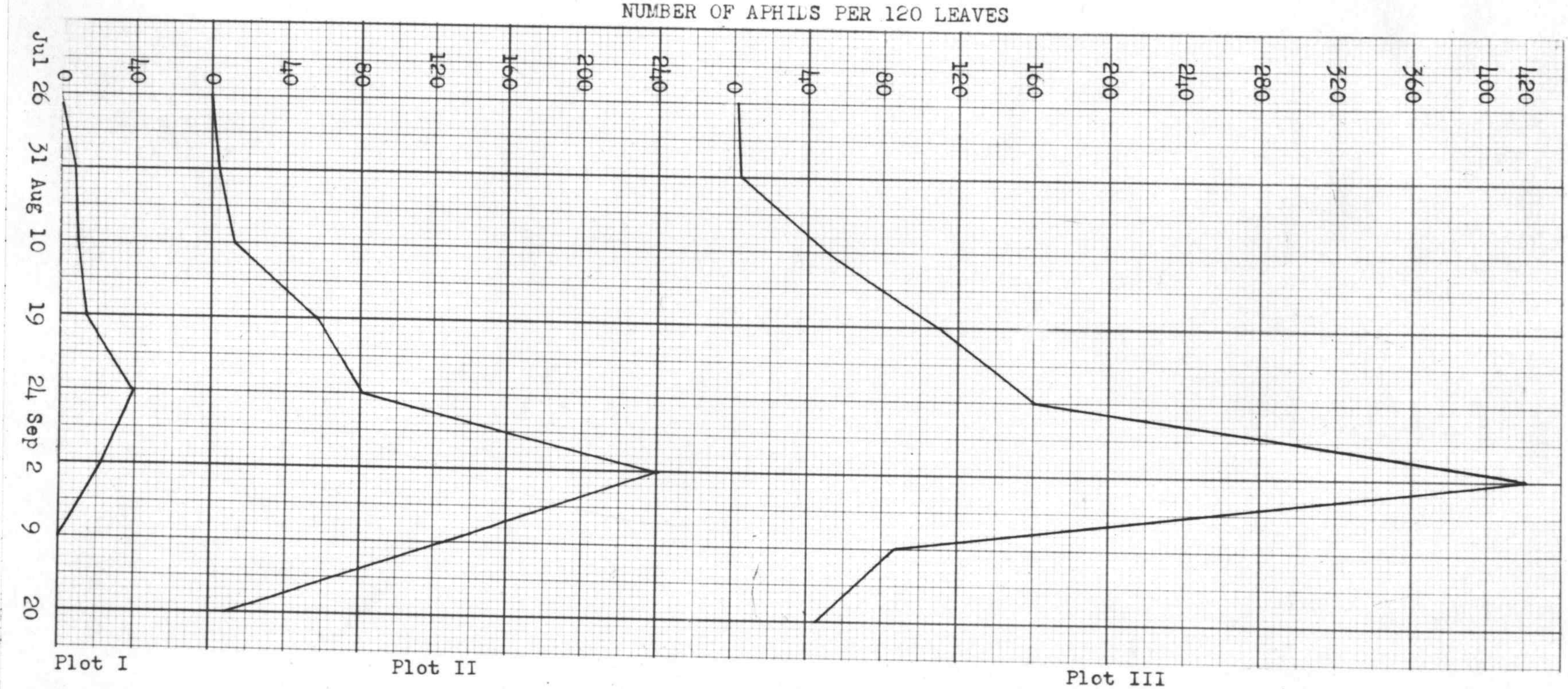


Fig. 15 Aphid Populations in McKay Plots, Corbett, 1946.

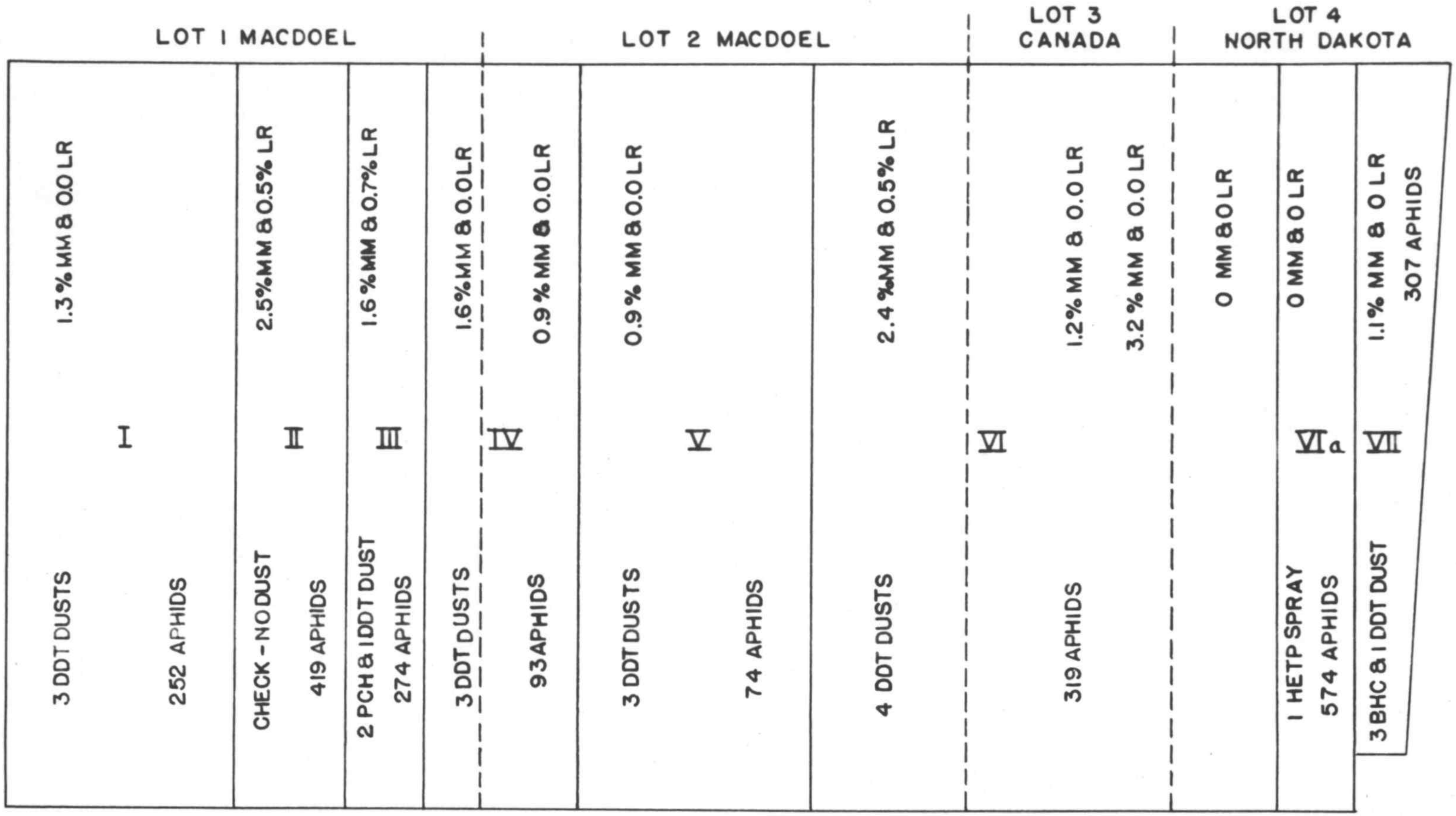


FIG. 16

SCOTT WARREN PLOTS, ALGOMA - 1946

100 ACRES WHITE ROSE POTATOES

tuber samples from these plots is tabulated in Table 8. While there was considerable changing of dusts used in the plots during the season, and results are therefore not as reliable as they would otherwise be, it again appeared that the reductions obtained in numbers of aphids was reflected in a smaller amount of the viruses in the tubers. It must be noted in connection with this experiment that there are a number of seed lots in sections of the field, and seed carrying little or no virus disease will show much less in next year's crop than another lot carrying a great deal, even though the numbers of aphids in the lots are just the opposite of this situation. Table 9 shows the amount of disease in tuber samples from plots, treated as the main aphid plots were, but no aphid counts were made here. It will also be noted that some of these seed lots are not the same as those in Figure 16.

Also at Klamath Falls, two other growers made fields available; the Cheyne field being divided into three plots (Table 8), one of which was dusted with DDT and not rogued, the second was not rogued but was dusted, and the third was rogued and dusted. The samples from this field reveal nothing in regard to the efficacy of the various treatments, other than that all were ineffective. It also points out that ten per cent mild mosaic in the seed is too much to start with.

Table 9

Amounts of Potato Virus Diseases in 1946 Insecticide Plots, Warren Field, Klamath Falls*

Plot No.	Seed	Treatment	Total Disease In Sample in %
I	Lot 5--N. Dak.	DDT-3X	0.0 LR 1.7 MM
I	Lot 6--Minn.	DDT-3X	0.0 LR 0.7 MM
II	Lot 6--Minn.	Check--no dust	0.0 LR 0.5 MM
II	Lot 7--Hoven	Check--no dust	0.4 LR 3.5 MM
III	Lot 7--Hoven	PCH-2X, DDT-1X	1.8 LR 2.8 MM
III	Lot 8--Sester	PCH-2X, DDT-1X	0.5 LR 3.4 MM
IV	Lot 8--Sester	DDT-3X	0.9 LR 2.0 MM
V	Lot 8--Sester	DDT-3X	0.0 LR 0.9 MM
V	Lot 9--Sester	DDT-3X	0.5 LR 0.0 MM
VI	Lot 9--Sester	DDT-4X	2.3 LR 0.5 MM
VI	Lot 10--Sester	DDT-4X	0.7 LR 2.5 MM
VI	Lot 10--Sester	DDT-4X	1.4 LR 1.8 MM
VI	Lot 11--Sester	DDT-4X	0.7 LR 3.4 MM
VIa	Lot 11--Sester	HETP spray-1X	3.2 LR 11.2 MM

*These plots were located in a portion of the field where aphid counts were not made.

The second field was that of J. Short. Here again the seed contained ten per cent mild mosaic, and the plots were arranged just as those in the Cheyne field. The samples were even more discouraging, however, since the best treatment sample had more mild mosaic than did the others.

With all these erratic results, 1946 proved a disheartening year. However, it was decided to use only the best material which had been tried to date, and determine whether or not careful dusting with this material[1],

[1]Stauffer Chemical Co. D-Fusul-4, containing 4% DDT, 80% sulfur, and 1% oil.

combined with roguing of diseased plants from the field, would reduce the spread of leafroll and mild mosaic.

(3) Field Experiments, 1947:

A ten-acre field of White Rose potatoes was made available for use during the 1947 season (82). The field was divided into eight plots, as shown in Figure 17, four of which were to be rogued, four not rogued, four dusted, and four not dusted. Thus, two plots were rogued and dusted, two were rogued and not dusted, two were not rogued but were dusted, and two were not dusted nor rogued. Seven applications of dust were made in the treated plots, at rates shown in Table 10. Unfortunately, several of the first dusts were put on the plots during windy periods, and this affected the final results. Also, there was a rapid buildup of the potato aphid in all plots near the end of the season that went undetected for some time. Either of these factors could have been responsible for the erratic results observed in the tuber samples.

Table 10 shows that the mean number of aphids per 100 leaf sample in Plots 1 and 3, which were dusted, was 121.73; the same figure for Plots 2 and 4, which were not dusted was 1953.73. In Figure 18 the seasonal trends in the aphid population in the two sets of plots is shown graphically. This was very encouraging, although the number of aphids in the dusted plots is far too high when

N

NOT ROGUED 215 APHIDS 25%MM & 3.8% LR PLOT I B 60 ROWS	ROGUED 7448 APHIDS 29%MM & 1.7% LR PLOT II B 42 ROWS	ROGUED 165 APHIDS 16% MM & T-LR PLOT III B 42 ROWS	NOT ROGUED 3209 APHIDS 31%MM & 1.0% LR PLOT IV B 46 ROWS
DUSTED PLOT I A ROGUED 342 APHIDS 13% MM & 2.5% LR	UNDUSTED PLOT II A NOT ROGUED 6445 APHIDS 36%MM & 6.5% LR	DUSTED PLOT III A NOT ROGUED 260 APHIDS 36%MM & T-LR	UNDUSTED PLOT IV A ROGUED 3794 APHIDS 28%MM & 3.0% LR

FIG. 17 MULTNOMAH COUNTY FARM-1947
10 ACRES WHITE ROSE POTATOES
SEED-3% MILD MOSAIC & 1.5% LEAFROLL

Table 10

Numbers of Aphids Found in Multnomah County Farm Plots, 1947

Date Dusted	Pounds per Acre	Date Count Made	Aphids per 100 Lower Leaves in Plot Number 1	2	3	4	Totals Plots 1 & 3	Totals Plots 2 & 4
		12 July	134	134	134	134	268	268
14 July	25	17 July	70	174	19	153	89	327
18 July	30	23 July	18	162	10	139	28	301
		30 July	43	133	24	91	67	224
30 July	35	7 August	3	137	12	171	15	308
7 August	40	14 August	7	81	5	66	12	147
14 August	45	22 August	4	91	0	80	4	171
		29 August	30	773	9	93	39	866
		5 Sept.	232	1487	110	412	342	1899
13 Sept.	45	15 Sept.	146	3306	155	1732	301	5038
20 Sept.	50	23 Sept.	74	7723	100	4219	174	11942
		Totals	761	14201	578	7290	1339	21491
		Mean					121.73	1953.73

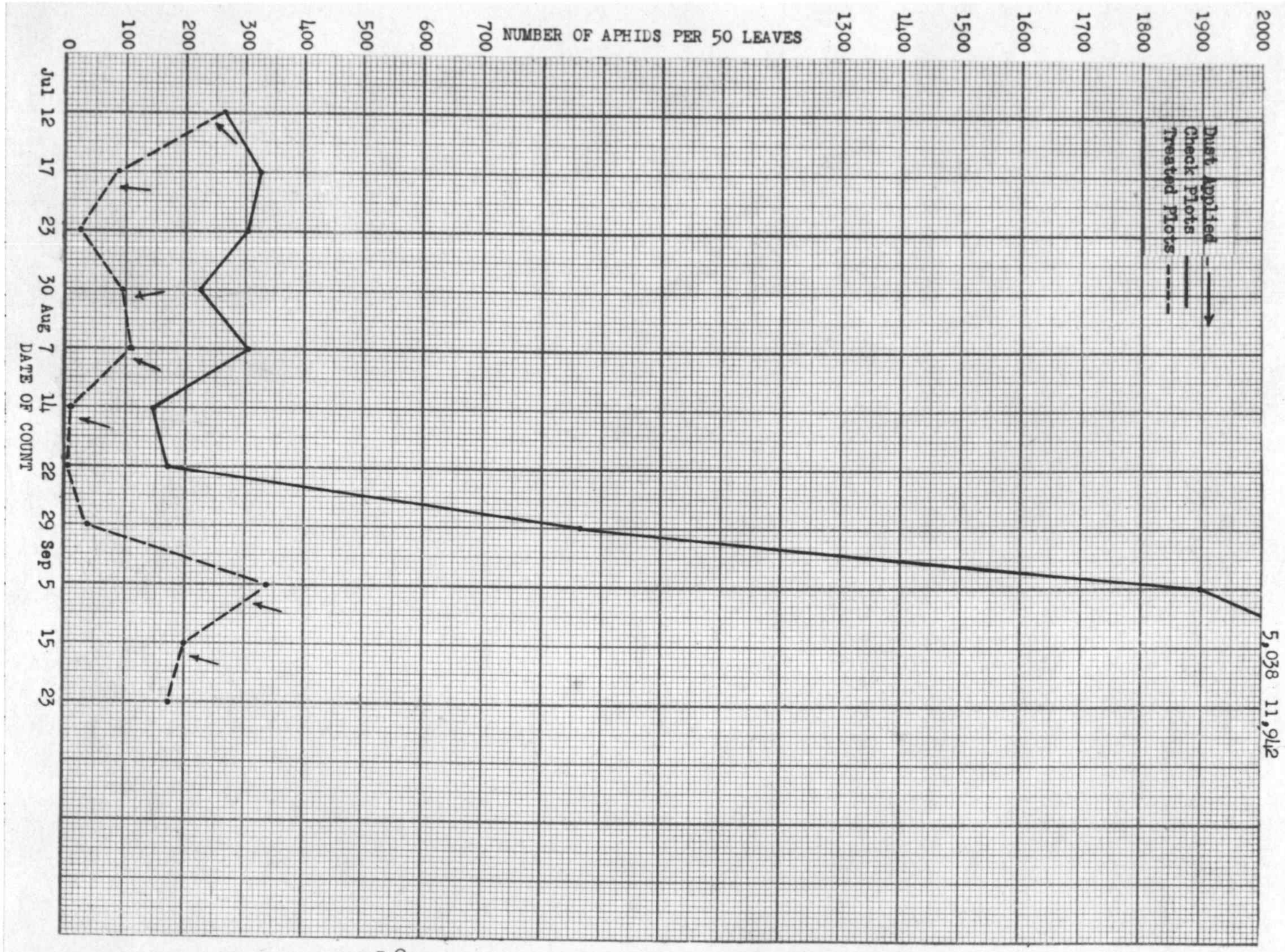


Fig.18 Aphid Populations in Multnomah County Farm Plots, 1947.

the expense of seven applications of dust at rates of 35-40 pounds per acre is considered. The disease readings in these plots, as shown by samples of the tubers (Table 10), are even more discouraging. In general, numbers of aphids found and amount of disease in the tubers were loosely correlated, but there was a great deal more transmission in even the best treated plots than had been anticipated, and these results cannot be said to offer concrete hope for control in this manner. For example, there were only 1339 aphids in the dusted plots, and an average of 21 per cent mild mosaic in the samples. There were 21,491 aphids in the undusted plots, but an average of only 31 per cent mild mosaic. This difference does not justify seven applications of dust and careful roguing of the diseased plants from the field.

At Klamath Falls (83), in a ten-acre field of Netted Gems of Kandra's, three plots were laid out. The seed used contained five per cent leafroll. The center plot was rogued once, and the two outside plots were not rogued. No insecticide was applied. At the end of the season a tuber sample was dug, which later showed six per cent leafroll in the rogued plot, and only eight and nine per cent in the other two plots. There was a total of 422 aphids in the field during the season, so the only thing learned was that there could be a considerable number of aphids in certain localities without great consequent leafroll transmission.

Another experiment was made in a pair of fields of Netted Gems of Earl Mack's. Table 11 summarizes the data on the plots here. Plot III was planted to seed containing 0.5 per cent leafroll, and was not sprayed or rogued. Plot IV had the same seed as III, but was sprayed once with 4.5 per cent DDT in kerosene base oil[1] by airplane, just prior to the one roguing. The treated plot had but half the aphids, and half the leafroll in the tuber sample, that the untreated plot had. Plots I and II merely show that the more leafroll in the seed, the greater amount that may be expected in tubers produced by those plants. Figure 19 shows the trend of the aphid population in the two plots of the same seed lot, based on four 100-leaf samples. This graph shows that the aphids in the treated plot began increasing about one week after spraying was done. ([1]Shell Oil Co., Vapona 1-D)

Table 11

Number of Aphids, and Amount of Leafroll, in Mack Netted Gem Plots, Klamath Falls, 1947

Plot No.	Disease in Seed	Treatment	Total Aphids	Leafroll in Tuber Sample
I	1.0% LR	None	876	39.0%
II	Tr Lr	None	876	12.0%
III	0.5% LR	None	876	23.0%
IV	0.5% LR	1 Rogue, 1 spray	402	12.0%

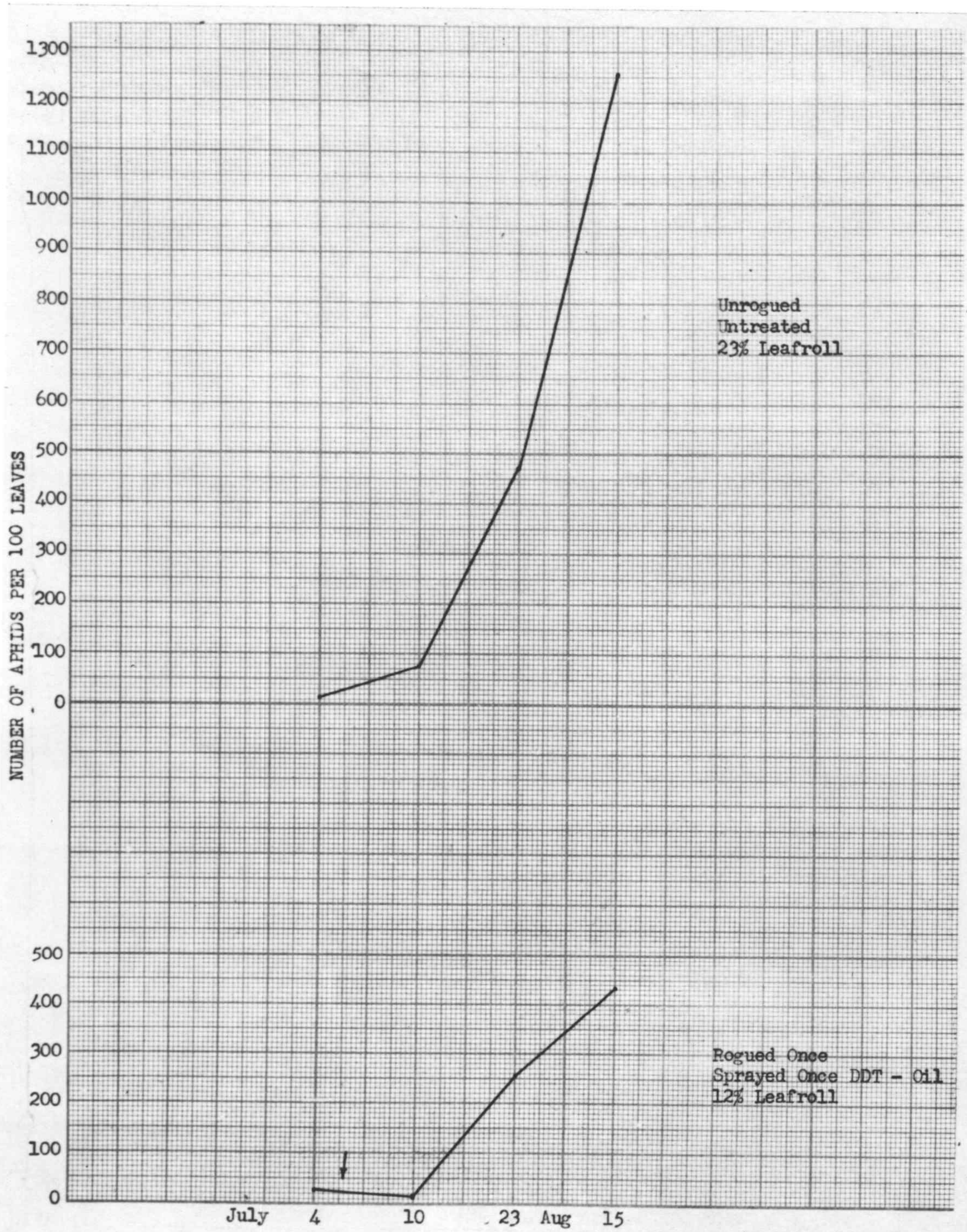


Fig. 19 Aphid Populations in Mack Plots, Klamath Falls, 1947.

A third set of experiments were made in a 12-acre field of Netted Gems of E. Stastney's at Klamath Falls. The seed here contained 3.5 per cent leafroll. Figure 20 shows the number of aphids found in each plot at each count. In reference to this figure, the first dust was applied on the date represented by the fourth bar; the second dust was applied on the date represented by the line between the sixth and seventh bars. Table 12 summarizes the amount of leafroll in the samples taken from these plots at the end of the season. It is apparent that even one dust helped reduce the amount of transmission, particularly the July 24 dust. All applications reduced the amount of transmission below that in the undusted check, and this reduction is remarkable, considering that the field was not rogued at all. Here again, the number of aphids found is not closely correlated with the amount of transmission, although it is apparent that the treatment was of value. This again emphasized the need for plots replicated a number of times within a field. This is difficult to accomplish, since the growers who are vitally interested in this work are seed growers, who cannot afford to leave check plots in their fields. Commercial growers are willing to leave checks, but are not willing to trouble themselves with application of the same material to several scattered portions of the field.

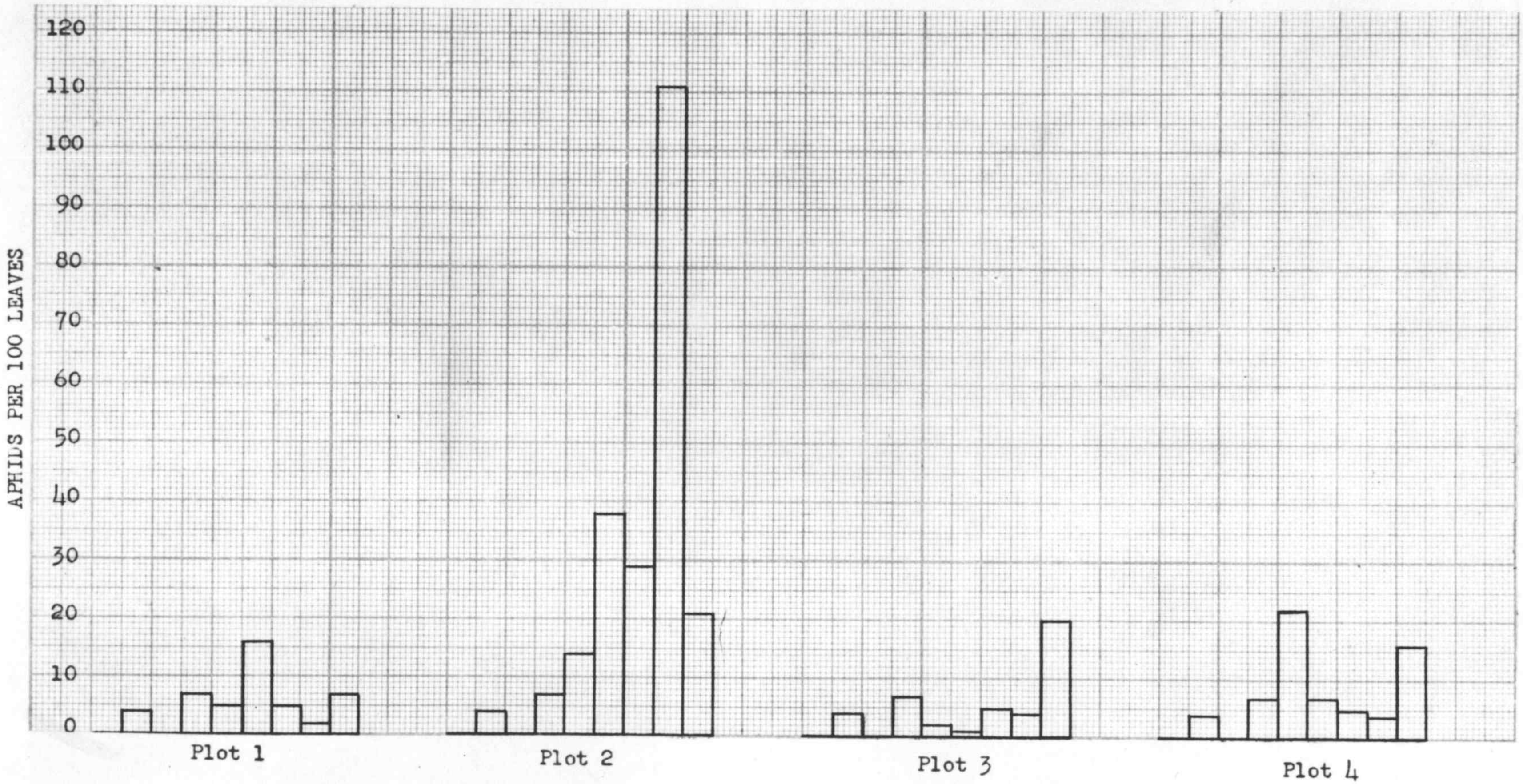


Fig. 20 Aphid Populations in Stastney Plots, Klamath Falls, 1947.

Table 12

Number of Aphids, and Amount of Leafroll in Tuber Samples, Stastney Plots, Klamath Falls, 1947

Plot No.	Treatment	Total Aphids	Leafroll in Tuber Sample
I	First and second dusts	56	8.4%
II	No dust	252	28.0%
III	First dust	60	13.7%
IV	Second dust	75	6.6%

Figure 21 summarizes the important data for a series of plots in a 35-acre field of Netted Gems at Merrill, belonging to Louis Lyon. Here, the five per cent leafroll in the seed increased to 85 per cent in the poorest plot, but increased to only 23 per cent in the best plot. This field is located in an area where leafroll spreads rapidly year after year, as well. In these plots dusting is closely correlated with fewer aphids, and those plots with few aphids showed less leafroll in the tuber sample. These results were very encouraging, being the best and most consistent to date. They indicate that two or three applications of a good insecticide and one poor roguing can do a lot toward lessening the transmission of leafroll. One difficulty resulted from these findings, however. Growers, desperate for control measures, seized upon this series of trials as their salvation, but a comparison of these plots with the amount of disease allowed under the certification standards will convince the

Seed	Treatment	Plot	Rows / Aphids	TUBER SAMPLES
WEST & LYON SEED 5.5% LEAFROLL	UNROGUED UNDUSTED	I	80 ROWS 1050 APHIDS	85% LR
WEST & LYON SEED 5.5% LEAFROLL	UNROGUED 1 DUST & 1 SPRAY	II	60 ROWS 71 APHIDS	38% LR
WEST & LYON SEED 5.5% LEAFROLL	UNROGUED 1 DUST & 2 SPRAYS	III	60 ROWS 12 APHIDS	23% LR
WEST & LYON SEED 5.5% LEAFROLL	ROGUED UNDUSTED	IV	159 ROWS 741 APHIDS	80% LR
WEST & LYON SEED 5.5% LEAFROLL	ROGUED 2 SPRAYS	V	60 ROWS 598 APHIDS	50% LR
WEST & LYON SEED 5.5% LEAFROLL	ROGUED 1 SPRAY	VI	60 ROWS 609 APHIDS	50% LR
WEST & LYON SEED 5.5% LEAFROLL	ROGUED 1 DUST	VII	60 ROWS 155 APHIDS	38% LR
WEST & LYON SEED 5.5% LEAFROLL	ROGUED UNDUSTED	VIII	60 ROWS 806 APHIDS	84% LR
WEST SEED .5% LR	ROGUED UNDUSTED		48 ROWS	40% LR
POPE SEED T- LR	ROGUED UNDUSTED		86 ROWS	20% LR

FIG. 21

LOUIS LYON PLOTS, MERRILL - 1947

35 ACRES NETTED GEM POTATOES

uninterested observer that this is a lead, not a solution.

A 70-acre field, also belonging to Mr. Lyon, was utilized in another test. Here the field was divided in half, one side being dusted twice with an airplane, the other half left undusted. Each half was poorly rogued once during the season. The seed contained about one per cent leafroll. Ten 100-tuber samples were taken from each half of the field when the plants were frosted at the end of the season, and it was found when they were grown back that the percentage of leafroll and weak plants in the dusted sample was about one-half that found in the undusted one. Air applications of dust are considered unsatisfactory for aphid control, as opposed to ground dusting with a good machine. The correlation between aphids and leafroll here (Fig. 22) is, then, surprising.

The last group of field plots for 1947 to be considered are those in the Scott Warren field at Algoma. Here three applications of five per cent DDT and two per cent oil in talc[1] were compared to four applications of the standard D-Fusul-4 as an aphicide. No tuber samples were collected in these plots. The aphid counts, summarized in Figure 23, show that 96 aphids were found on 116 plants and 800 leaves in the DDT-sulfur plot, while only 45 aphids were taken in the DDT-talc plot. The

[1] du Pont Deenate dust.

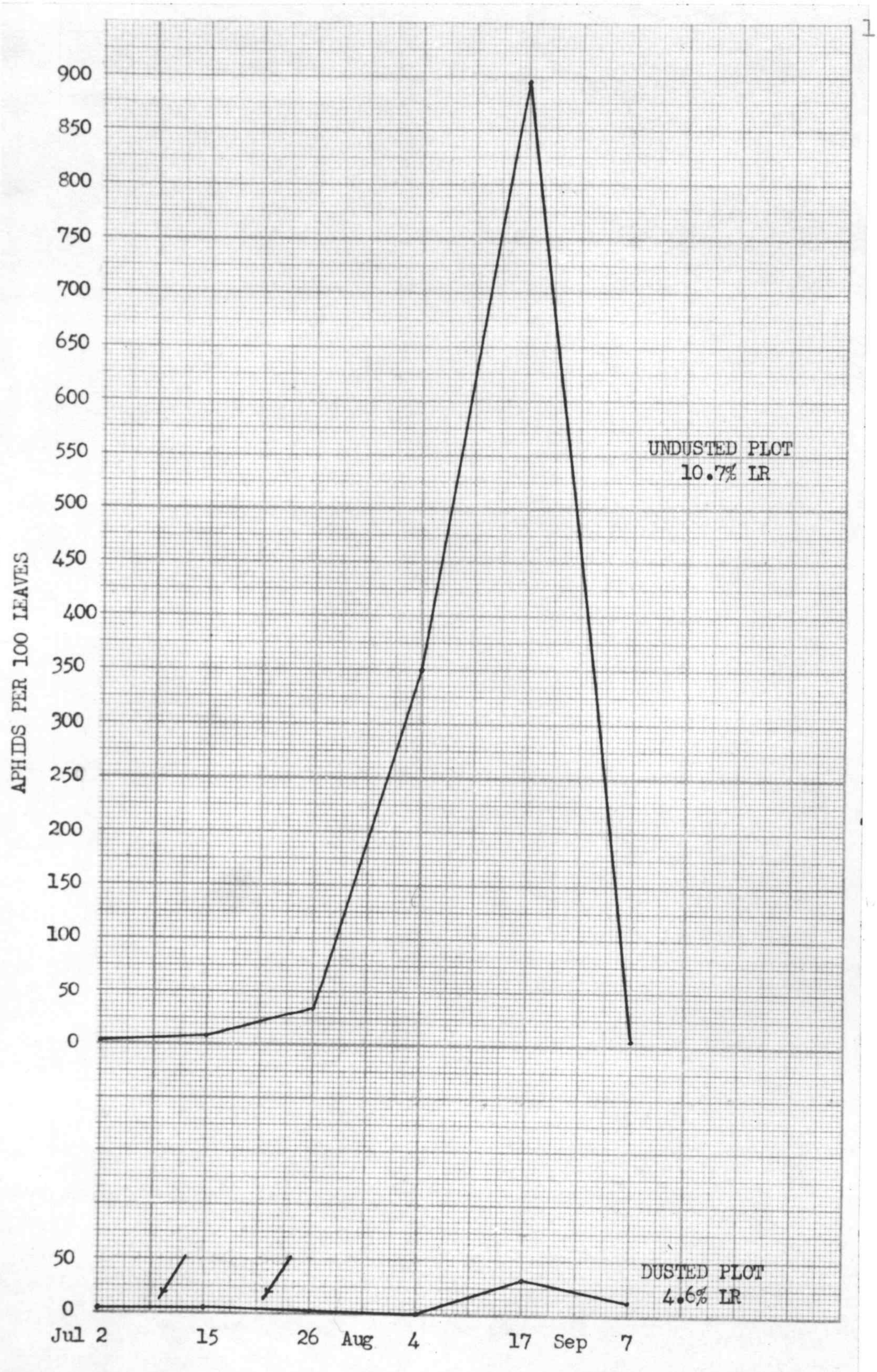


Fig.22 Numbers of Aphids in Lyon State Line Plots, Merrill, 1947.

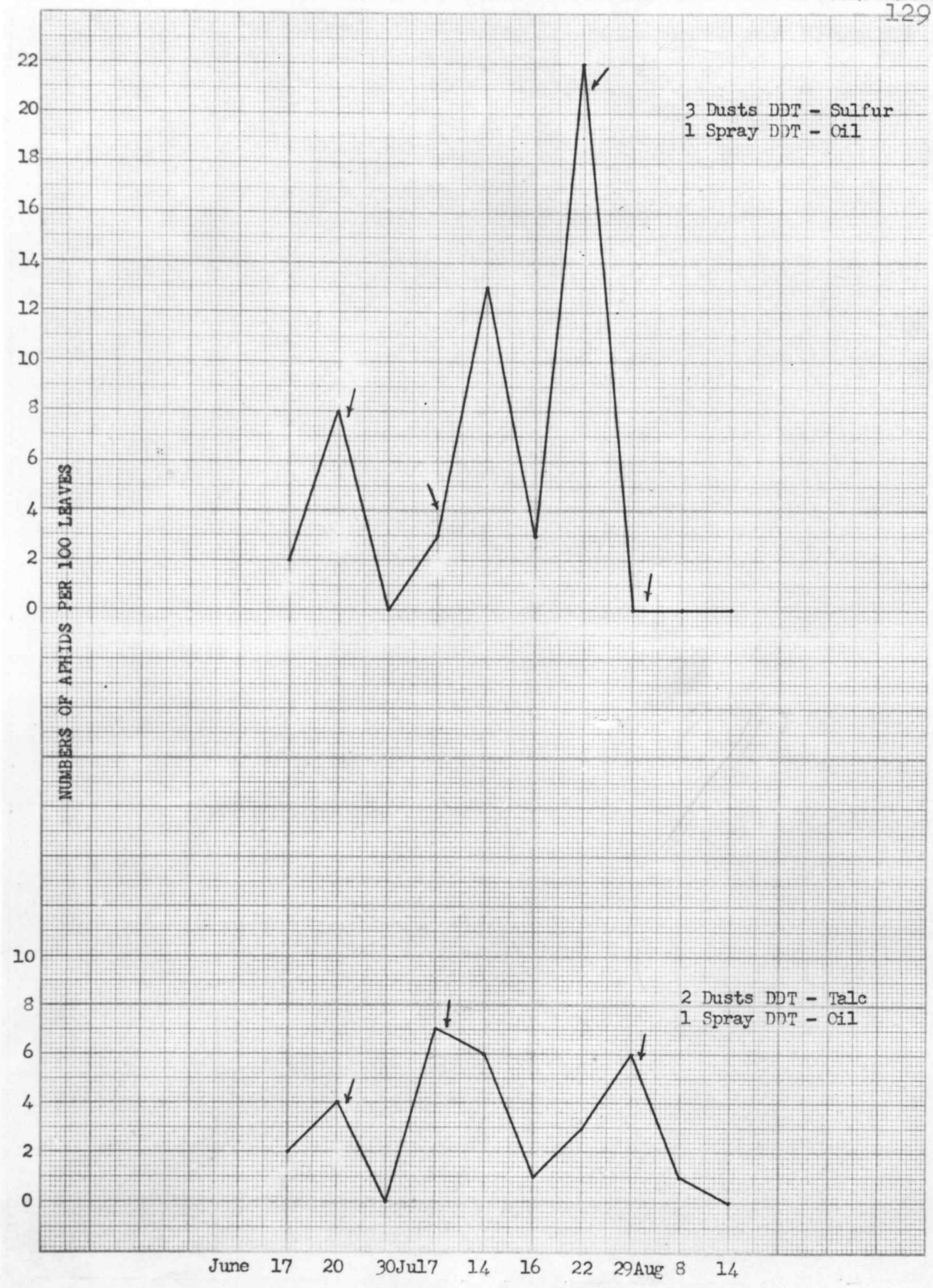


Fig.23 Aphid Populations in Warren Plots, Klamath Falls, 1947.

difference may be due to varying conditions in different parts of the field, but prove DDT-talc to be at least as satisfactory an aphicide as DDT-sulfur.

(4) Small Insecticide Plots, 1947:

Since the large field plots for 1947 were treated with a single material, small plots of White Rose potatoes at the Entomology Farm, Corvallis, were utilized for testing insecticides whose capacity as aphicides was not known. These plots were three rows wide, and approximately 75 feet long. All three rows were dusted carefully with a hand duster, but only the center row was used in estimating numbers of aphids. Counts were based on 50 leaf samples of lower leaves, and were made before dusting, and then following dusting at 4, 24, 48, and 96 hours.

It was found that the materials used killed in the following order, with the most rapid acting material listed first: HETP[1] spray 1-800, three per cent nicotine dust, one per cent gamma isomer of benzene hexachloride, five per cent piperonyl butoxide, 2.5 per cent piperonyl cyclonene, three per cent DDT plus 89 per cent sulfur and two per cent oil, ten per cent DDT plus pyrethrum, five per cent chlordane, and five per cent chlorinated camphene.

In order of residual effectiveness, with the

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[1] California Spray-Chemical Co. Vapotone, containing 10% hexaethyl tetraphosphate.

longest-acting material listed first, they were: three per cent DDT plus 89 per cent sulfur and two per cent oil, ten per cent DDT-pyrethrum, one per cent gamma benzene hexachloride, five per cent chlordane, five per cent chlorinated camphene, five per cent piperonyl butoxide, 2.5 per cent piperonyl cyclonene, three per cent nicotine dust, and 1-800 HETP spray.

The same year, Stitt (62) found the following to be the best insecticides for potato aphids in Washington, best materials being listed first: five per cent DDT, one per cent gamma benzene hexachloride, one per cent Parathion, five per cent chlordane, and ten per cent chlorinated camphene. Landis (66) found HETP sprays to be very effective, but noted that their effect was lost almost immediately. He concluded that five per cent DDT was the best all-round insecticide for potato aphids.

(5) Laboratory Insecticide Tests, 1948:

To supplement and substantiate the findings in the small insecticide plots in the field, laboratory studies were initiated in the spring of 1948 to test various insecticides. The particular aim was to determine which insecticides killed more quickly than did DDT, and which were effective for long periods.

The tests were made in the basement of Agriculture Hall, in a room held at constant temperature and humidity.

The aphids (peach) were cultured on seedling cabbage plants. Whole leaves, infested with aphids, were cut from the plants, and placed in vials of water in large petri dish halves. A film of mineral oil around the edge of the dish prevented the escape of the aphids. The detached leaves were placed in a dust-settling chamber ten inches in diameter and about 40 inches tall, housed in a large rectangular chamber of composition board to nullify convection currents. The dust was weighed carefully, placed in a glass nozzle, and blown up into the chamber with air from a specially rebuilt bicycle pump. Tests with glass slides showed that a given charge of dust settled out uniformly in all parts of the chamber for a given unit of time.

Twelve different materials were tested, some at more than one concentration. Of these, two showed definite promise alone, and two were rapid killing and might prove of value with DDT or similar materials. One or two tests, with five leaves in each test, were made with each of the insecticides used. The results of the tests are summarized below:

Faster than DDT-sulfur:

1. Three per cent nicotine dust from 14 per cent alkaloid concentrate--100 per cent KD[1] in one hour.

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[1] Knockdown.

2. One and one-half per cent nicotine--100 per cent KD in one hour, but partial recovery in 48 hours.

3. Five per cent alkyl sulfonate--100 per cent KD in 24 hours.

4. One per cent HETP (Brand I)--100 per cent KD in 24 hours.

5. One per cent HETP (Brand II)--99 per cent KD in one hour.

6. T-282 at 1/2 strength (thus, 1.25 per cent rotenone, 1.25 per cent piperonyl cyclonene, 0.0625 per cent pyrethrins)--100 per cent KD in one hour.

7. 1/4 per cent parathion--100 per cent KD in four hours.

Same speed as DDT-sulfur:

1. Five per cent chlorinated camphene--100 per cent KD in 48 hours.

2. Five per cent chlordane--95 per cent KD in 48 hours.

Poorer than DDT-sulfur:

1. Dust base 1-4 (one per cent rotenone, four per cent piperonyl cyclonene)--60 per cent KD in 24 hours.

As a result of these and other trials, nicotine and HETP (TEPP) were added to DDT dusts in the 1948 season. Parathion was tested in small field plots, since its effects on humans are not as yet well understood. Aryl alkyl sulfonate will be tested in the field in 1949, if sufficient quantities are available.

(6) Field Experiments, 1948:

With the results of the insecticide plots and laboratory tests in mind, the unexplainable results obtained with DDT became clearer. If DDT requires 48 to 96 hours to kill aphids, this is more than ample time for them to move about a great deal before they die. Unless aphid counts are made soon after dusting, then, they do not represent a true picture of the transmission possibilities.

During the 1947 season, aphids had been abundant in both the central Oregon and Klamath districts. In Multnomah county, the aphids were very numerous, much more so than in any other potato growing area. In 1948, the usual great number of aphids was found in Multnomah county, and about the same abundance in central Oregon as there was in 1947. At Klamath Falls, however, there were not nearly so many aphids as in 1947, and this explains, partially, why such a large proportion of the acreage entered for certification passed. Figures 38 to 43, in the Appendix, show the monthly mean temperature and total monthly rainfall for the three areas for 1947 and 1948. An examination of these data offers no clue to the differences in aphid abundance in the two years. The spring of 1947 was warmer than normal at Klamath Falls, and the spring of 1948 was cooler than normal, but this trend occurred in the other areas also. The year 1948 was a comparatively wet year, but this was also true for all areas. Until the complete life history and habits of this aphid are better understood, phenomena of this type will remain in the realm of speculation.

(a) Klamath Branch Station: There were a number of objectives to be attained in the 1948 program, and two of the most important were accomplished in a two-acre field of Netted Gems at the Klamath Branch Experiment Station. The seed contained about one per cent leafroll, none of which was rogued from the field. The field was divided in half, so that two one-acre plots resulted. Plot I was dusted twice, once on July 3 and again on July 15 at the rate of about 25 pounds per acre[1], using a small Root duster altered so as to provide two nozzles per row, set low in reference to the plants. Plot II was not treated during the season.

Aphid counts were made through the season, the estimates being based on six 100-leaf samples. The seasonal trends in both plots are shown in Figure 24. It is interesting to note that while the dusted plot had more winged aphids migrate into it (a mean of 0.83 per 100

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[1] California Spray Chemical Co. Vapotone-DDT dust, containing 5% DDT, 1% oil, 92% inert materials, and 1.5% total organic phosphates of which 0.5% was tetraethyl pyrophosphate (TEPP). Standard Klamath Falls dust for 1948.

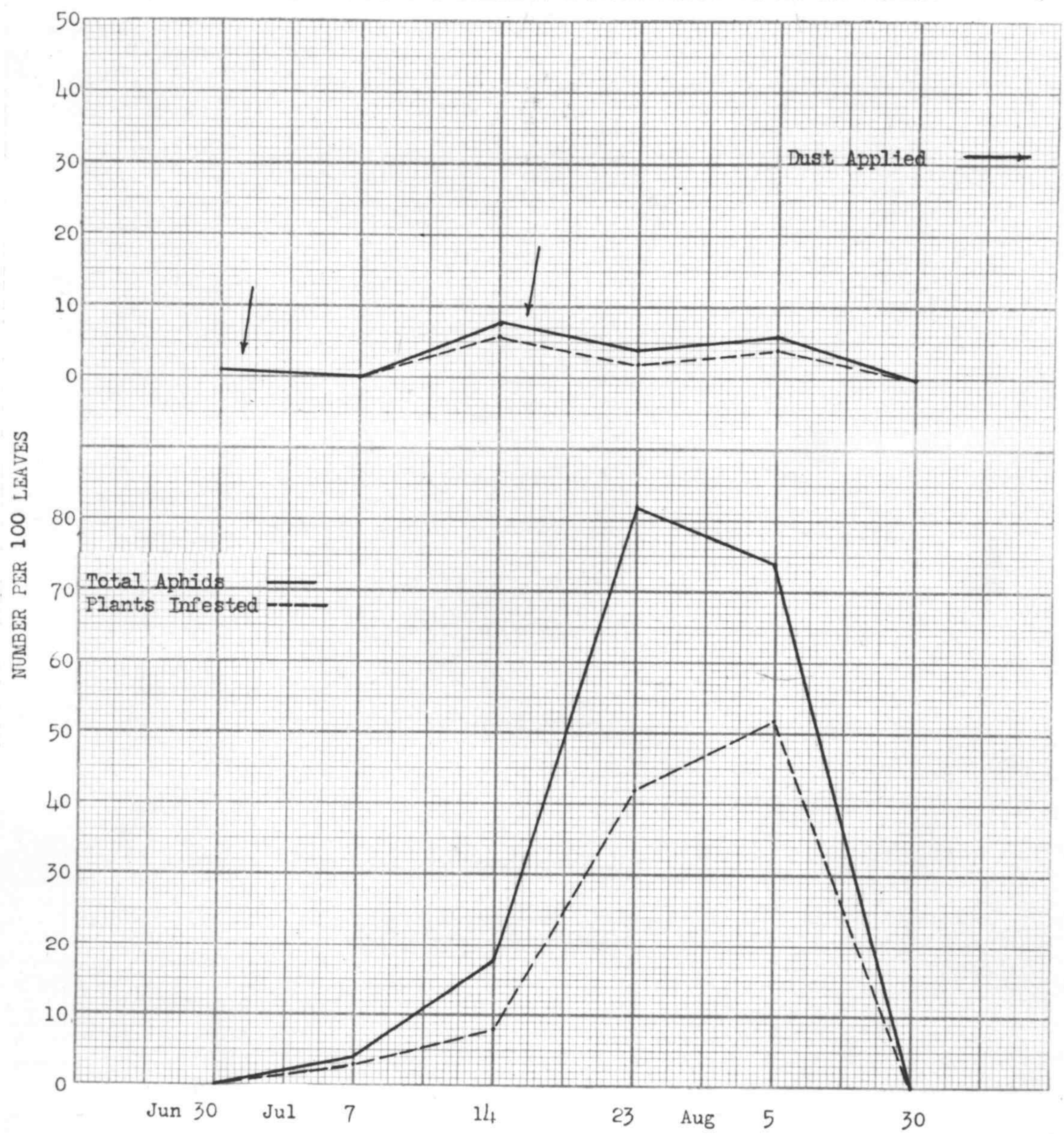

Fig. 24 Numbers of Aphids, and Leaves Infested, in Klamath Branch Experiment Station Gems, 1948.

Top, Plot I. Dusted Twice With 5% DDT, 1% Oil, 0.5% TEPP
Bottom, Plot II. Check, No Treatment.

lower leaves, as opposed to 0.5 for the check), the total aphids found during the season was much lower. The difference in mean aphids per 100-leaf sample, 3.01 as opposed to 29.66 in the check, is far greater than had been anticipated. The fact that this treatment accomplished its objective can well be seen in Figure 23.

The tuber samples dug from these plots have not yet been planted at Corvallis. But at the end of the growing season it was apparent from simple inspection that Plot II had a much greater amount of current season leafroll than did Plot I.

This small experiment indicated, then, two things not previously known: first, that small plots of one acre or less may be used in work of this type; and second, careful dust applications early in the season will aid greatly in reducing transmission of leafroll in areas where but one or two migrations into the fields occur each year.

(b) Louis Lyon Plots: A 35-acre field of Netted Gems at Merrill was divided into six plots of unequal size. The seed planted was the best available, with little, or no, virus diseases. The data, summarized in Table 13, show that aphid reduction was achieved about as was anticipated.

Plot I was dusted weekly by means of a Niagra six-

Table 13

Numbers of Aphids Found on Leaf Samples From Lyon Plots, Merrill, 1948

Plot No.	Date of Count June 20	21	22	26	July 2	6	13	17	28	August 4	Totals	Dates Dusted[2]
I	0[1]	2	0	0	0	0	2	1	0	1	6	22 June, 29 June, 8 July, 13 July, 22 July
II	0	1	0	0	0	0	1	1	0	1	4	29 June, 13 July, 22 July
III	0	2	0	6	0	6	6	14	5	2	41	29 June, 22 July
IV	0	1	1	1	0	0	2	21	2	1	29	29 June, 22 July
V	0	1	0	0	2	2	9	1	0	8	23	13 July
VI	0	2	0	0	2	2	9	28	246	36	325	Check--no dust

[1]The numbers in the body of the table represent number of aphids on 300 lower leaves.

[2]All applications were ground dusts (DDT-sulfur), except the treatment of 22 July consisted of a spray containing 4.5% DDT in kerosene base oil and applied by airplane.

The dust used on Plot IV contained 5% DDT plus 0.5% TEPP.

row, 12-nozzle, Model AA duster, driven by a power takeoff on the tractor carrying it. The amounts applied varied from 15 to 38 pounds per acre, depending on the size of the plants. Plot II was dusted every two weeks, Plot III was dusted whenever the aphid count rose, and Plot IV was dusted the same dates as III, except that DDT-TEPP was used here, instead of the D-Fusul-4 used on the other plots. Plot V had but one application during the season, and VI was an untreated check. Plots one through four were sprayed once at the rate of 6.5 gallons per acre, by means of a Stearman biplane carrying a 30-foot boom beneath the wings, and discharging the spray through 36 nozzles spaced uniformly along the boom.

The total counts of aphids on 3000 lower leaves during the entire season reveal that Plots I and II had about the same number, showing that a dust every two weeks was as good as one a week, under these conditions. Plot IV had fewer aphids than III, indicating that the addition of the TEPP was of some value; perhaps it will be shown to have more value when the tuber samples are read. Plot V had a few less aphids than III and IV, and this can be explained only as a variation within the field. Plot VI had a great many more aphids than any other, as would be expected, since it had no treatment.

The first inspection of this field revealed not a diseased plant. The second inspection report lists a trace of rugose mosaic and a trace of late breaking virus.

(c) Dehlinger Plots, 1948: In the 22-acre Netted Gem field of Dehlinger, eight plots were laid out to compare the effectiveness of DDT-TEPP dust with two formulations of DDT-sulfur, in rogued and unrogued plots, in reducing the aphids to economic zero. The end result, of course, was to determine whether a quick killing agent added to DDT would hold the transmission of leafroll to a low point. The layout of plots is shown in Figure 25, as well as the treatments applied and the total aphids for the season found on 3300 lower leaves. The seed used contained approximately one per cent leafroll, and it is presumed this was removed from the east half of the field during the roguing operation.

Two applications of dust, at the rate of 25 pounds per acre, were made in all treated plots. A Niagra six-row duster with six Y-type nozzles, powered from the tractor on which it was mounted, was used to apply the materials. Toward the end of the season, the grower had an airplane spray the entire field with 4.5 per cent DDT in kerosene base oil.

The number of aphids found in each plot at the time of each count appears in Figures 25 a, b, c, d. It becomes apparent after a study of these figures that a third

22 ACRES NETTED GEMS

PLOT IA ROGUED IX 146 APHIDS	PLOT IIA ROGUED IX 145 APHIDS	PLOT IIIA ROGUED IX 275 APHIDS	PLOT IVA ROGUED IX 125 APHIDS
5% DDT, 0.5% TEPP PLOT IB UNROGUED	5%DDT,88%S,1%OIL PLOT IIB UNROGUED	UNDUSTED PLOT IIIB UNROGUED	4%DDT,80%S,1%OIL PLOT IVB UNROGUED

(ALL PLOTS RECEIVED ONE 4.5%DDT-OIL SPRAY BY PLANE)

FIG. 25 KARL DEHLINGER-KLAMATH FALLS-1948

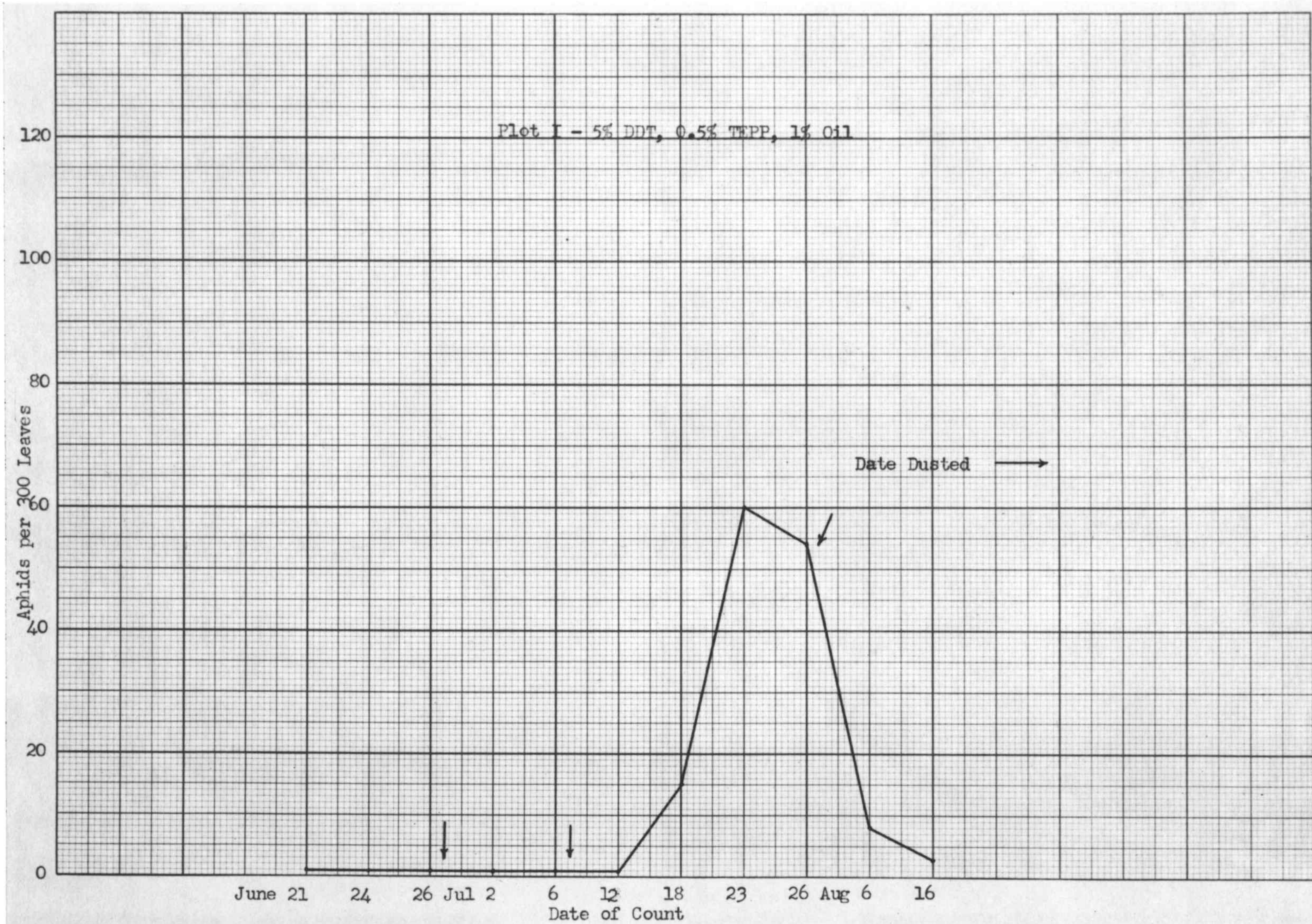

FIG. 25a KARL DEHLINGER NETTED GEMS
Klamath Falls - 1948

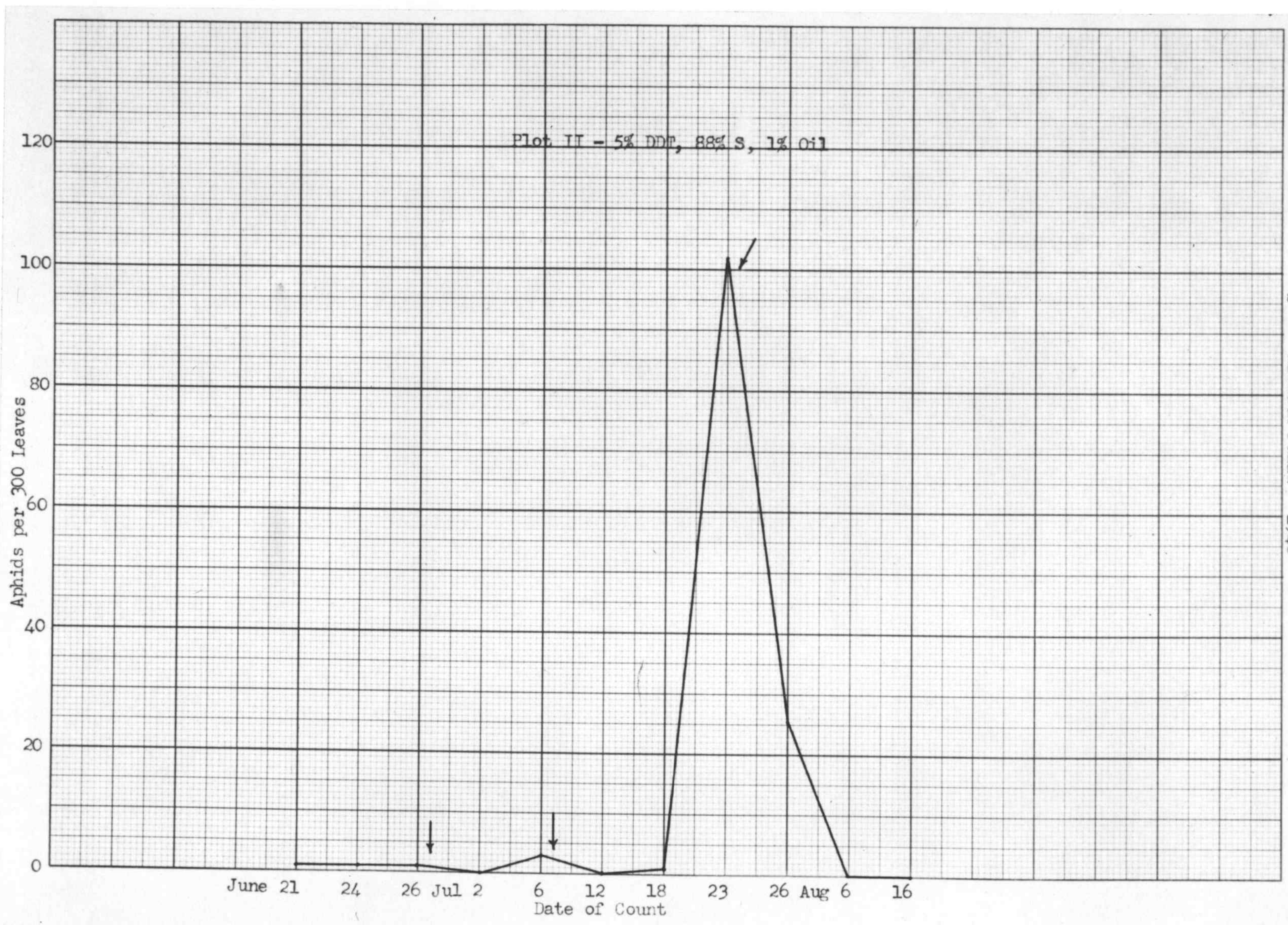

Fig. 25b KARL DEHLINGER NETTED GEMS
Klamath Falls - 1948

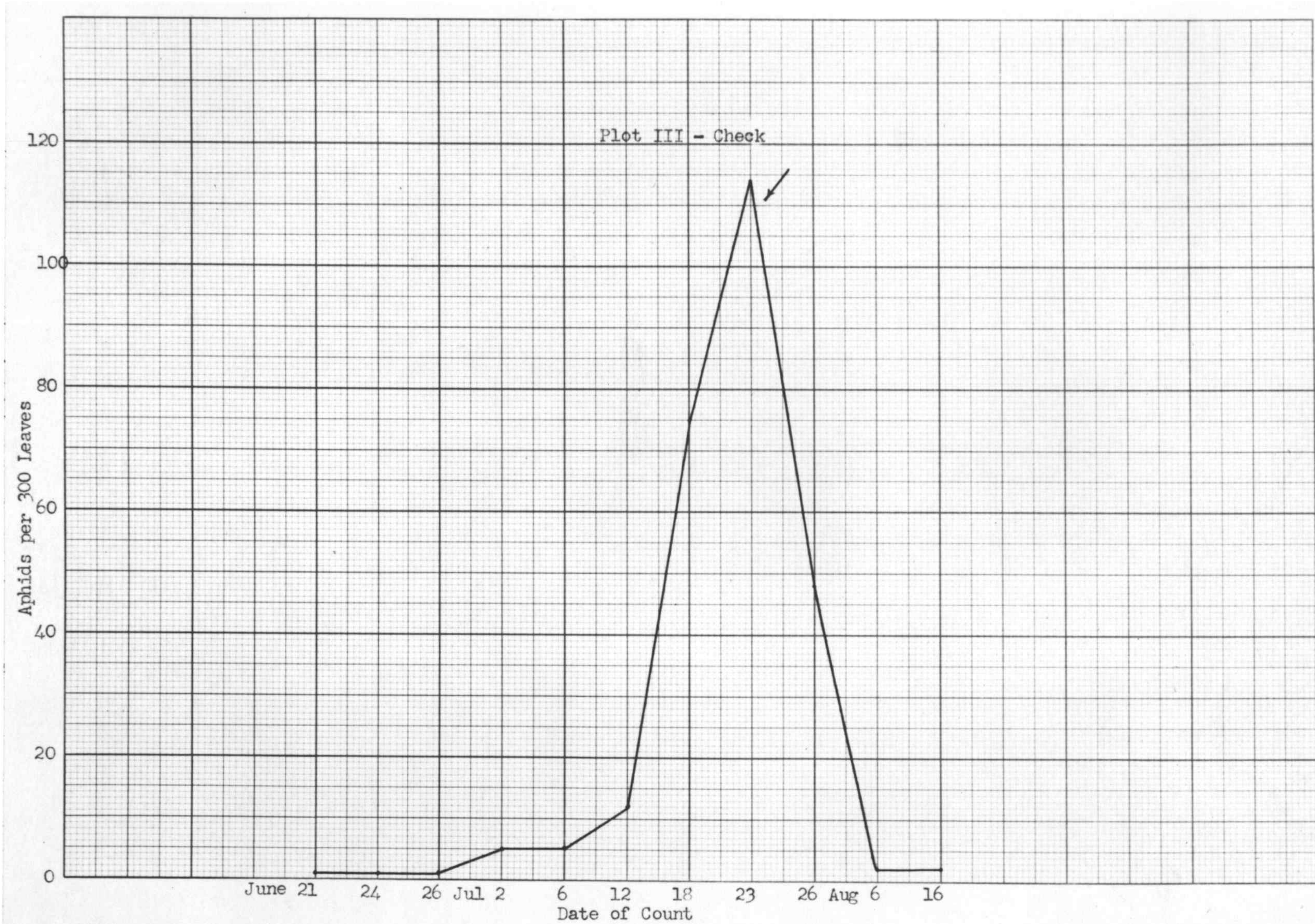

Fig. 25c KARL DEHLINGER NETTED GEMS
Klamath Falls - 1948

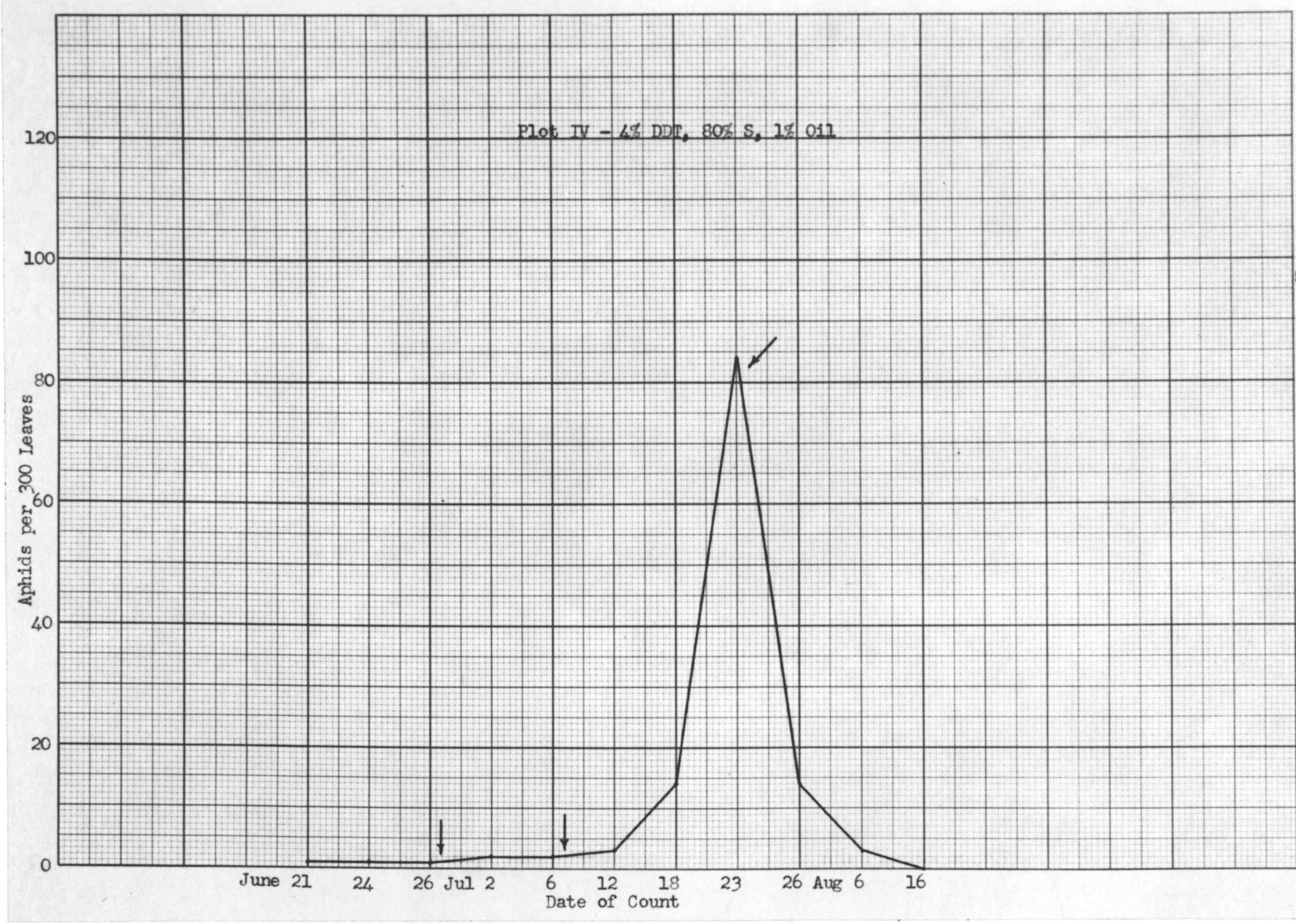

Fig. 25 d
KARL DEHLINGER NETTED GEMS
Klamath Falls - 1948

dust should have been applied on or about July 18, when the number of aphids in each plot reached 15 or more. This failure to apply a treatment at this time may well nullify the effects of the materials prior to this occurrence.

The curves well illustrate the tendency of DDT-TEPP to bring about a continued lag in aphid buildup following treatment, in addition to killing more quickly. Although the DDT-sulfur dusts gave good control early, the number of aphids in these plots begins to approach that in the checks following July 18. The number of aphids in all plots is far higher than can be left alive, if there is hope of controlling disease spread.

The tuber samples collected here will probably not show the differences that would be expected, since more than enough aphids were present part of the season to transmit a great deal of leafroll to healthy plants in all plots.

(d) Warren Plots, 1948: In the Warren field, as in the other Klamath Falls plots, the two plots were arranged to compare the effectiveness of DDT-TEPP dusts with DDT-sulfur in reducing the number of aphids present. The particular seed lot chosen for the plots was the Sester-5 lot, and it contained 1.5 per cent mild mosaic at the beginning of the season. Plot I was treated with three applications of D-Fusul-4, Plot II with DDT-TEPP. Both received one application of airplane spray at 6.5 gallons per acre. The dusts were applied at 25, 35, and 45 pounds per acre. At the end of the season, the usual 440 tuber sample was taken from each plot, to be grown back at Corvallis.

Twice during the season the aphids multiplied rapidly enough to produce large numbers. They were reduced soon in both cases, but these buildups could easily confuse the results. It is evident, on examination of Figures 26 a and b, that the DDT-TEPP dust was superior, though not dramatically so. The hope is that the careful sample collected may show differences in the two plots, although a gross sample collected for certification disclosed practically no disease whatsoever.

This seed grower is careful to carry out all measures possible to accomplish aphid control, and to remove diseased plants from his field. He uses a Harvey Berg six-row duster, with a single nozzle per row, directed on the tops of the plants. The machine has a hood two feet wide, and a trailing canvas eight feet long, which increases its efficiency a great deal, and allows its successful use even during light windy weather.

(e) Glenn Wright Plots, 1948: This experiment was made in a 30-acre field planted with four different

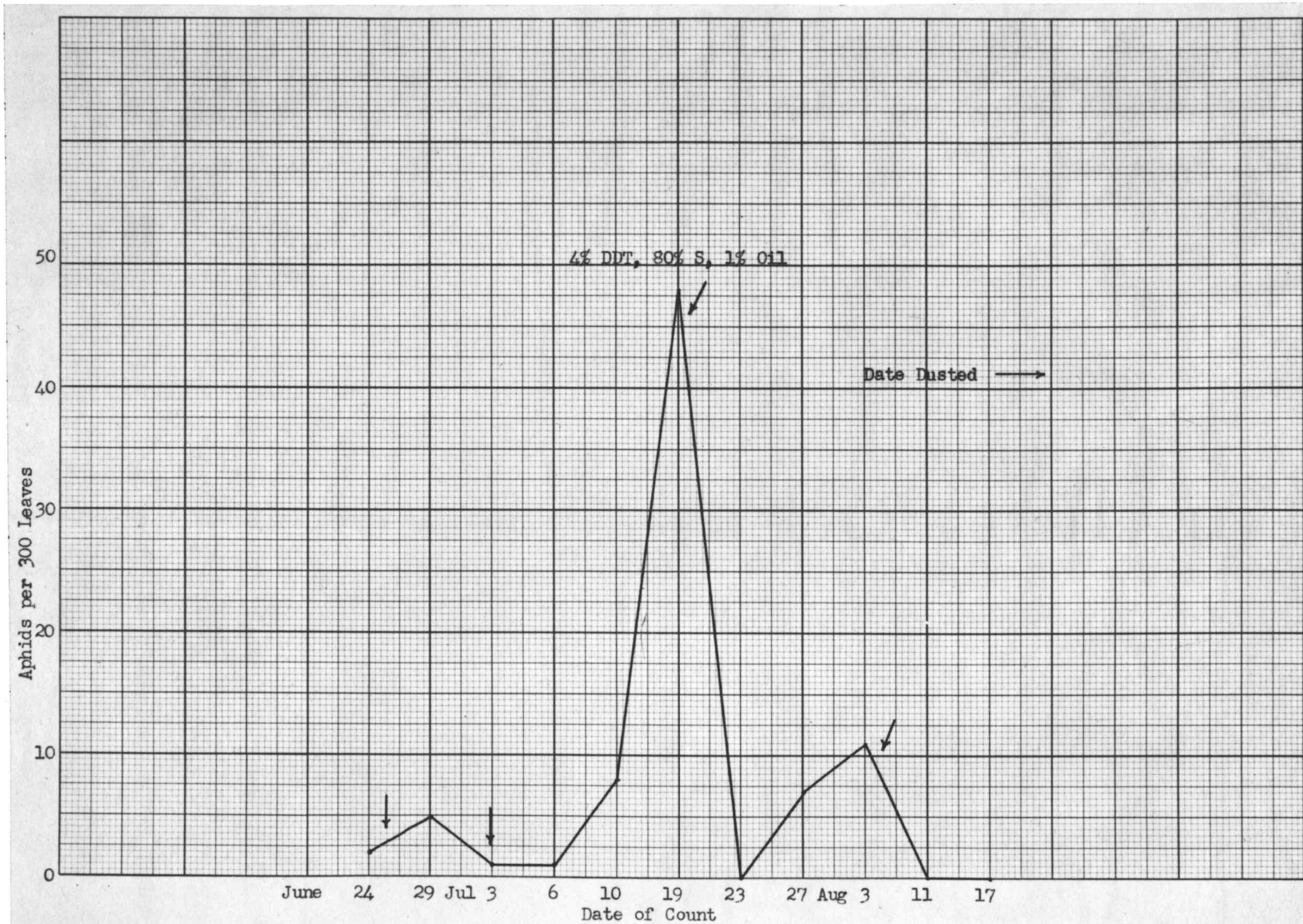

FIG. 26 SCOTT WARREN WHITE ROSE
a Klamath Falls - 1948

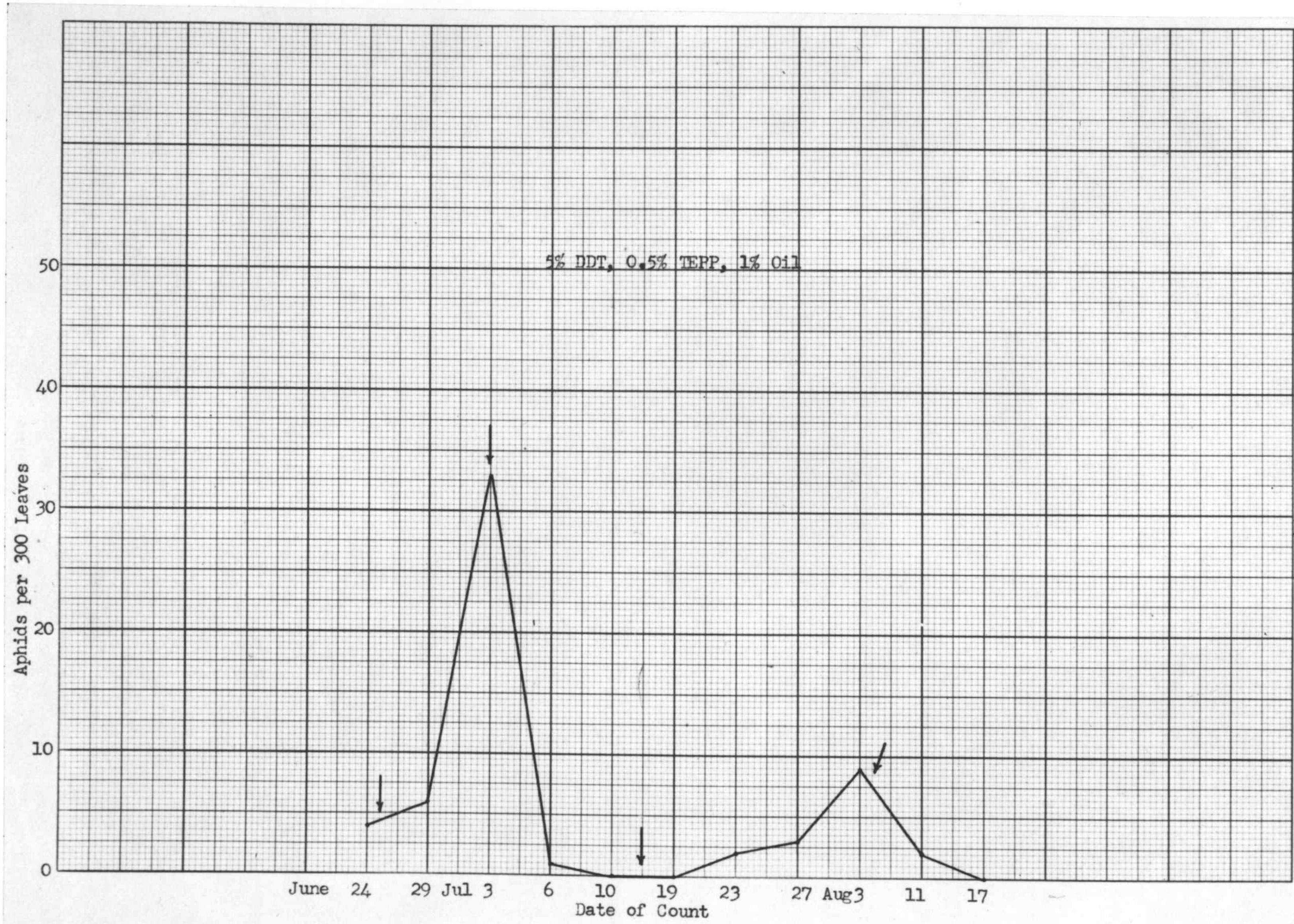

Fig. 26b SCOTT WARREN WHITE ROSE
Klamath Falls - 1948

seed lots. The field was somewhat rectangular in shape, with seed lots planted side by side. On the south end was a lot of McKaig seed carrying one per cent leafroll, next a two-acre lot of Montana seed with only a trace of leafroll, then a two-acre piece planted to Canadian seed with six per cent leafroll, and last a Canadian lot containing 2.5 per cent leafroll. One-half the entire field was sprayed by airplane in order to determine whether late season aphid control was worth the cost by depressing the rate of disease transmission. At the end of the season, a tuber sample was collected from the sprayed and the unsprayed half of each seed lot. It is to be determined from this sample, for example, whether late spraying will help in a seed lot carrying very little leafroll and perhaps not be nearly so good in a lot carrying one per cent or more leafroll.

One hundred seventy-five aphids were found on the 1000 lower leaves examined in the untreated plot, while only 51 were collected in the sprayed plot (Table 14). It is apparent from the table that rather good aphid control was obtained by the spray, but it is not known how many aphids there were present in the field during the early part of the season, and even if the samples show slight differences it will be difficult to explain them since it is not known when transmission occurred.

Table 14

Number of Aphids Found in Wright Plots,
Klamath Falls, 1948

Date	No. of Leaves Examined	No. of Aphids Found	No. of Leaves Infested
	Plot I--Unsprayed		
July 24	500	35	20
August 2	200	60	20
August 12	100	61	25
August 18	200	19	15
Totals	1000	175	80
	Plot II--Sprayed		
July 24	500	23	14
August 2	200	25	15
August 12	100	2	1
August 18	200	1	1
Totals	1000	51	31

The comparative changes during the season in numbers of aphids in all check plots in Klamath County for 1948 are shown in Figure 27. This also illustrates the fact that the number of aphids varies a good deal from area to area, and from time to time.

(f) Multnomah County Farm Plots, 1948: Again, a ten-acre field of White Rose potatoes was made available on this farm for dusting experiments. The field was long and narrow (Figure 28), which necessitated planting the long distance of the field. Thus, the duster treated one plot, drove through the next plot, dusted the

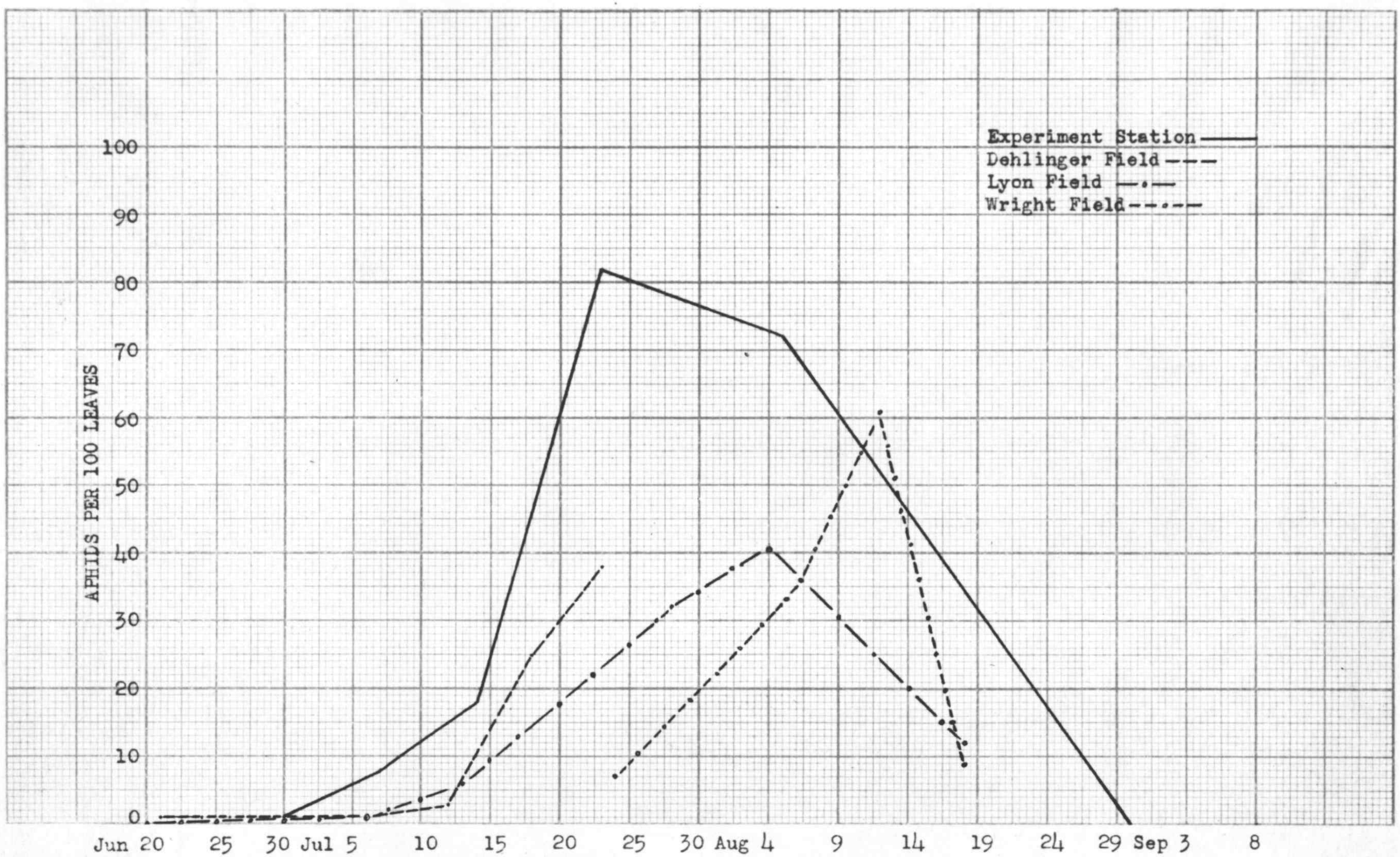

Fig. 27 Aphid Populations in Check Plots, Klamath Falls, 1948.

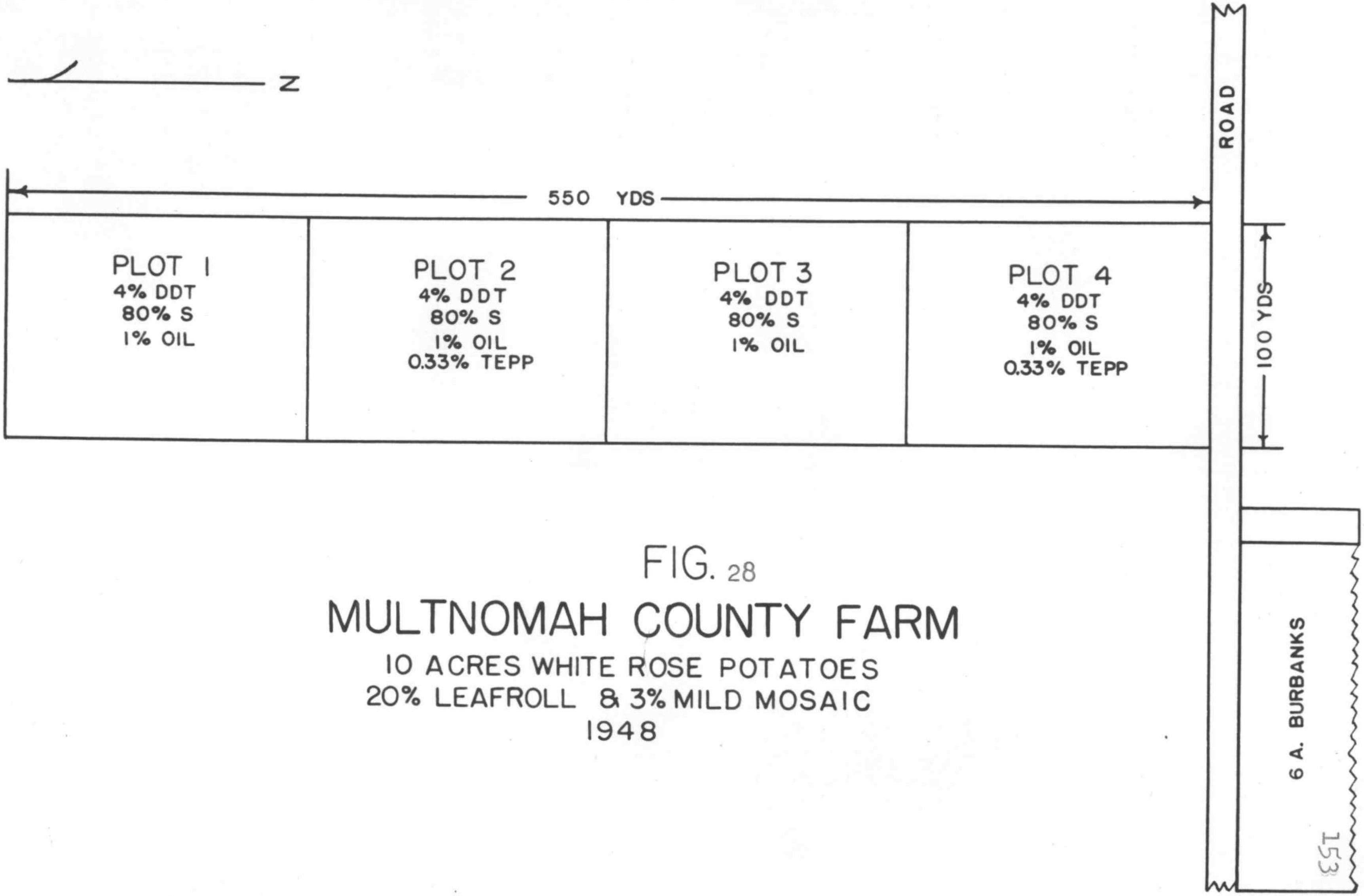

FIG. 28
MULTNOMAH COUNTY FARM
10 ACRES WHITE ROSE POTATOES
20% LEAFROLL & 3% MILD MOSAIC
1948

next, and so on. This caused concern as to how much insecticide was being dropped in a plot where it did not belong. The results obtained were rather better than had been expected, however.

Plots I and III received six applications of D-Fusul-4, at rates of from 15 to 45 pounds per acre, depending on the size of the plants, and Plots II and IV were dusted with this same material, to which had been added 1.5 per cent total organic phosphates[1]. Counts of aphids on 100 lower leaves were made in each plot before dusting, and then four hours, 24 hours, and four to five days after dusting. At no time during the season was perfect aphid reduction obtained, despite the fact that applications were made at ample rates, and the machine was adjusted to give as good coverage as is obtainable with machines now on the market. It was a six-row Messenger duster, with two nozzles set very low and directed in toward each row, and it was equipped with a ten-foot trailing canvas. Dusting was always done from about 7:30 A. M. until noon, and excessive winds were not encountered. Several times it rained lightly within eight to 24 hours after dusting.

The TEPP-DDT dust not only killed aphids more

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[1]Stauffer Chemical Co. mix, containing 4% DDT, 80% sulfur, 1% oil, 14.5% inert materials, 0.33% TEPP, and 1.17% related organic phosphates.

rapidly, but continued to hold them at lower levels than did the DDT alone. Figure 29 shows this reduction of the TEPP-DDT plots over the other two very well. Except for a few days in early September, it was from 40 to 80 per cent better than the DDT-sulfur alone in reducing the number of aphids. Individual records were kept for each leaf in the 100-leaf sample taken in each plot. Thus, Figures 30 a, b, and c show the number of aphids on 100 leaves at each count, and the number of leaves of the 100 on which aphids were found, and also the number of winged aphids present. This latter figure is of value in showing when the migration into the field ended. In other areas the migration did end, but here it merely slowed during mid-summer, and picked up again in the fall when the aphids left the field.

The amounts of virus diseases in the tuber samples collected in these plots are not yet known. Since the seed planted contained 20 per cent leafroll and three per cent mild mosaic, it will be fortunate if any of the samples contains below 100 per cent disease. A difficulty such as this merely emphasizes the necessity of growers utilizing every means at their command to combat potato viruses.

At the Multnomah County Farm, six acres of Burbank potatoes were also made available for testing insecti-

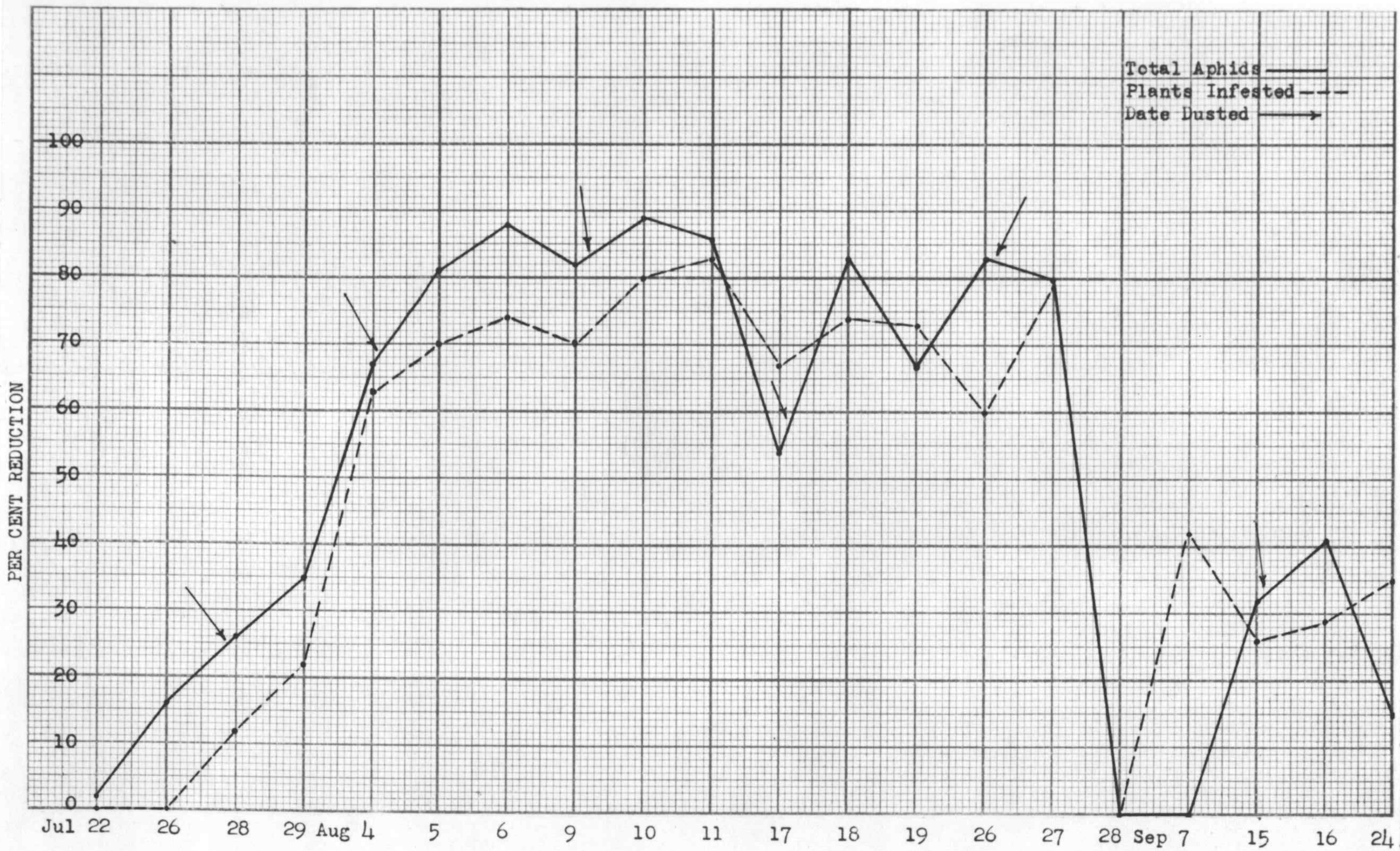

Fig. 29 Reduction in Numbers of Aphids in Plots 2 & 4 Over Plots 1 & 3, Multnomah County Farm, 1948.

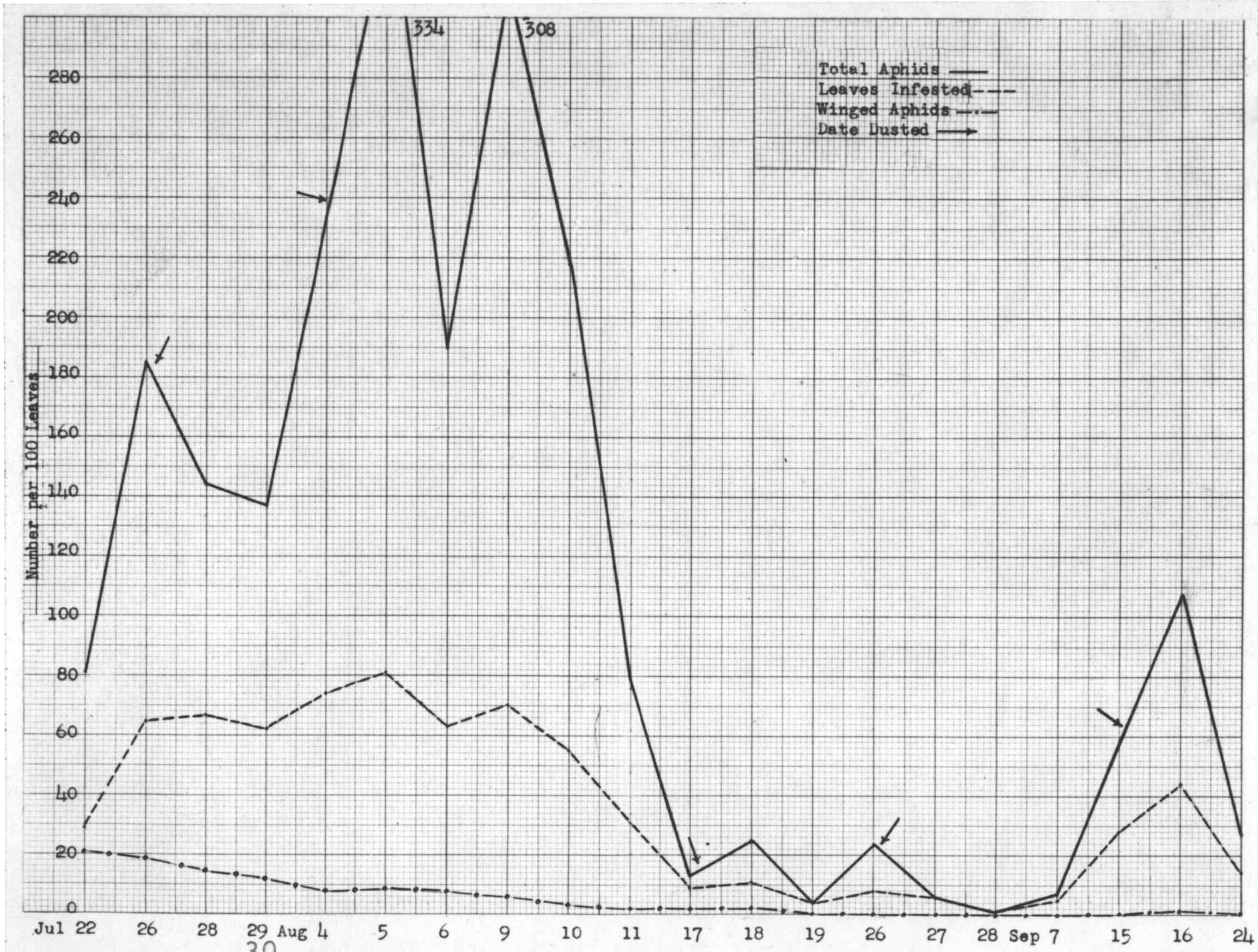

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Fig. a Numbers of Aphids, and Leaves Infested, Plot I Multnomah County Farm, 1948.

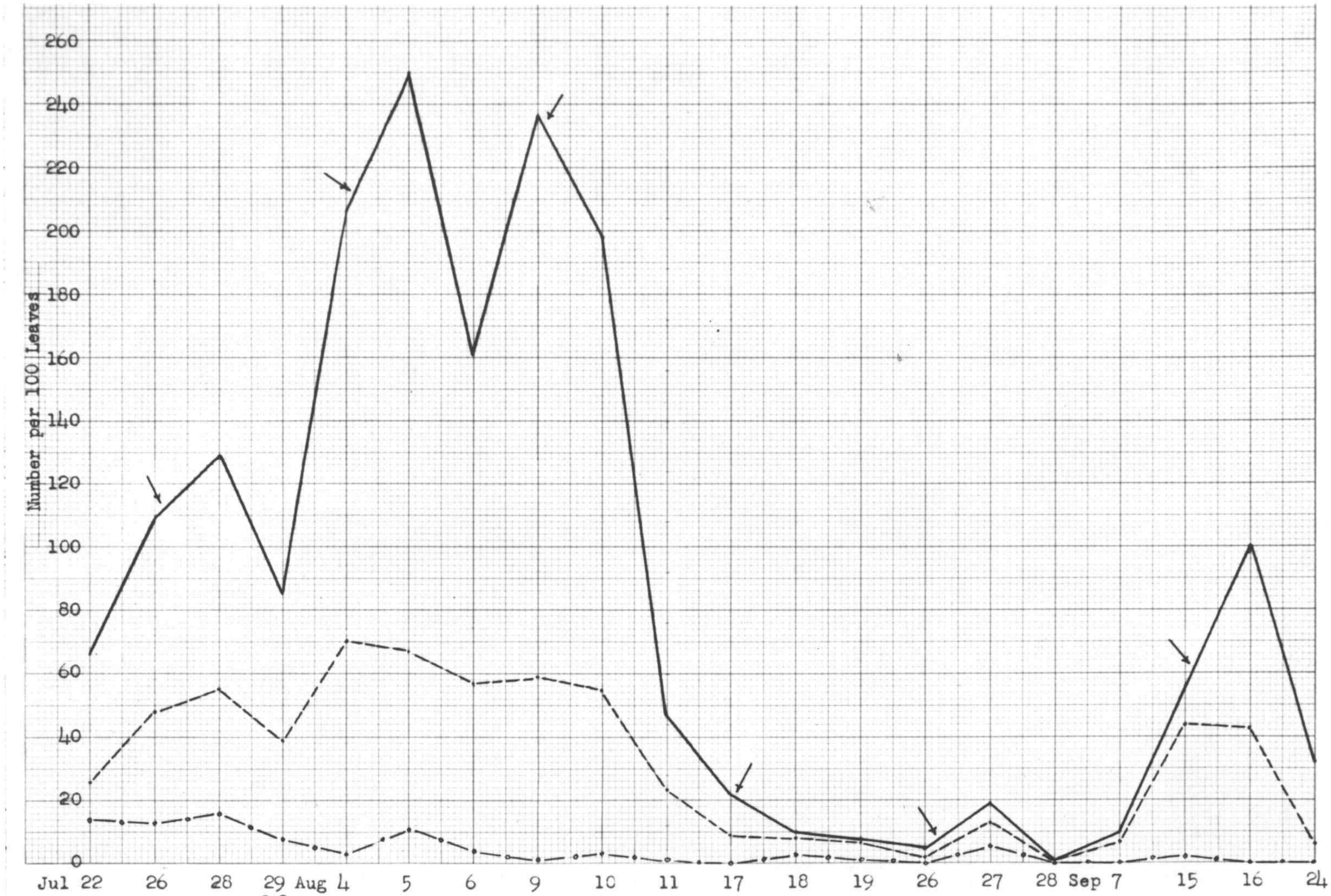

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Fig. b Numbers of Aphids, and Leaves Infested, Plot III Multnomah County Farm, 1948.

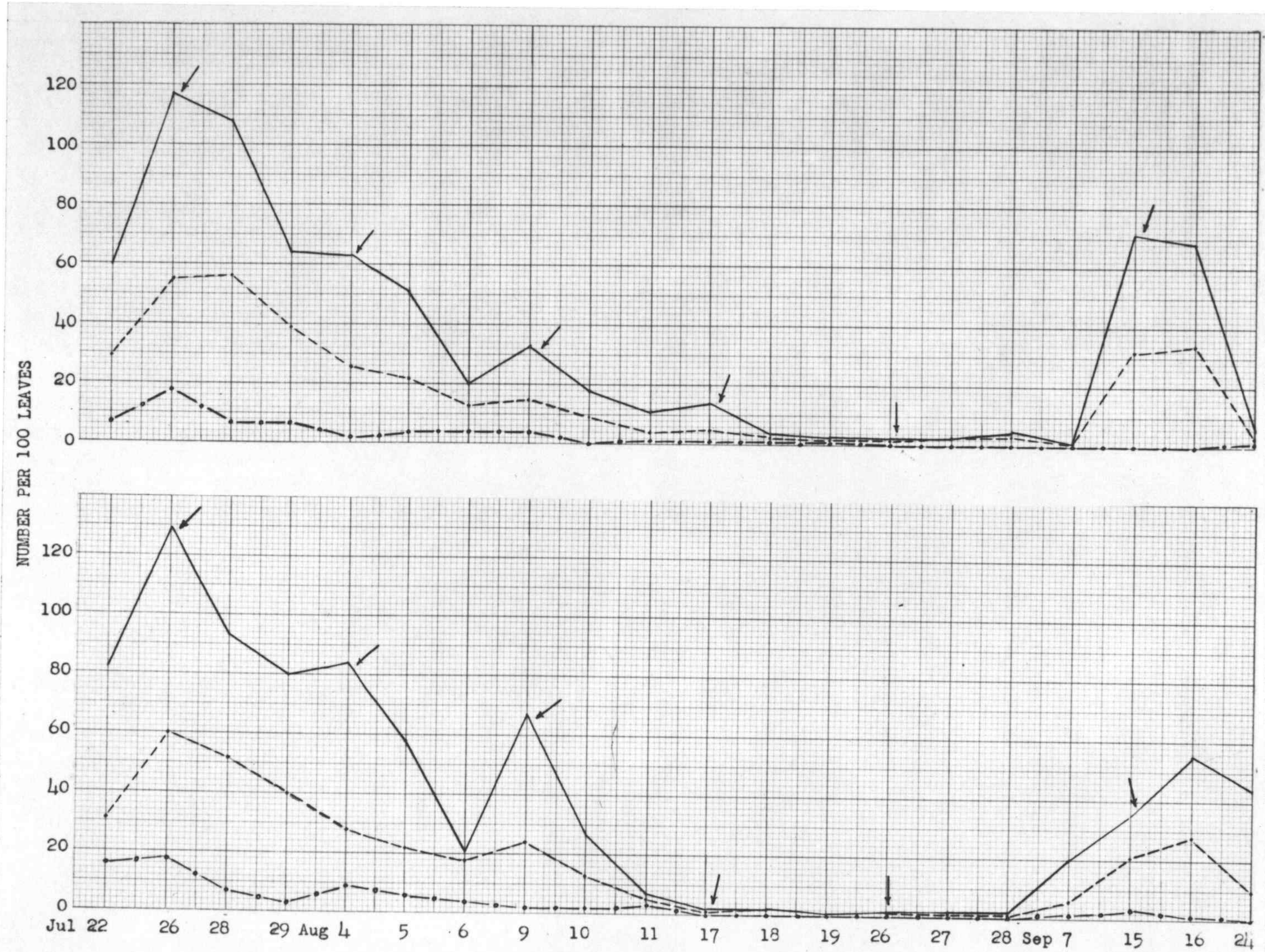

Fig. 30 Top - Numbers of Aphids, and Plants Infested, Plot IV Multnomah County Farm, 1948.
C Bottom - Numbers of Aphids, and Plants Infested, Plot II Multnomah County Farm, 1948.

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cides. The field was divided in half, and two applications of a dust containing five per cent DDT plus 42 per cent sulfur were made on one half. A dust containing five per cent DDT without oil was applied to the other half, both being put on on the same dates, with the machine used in the White Rose plots described previously.

While it appeared that the sulfur dust gave very slightly better reduction of aphids than did the plain DDT immediately following dusting, the number of aphids fell off sharply in both plots. This may have been due to the insecticides, or to natural conditions; which, being unknown, since an untreated check could not be arranged. It was found (Fig. 31) that the DDT-sulfur plots had a mean number of aphids of 59.82 per 100 lower leaves, while the plain DDT dust plot had 72.36. This difference is slight, and not significant with but one replicate of each treatment. Especially is this small disparity apparent when it is noted the mean number of winged aphids per 100 leaves for the two plots was four and five, and the mean number of leaves infested was 23.09 and 23.45, respectively.

(7) Small Insecticide Plots, 1948:

(a) Klamath Branch Station Plots: This Station provided two acres of White Rose potatoes for testing insecticides for their value in the aphid control program.

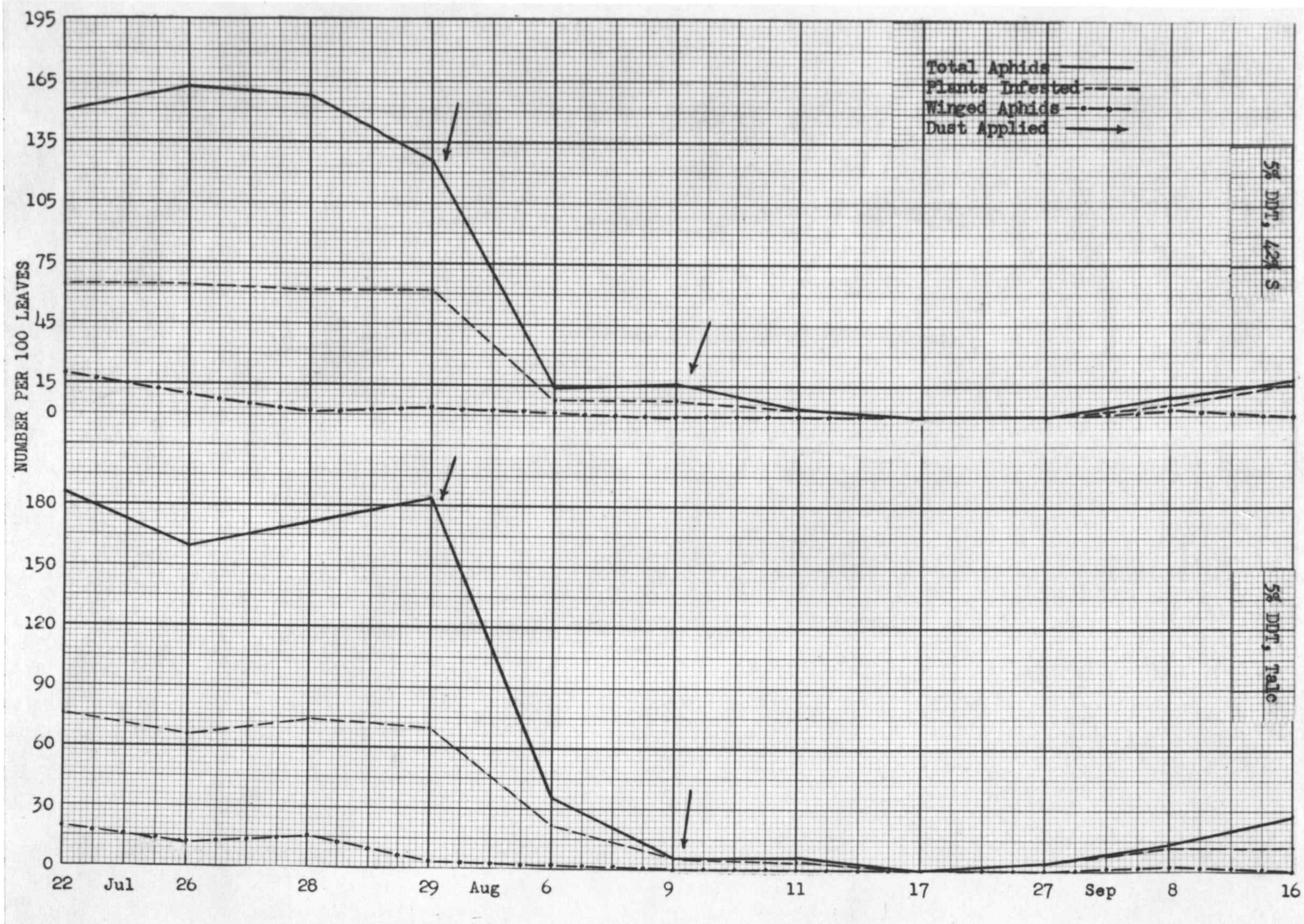

Fig. 31 Numbers of Aphids, and Plants Infested, in Multnomah County Farm Burbanks, 1948.

The field was divided so that each of the 14 materials was applied to four rows, and then two rows were left untreated between each two sets of materials. A Root four-row duster adapted so as to cover two rows with two nozzles per row was used to apply the dusts. The plants were dusted July 26, at about 20 pounds per acre. The reduction of aphids is summarized in Table 15 and in Figures 32 a, b, c. The table lists the materials and presents a summary of the mean aphid reduction, while the three figures graphically show the reduction of aphids at each count following dusting. A 50-leaf sample was examined in each plot at each count.

It will be noted that Parathion, five per cent DDT plus 42 per cent sulfur, and five per cent DDT plus 0.5 per cent TEPP and one per cent oil all gave 100 per cent reduction of aphids. Five per cent DDT plus 88 per cent sulfur and the same dust plus oil both gave 99 per cent reduction. This apparently indicates that the oil does not materially improve the performance of DDT-sulfur dusts. Four per cent DDT plus 80 per cent sulfur and this dust with oil added both gave 98 per cent reduction, and again it appeared that the oil was of no value. Five per cent DDT plus two per cent oil in talc, five per cent DDT plus 50 per cent sulfur, and four per cent DDT plus 2.3 per cent solvent and 50 per cent sulfur all reduced the

Table 15

Materials Used, and Aphid Reduction Accomplished, Klamath Branch Station Insecticide Plots, 1948

Plot No.	Insecticide and Company	Average per cent Reduction
1	4% DDT, 80% sulfur (Pacific Guano Co.)	98
2	5% DDT, 0.5% TEPP, 1% oil (Cal-Spray)	100
3	4% DDT, 2.3% solvent (Geigy)	93
4	5% Methoxychlor, 2% oil (duPont)	74
5	10% Chlorinated Camphene, 1% oil (Chipman)	95
6	5% Chlordane, 1% oil (Chipman)	50
7	4% DDT, 2.3% solvent, 50% sulfur (Geigy)	97
8	5% DDT, 88% sulfur (Chipman)	99
9	5% DDT, 88% sulfur, 1% oil (Chipman)	99
10	5% DDT, 50% sulfur (Chipman)	97
11	5% DDT, 42% sulfur (Niagra)	100
12	5% DDT, 2% oil, talc (duPont)	97
13	4% DDT, 80% sulfur (fused), 1% oil (Stauffer)	98
14	1% Parathion (Stauffer)	100
Check	Mean aphids per 50 leaves--203	

Plots dusted July 26, when plants half grown, 20 pounds per acre. Counts made 5 times in 13 days; July 27, 29, 31; August 4 and 9.

aphids by 97 per cent. Ten per cent chlorinated camphene gave a 95 per cent reduction, and four per cent DDT plus 2.3 per cent solvent 93 per cent.

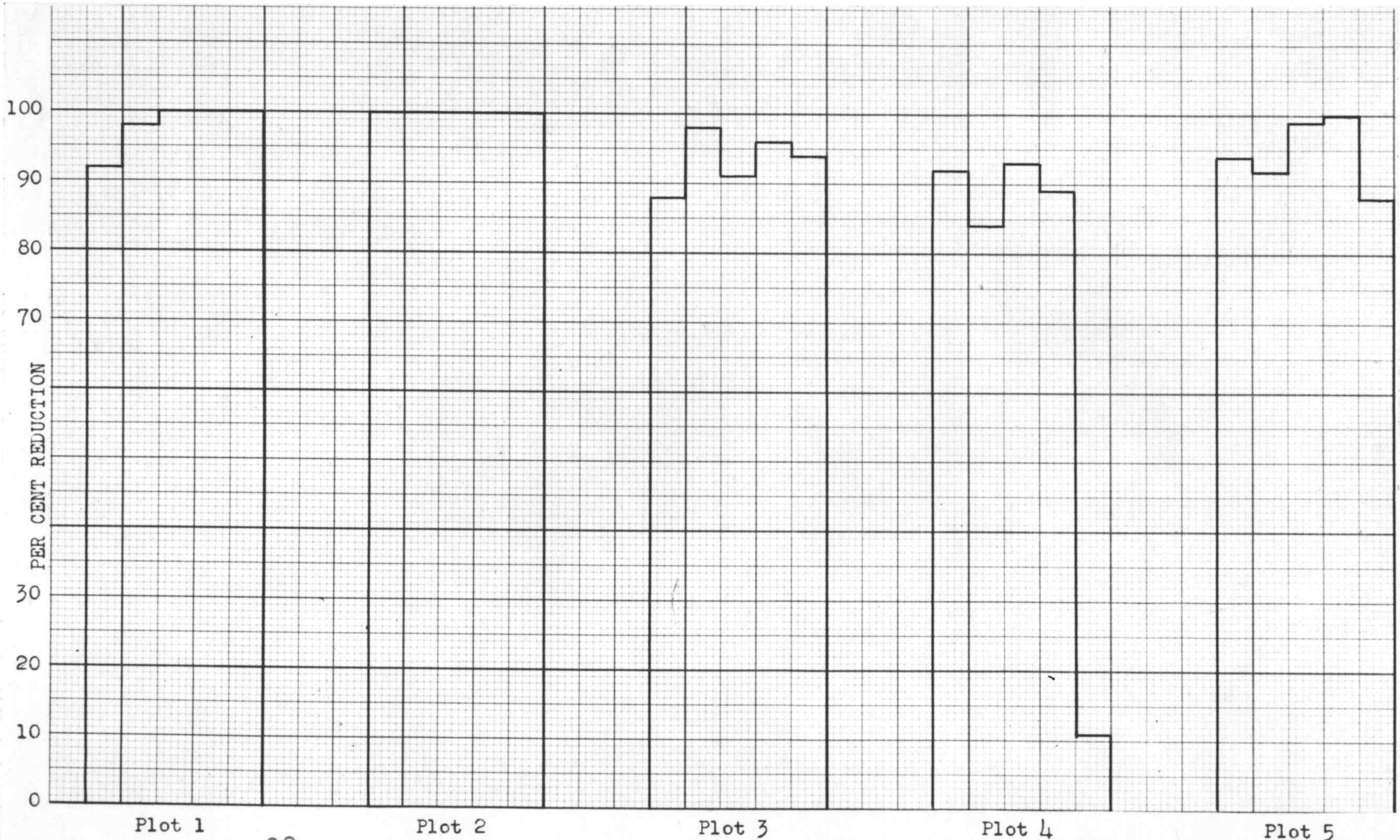

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Fig. a Aphid Populations in Insecticide Plots, Klamath Branch Experiment Station, 1948.

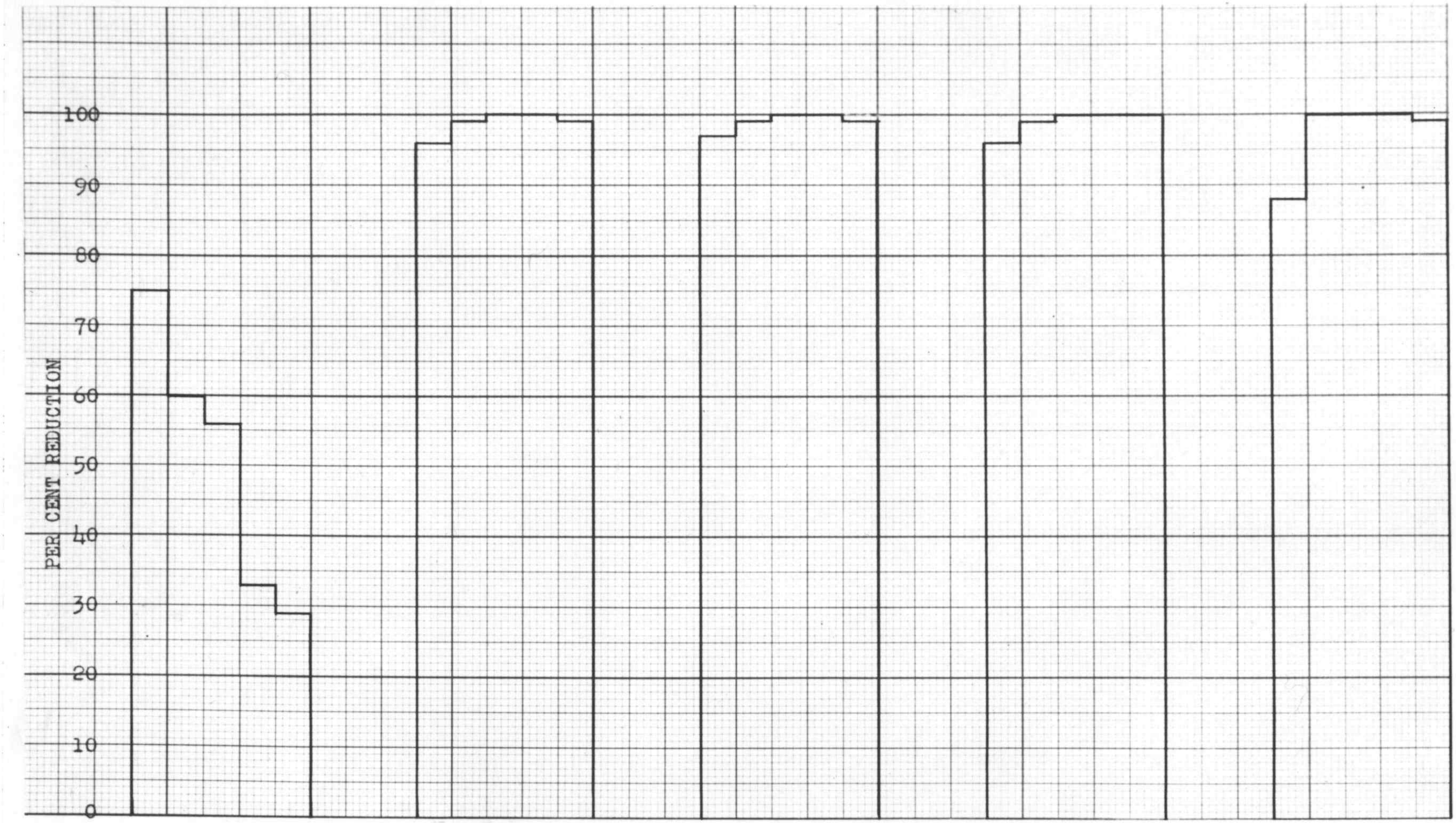

Fig. 32 b Aphid Populations in Insecticide Plots, Klamath Branch Experiment Station, 1948.

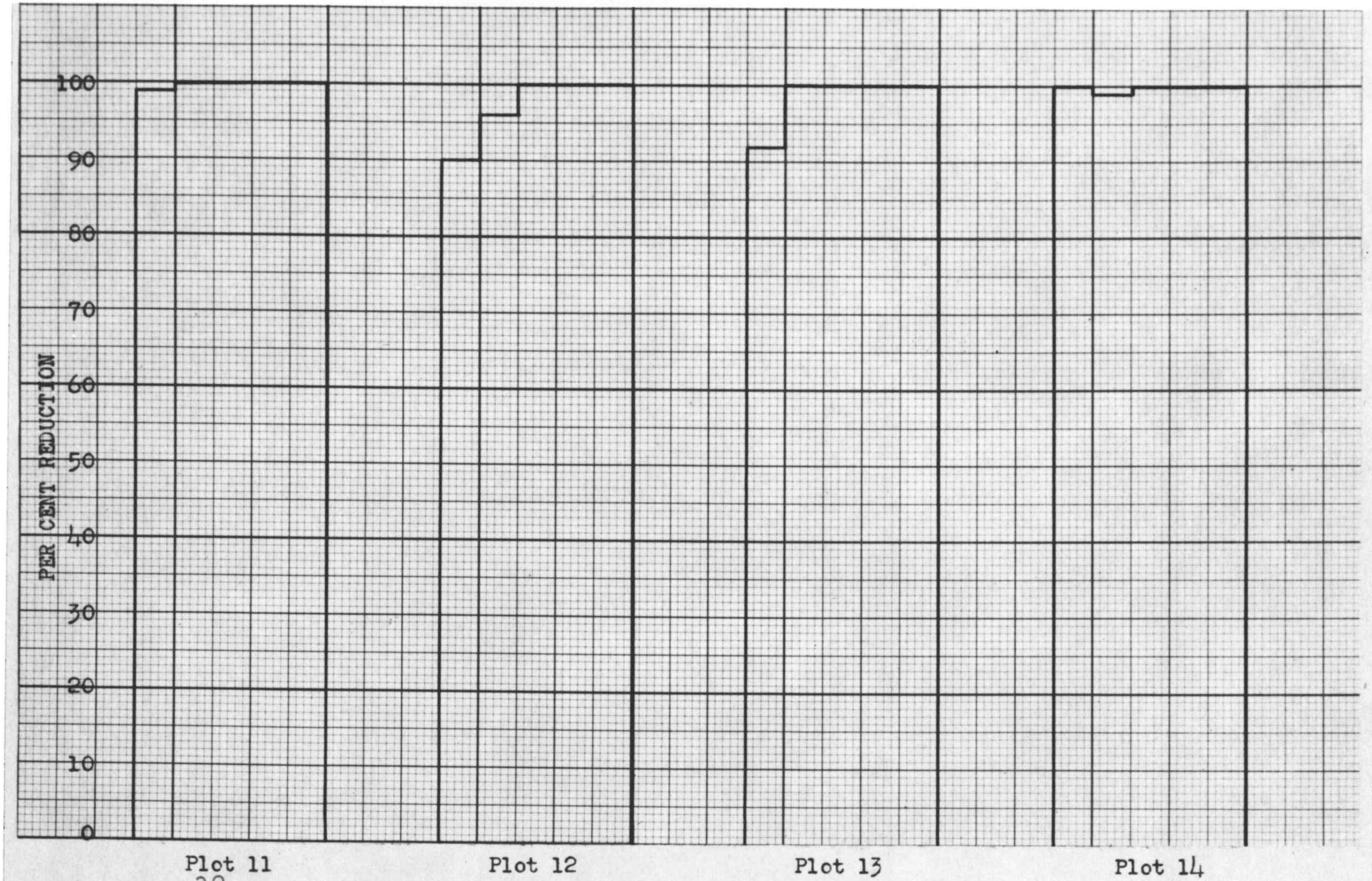

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Fig. C Aphid Populations in Insecticide Plots, Klamath Branch Experiment Station, 1948.

All the materials above appeared to be of value in aphid control, and probably in replicated plots would approximate one another in most respects, other than in speed of killing. The only materials used which seemed to be of no value were five per cent methoxychlor with two per cent oil, which killed but 74 per cent of the aphids, and five per cent chlordane with one per cent oil added, which reduced the number of aphids by 50 per cent. It can be seen in the figures that all these compounds killed more and more aphids as the test progressed, except the last two.

(b) Corvallis Plots, 1948: Small plots were laid out at Corvallis to select the best of the materials available for aphid control. The dusts were applied with a Root hand duster at approximately the same rates. At the Entomology Farm on White Rose (Fig. 33), Plot I was treated with four per cent DDT, 80 per cent sulfur and one per cent oil, Plot II received five per cent methoxychlor with two per cent oil, Plot III had five per cent DDD and one per cent oil, Plot IV was dusted with five per cent DDT plus ten per cent Lethane B-71. Plot V was left as an untreated check. A count was made prior to dusting, and one count made 24 hours following dusting.

It is apparent (Fig. 34) that DDT-sulfur and DDT-Lethane were superior to methoxychlor and DDD. The DDT-

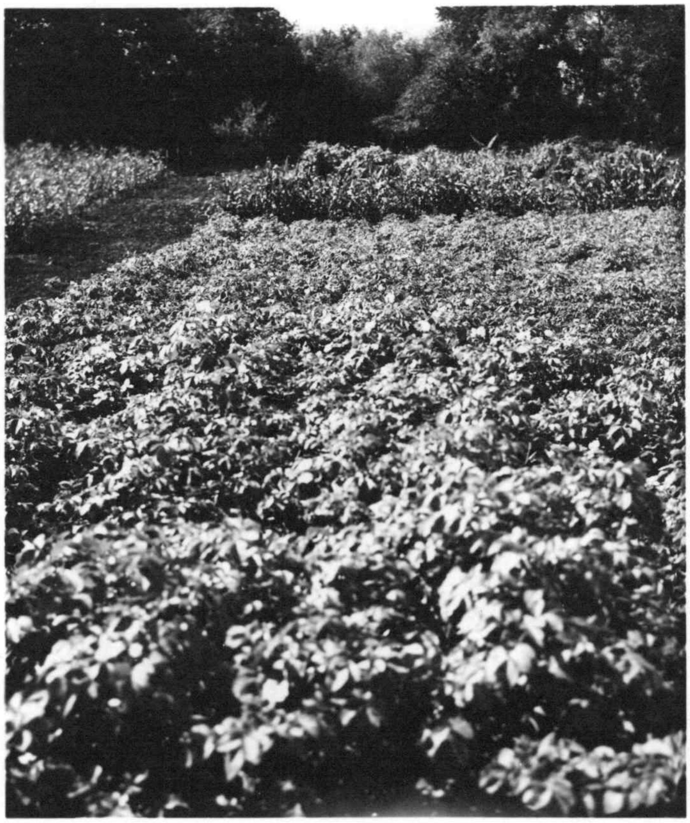

Fig. 33. Foreground, White Rose Insecticide Plots, Corvallis, 1948. Background, Netted Gem Plots.

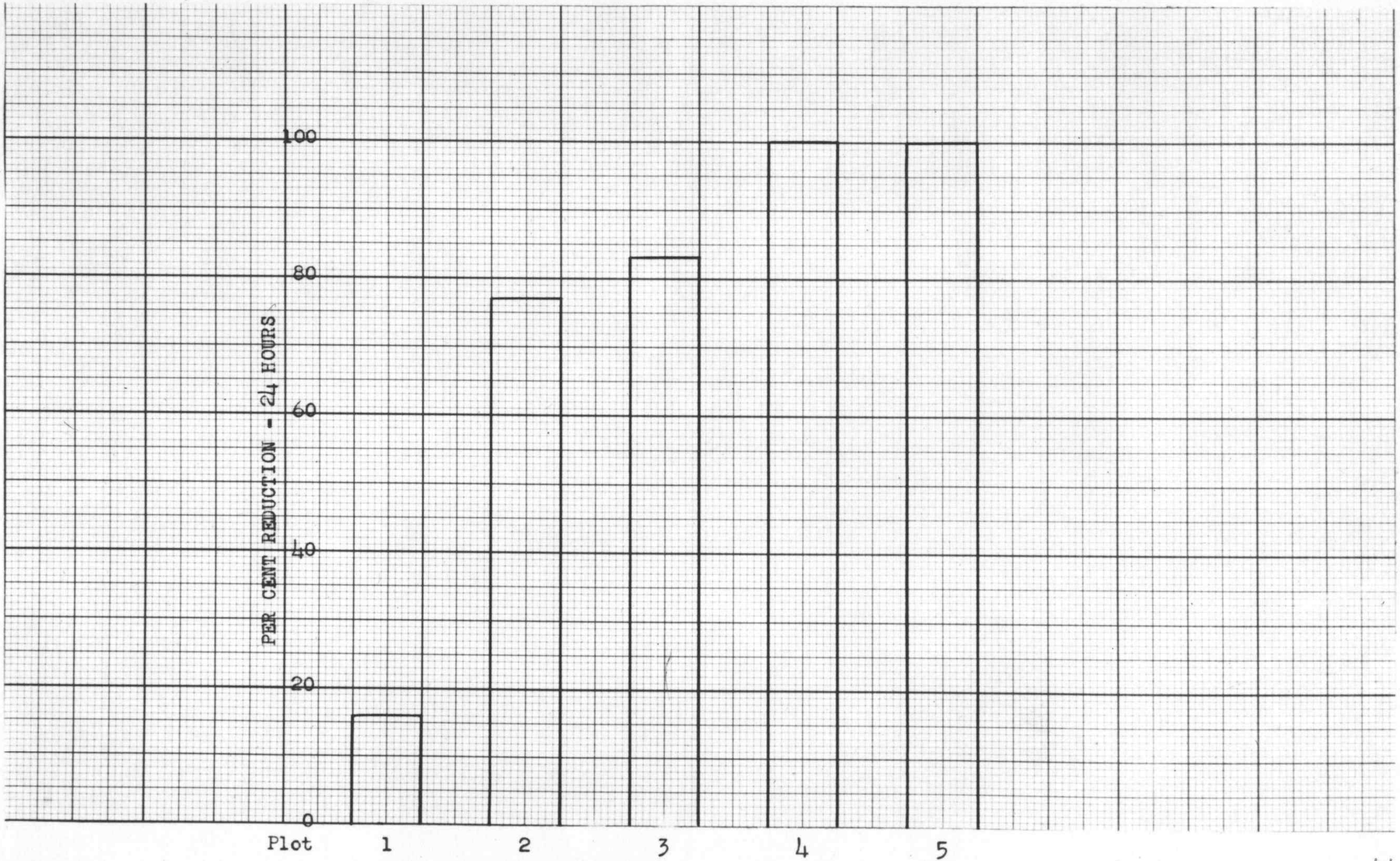

Fig. 34 Insecticide Plots, Entomology Farm White Rose, 1948

Lethane combination would be too expensive for general use, so is not of value.

In a one-acre eye index block at the east farm of the college, seven small plots were arranged to try a few materials. Plot I received four per cent DDT, 80 per cent sulfur, one per cent oil and 0.5 per cent TEPP dust, Plot II five per cent DDT and 42 per cent sulfur, Plot III five per cent DDT plus ten per cent Lethane B-71, Plot IV was an untreated check, Plot V was treated with four per cent DDT, 80 per cent sulfur and one per cent oil, Plot VI with five per cent DDD plus one per cent oil, and Plot VII had five per cent methoxychlor plus two per cent oil. A rain storm followed dusting at about 24 hours, so that the only criterion for rapidity of kill is the 48-hour count. The residual value is summarized in a count made one week following treatment (Fig. 35).

The DDT-TEPP dust gave best results in the 48-hour count, and the DDT-42 per cent sulfur was about equal to DDT-Lethane. DDT-sulfur 80 per cent and oil, DDD, nor methoxychlor had greatly reduced the number of aphids at the time of the 48-hour count. After one week, DDT-sulfur-oil was as good as DDT-TEPP, and DDT-Lethane was almost as good. Methoxychlor, DDD, and DDT-42 per cent sulfur were inferior to the others listed.

A small block of Netted Gem potatoes at the

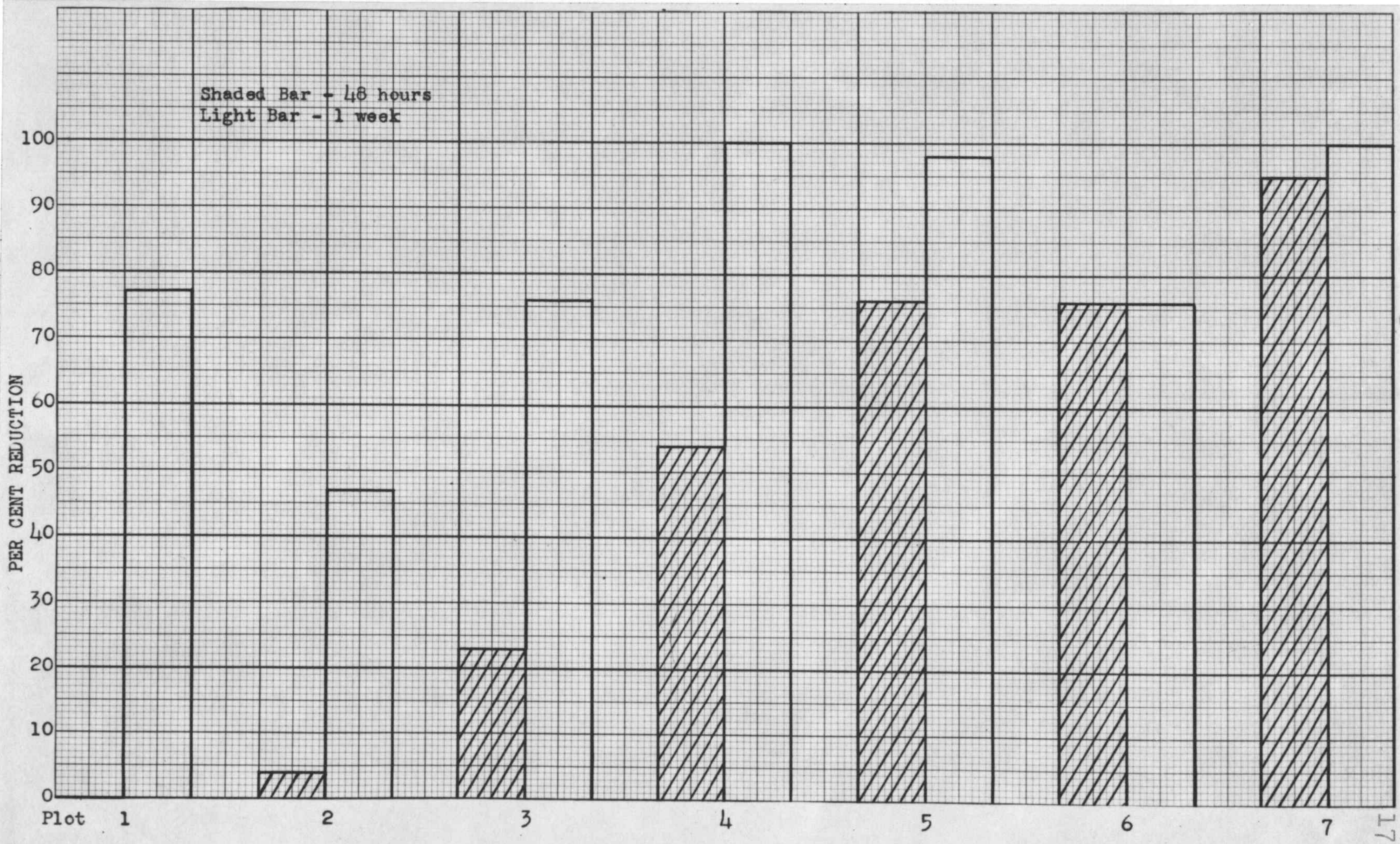

Fig. 35 Reduction of Aphids in Insecticide Plots, East Farm, 1948.

Entomology Farm was divided into two halves by several rows of tall corn. A very careful application of five materials was made, each material being applied to one row on either side of the corn. Plot I was an untreated check, Plot II received four per cent DDT, 80 per cent sulfur, one per cent oil, Plot III the same material as II, except that 0.33 per cent TEPP was added, Plot IV was dusted with 1.5 per cent gamma isomer benzene hexachloride, Plot V had 0.25 per cent Parathion applied, and Plot VI received one per cent Parathion dust.

It was found here (Fig. 36) by counting four and 24 hours, and one week following dusting, that certain standard materials were inferior to some newer materials in several ways. The two Parathion dusts killed almost all the aphids in four hours, and continued to hold them at economic zero even a week after treatment. The gamma isomer dust was nearly as effective as Parathion. The two DDT treatments were not nearly so good as these first three materials, in any respect.

Sylvester (80) had almost identical results with these in his plots at Bakersfield, California in 1948.

It appeared from the small plot tests at Klamath Falls and Corvallis, and from the laboratory tests, that Parathion was the best insecticide to control aphids that was available. This material will, then, be compared with

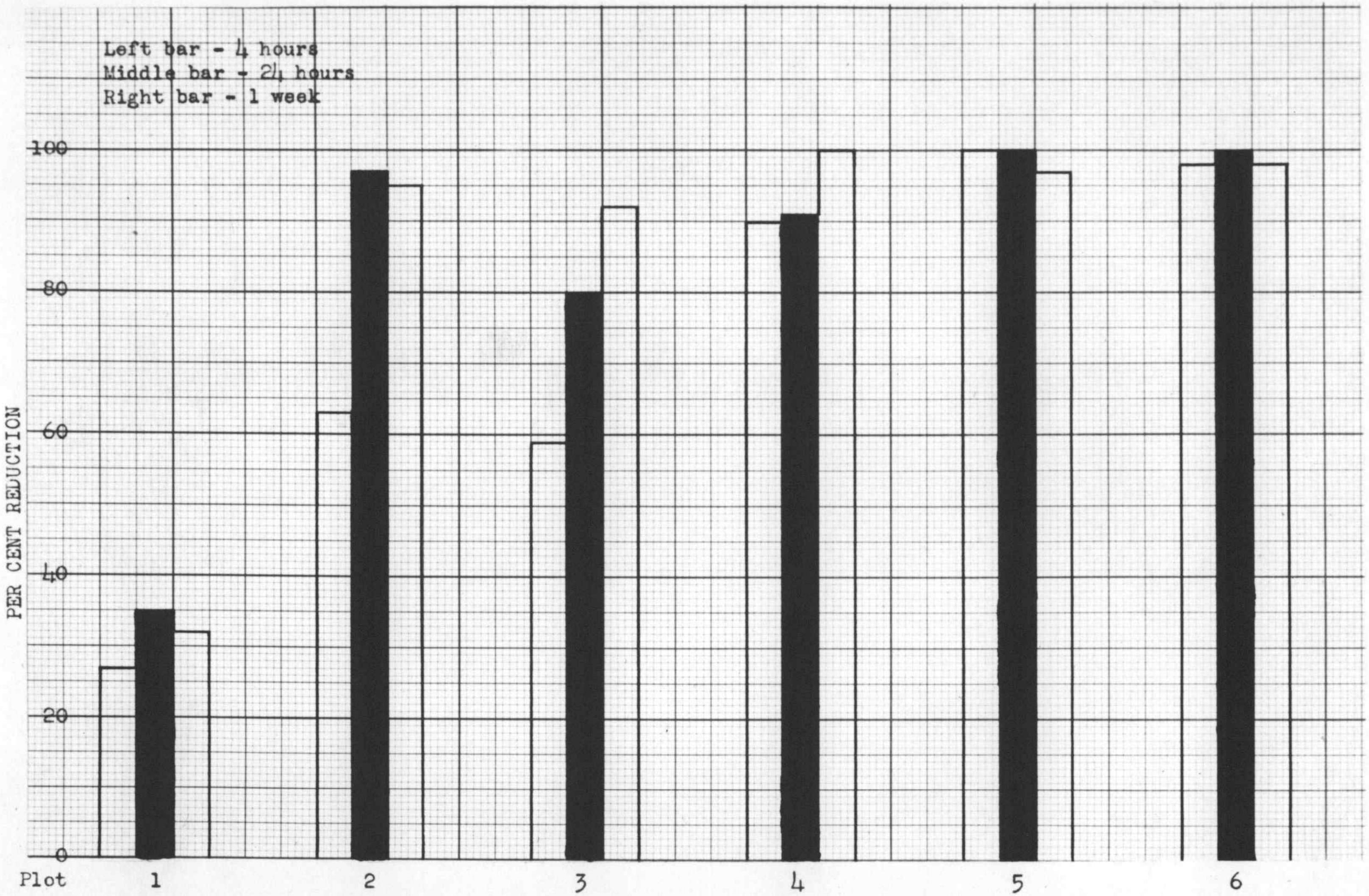

Fig. 36 Insecticide Plots, Entomology Farm Netted Gems, 1948

DDT in all the field plot tests during the 1949 season.

No recommendation for the use of Parathion can be issued on the basis of the little work to date. Also, this material has been variously reported as a possible hazard to the applicator, and also because it has been said to be absorbed by plants. Because of this possible hazard, samples were collected in plots dusted with Parathion in 1948, and one plot sprayed with Parathion wettable powder. These samples were then submitted for chemical analysis, to determine whether or not Parathion had been absorbed by the plants and then translocated to the tubers.

Table 16 summarizes the amounts of Parathion estimated to be in the tubers by the colorimetric test. One of the untreated check samples showed more Parathion present by this test than did any of the samples from dusted or sprayed plots, thus leading one to question the value of the test. Yet the sample treated directly with the material showed almost all of it by the same test. If we can accept the results of this test as true, there is apparently no great danger of large amounts of Parathion being translocated from dusted leaves to the tubers of the plant.

(8) Field Experiments, Central Oregon, 1948:

In this district, six grower cooperators were

Table 16

Results of Chemical Analyses of Potato Tubers for Parathion Residue, 1948 (63)

Variety	Source	Treatment Plants had Received	Parathion ppm
Netted Gem	Entomology Farm	Untreated check	0.027
Netted Gem	Farm Crops Dep't	Untreated check	0.013
Netted Gem	Entomology Farm	1% Parathion dust--25 lbs per acre	0.019
Netted Gem	Entomology Farm	0.25% Parathion dust--25 lbs per acre	0.021
Netted Gem	J. Wright Field, Klamath Falls	Airplane sprayed--1 lb 15% wettable parathion per acre	0.018
Netted Gem	Farm Crops Dep't	Received 0.044 mg parathion directly	0.037
White Rose	Klamath Branch Station Plots	1% Parathion dust--20 lbs per acre	0.015

located, and a series of experiments similar to those being conducted in other parts of the state was made. Here the grower was supplied with nicotine dry concentrate powder, and this he mixed with the dust applied to one-half of each of his fields. Thus eight comparisons in 16 plots resulted. One-half of each field was dusted with five per cent DDT plus two per cent oil in talc, and the other half received this same dust, to which 1.4 per cent nicotine was added.

Since the fields were dusted at different times and at different rates, and aphid counts were made at irregular intervals during the season, these data are not summarized here. However, a few generalizations may be made from them. The DDT-nicotine dust not only killed the aphids more quickly than DDT alone, but the number of aphids in these plots remained a great deal lower than the number in the other plots for the remainder of the season. This was true even where the nicotine was applied to that half of the field into which migrating aphids appeared in largest numbers.

The cost of this dust is prohibitive, and it would be difficult for the farmer to mix himself. It is only useful if a grower feels it worth the expense in order to get a quick kill.

The number of aphids in this series of fields was about the same as it was in 1946 and 1947. Yet, taking all the fields together, the best treated plots averaged 100,000,000 aphids per acre for the counts made through the season. Even if 99.9 per cent kill were obtained, and this would be difficult, there would still be 100,000 aphids per acre in each field. This points out the almost impossible task of attempting to control the spread of virus diseases by killing <u>all</u> the aphids.

In this area, the need for proper equipment was driven home forcibly. There are a few suitable machines there (Fig. 37), but many growers are using obsolete equipment suitable for flea beetle dusting, but not so for ahpids. It was borne out in many cases that a machine must have two nozzles per row, set low and directed in toward the plants, it should have a hood, and it must be equipped with motive power and fan capable of blowing the insecticide into the center of the dense plants. Equipment is just as important as the insecticide, and timing probably more important than either. In this area early dusts to kill the aphids from the one or two migrations are cheap, easy, and profitable.

MEASURES DIRECTED AT VIRUS HOST PLANTS

In order for the potato virus diseases to spread, it is necessary that there be a source of the virus, the

Fig. 37. A Hood Increases the Effectiveness of a Duster.

Two Nozzles Set Low and Directed in Toward the Plants Give Best Results.

insect vector must be present, and conditions must be such that the insects are moving about in the field. The removal of sources of the virus from the range of the insect vector constitutes the best, and one of the most certain, methods of breaking the transmission chain.

Roguing: This operation, the removal of diseased plants from the field, is one of the best control measures. It is difficult to recognize the diseases in the field without experience, and time consuming and costly to remove them.

Eye Indexing and Tuber Unit Planting: These methods, whose purpose is to establish that tubers are disease free prior to planting, and the second to make it easier to see diseased plants in the field, are of prime importance to obtain original disease free seed.

Certification of Seed: This is an important control measure, in that plants must not show a great amount of disease in the field in order to be tagged as certified. This, in turn, allows the commercial grower to buy cleaner seed and helps him to maintain yields.

Resistant Varieties: Certain varieties are resistant to some of the viruses, though not immune. For example, Katahdin, Chippewa, Sebago, and White Rose do not show net necrosis from current season leafroll infection. It is hard to get growers to accept new varieties, however, even if they are resistant to a disease.

Isolation: This is recognized in certification standards as necessary to grow disease-free seed. It is questionable whether potatoes can be grown where they will not be infested with aphids, and if even one per cent of them carry leafroll into a field, isolation is not effective alone.

Early Harvest: In areas where there is a late season increase in number of aphids, or where aphids move into fields from other crops late, early harvest may prevent late season transmission.

Destruction of Weed Hosts: If fields of potatoes grown for seed were disease free, and transmission still occurred, it would then be of value to kill weed hosts of the virus with herbicides. At present, however, there is sufficient disease in most potatoes to get rid of before this measure will assume importance.

COMBINED MEASURES

No single measure offers promise of controlling potato virus disease spread alone. Thus, it is necessary that growers be familiar with all possible measures and use them together to do the best job possible. Unless newer insecticides do a much better job of killing aphids than is now believed possible, dusting will never constitute a control alone. It is of a great deal of value, when combined with these other measures, however. Dusting several times early in the season to kill the aphids moving into fields prevents the birth of many, many more as the season progresses. Dusting prior to each roguing operation is of value in preventing the scattering of aphids from these diseased plants as they are carried from the field. Dusting an eye index block at weekly intervals or oftener with DDT-TEPP dusts would be economical, and could be done very carefully on such a small number of plants. DDT-sulfur or DDT-oil dusts are most economical for large fields of potatoes grown for seed. Parathion may prove to be the best potato aphicide, if results in large field plots are as good as in the small insecticide plots.

Thus it can be seen that the degree of aphid control made possible as a result of these experiments, while entirely incapable of effecting a stoppage of potato virus transmission alone, is still a valuable additional measure in the control of these diseases. This has been recognized, and is being practiced, by Oregon potato growers.

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APPENDIX

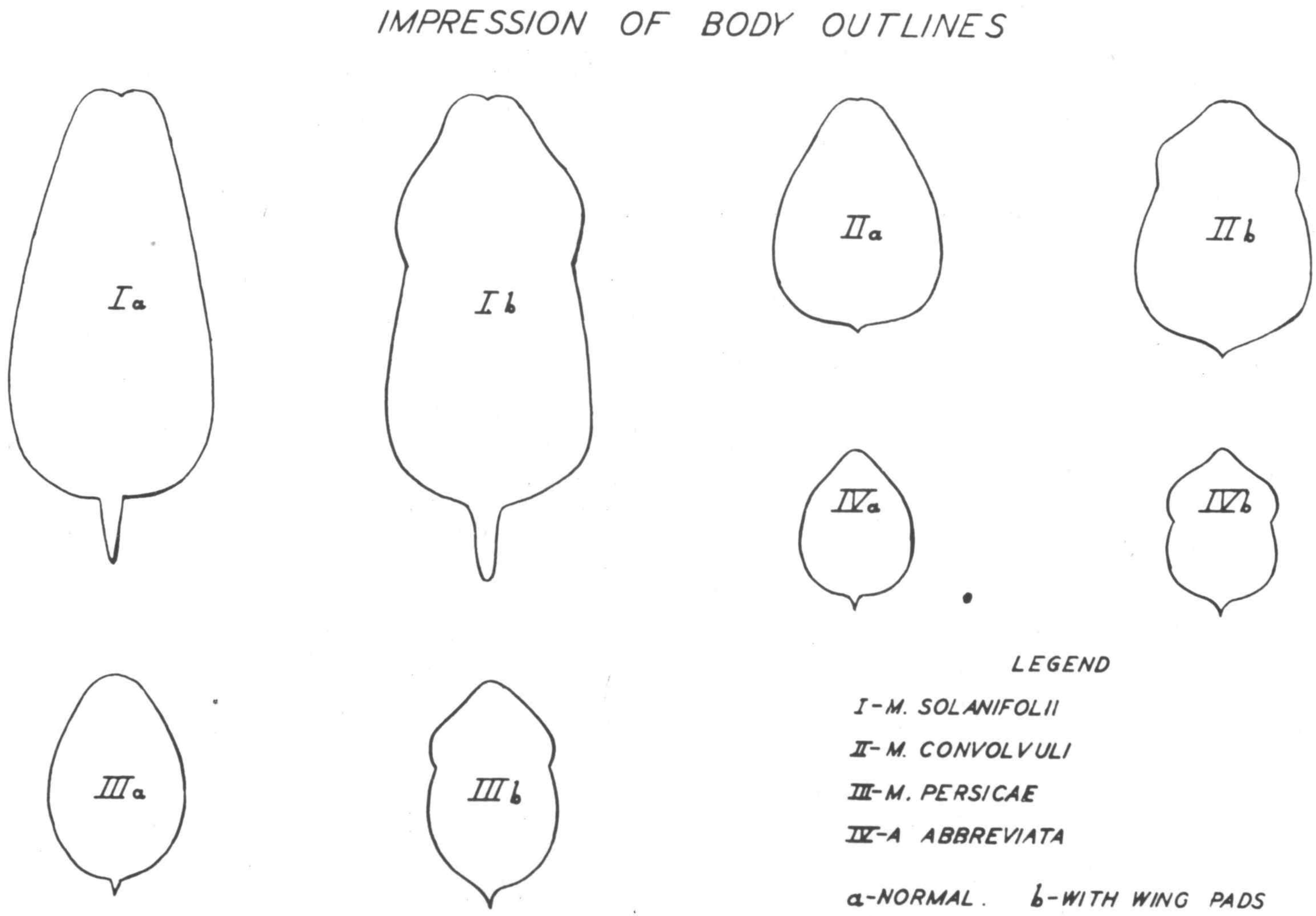


Diagram 1. (From Dionne, 1948)

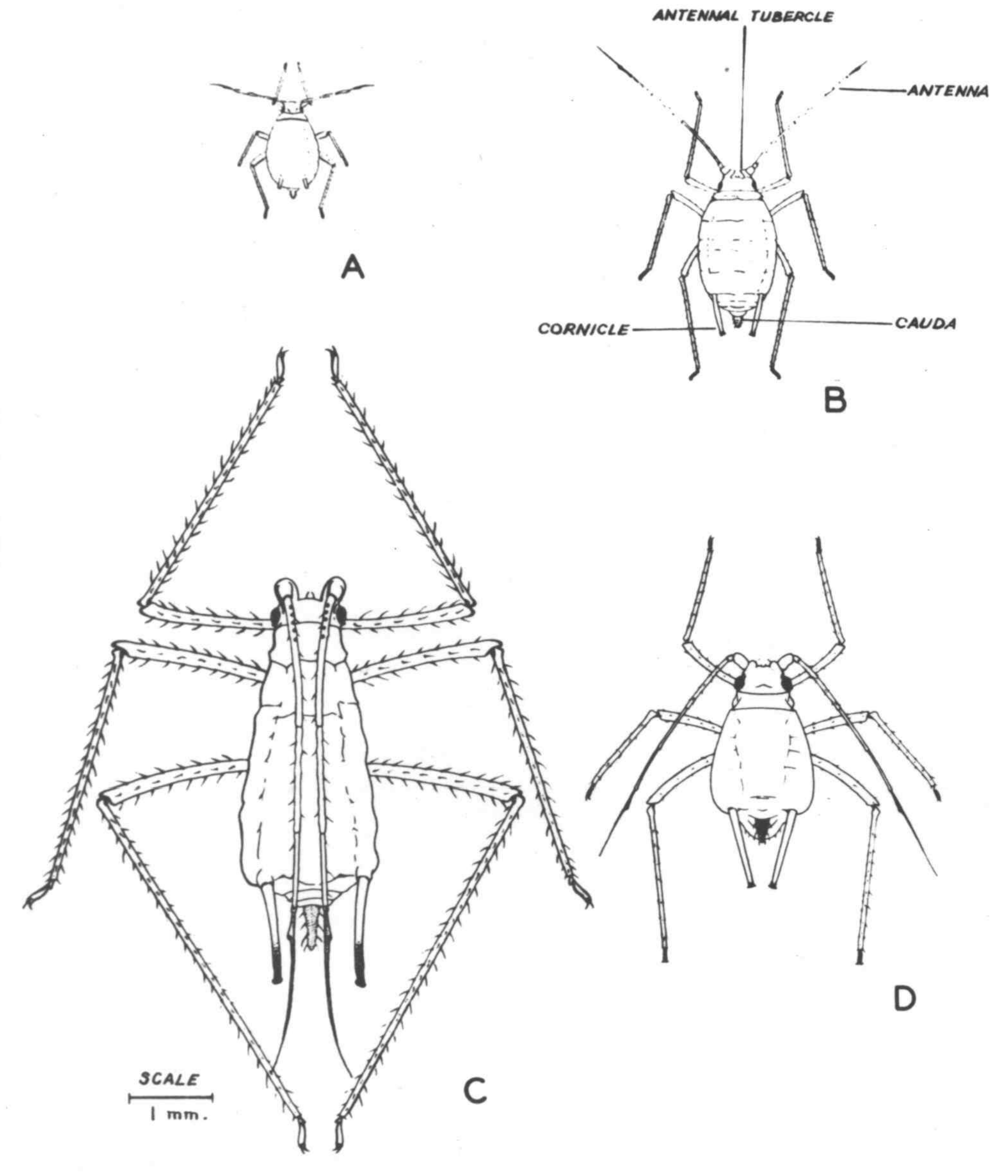


DIAGRAM II

Legend

A **<u>Aphis</u> <u>abbreviata</u> Patch**

B **<u>Myzus</u> <u>persicae</u> Sulzer**

C **<u>Macrosiphum</u> <u>solanifolii</u> Ashmead**

D **<u>Myzus</u> <u>convolvuli</u> Kaltenbach**

(From Dionne, 1948)

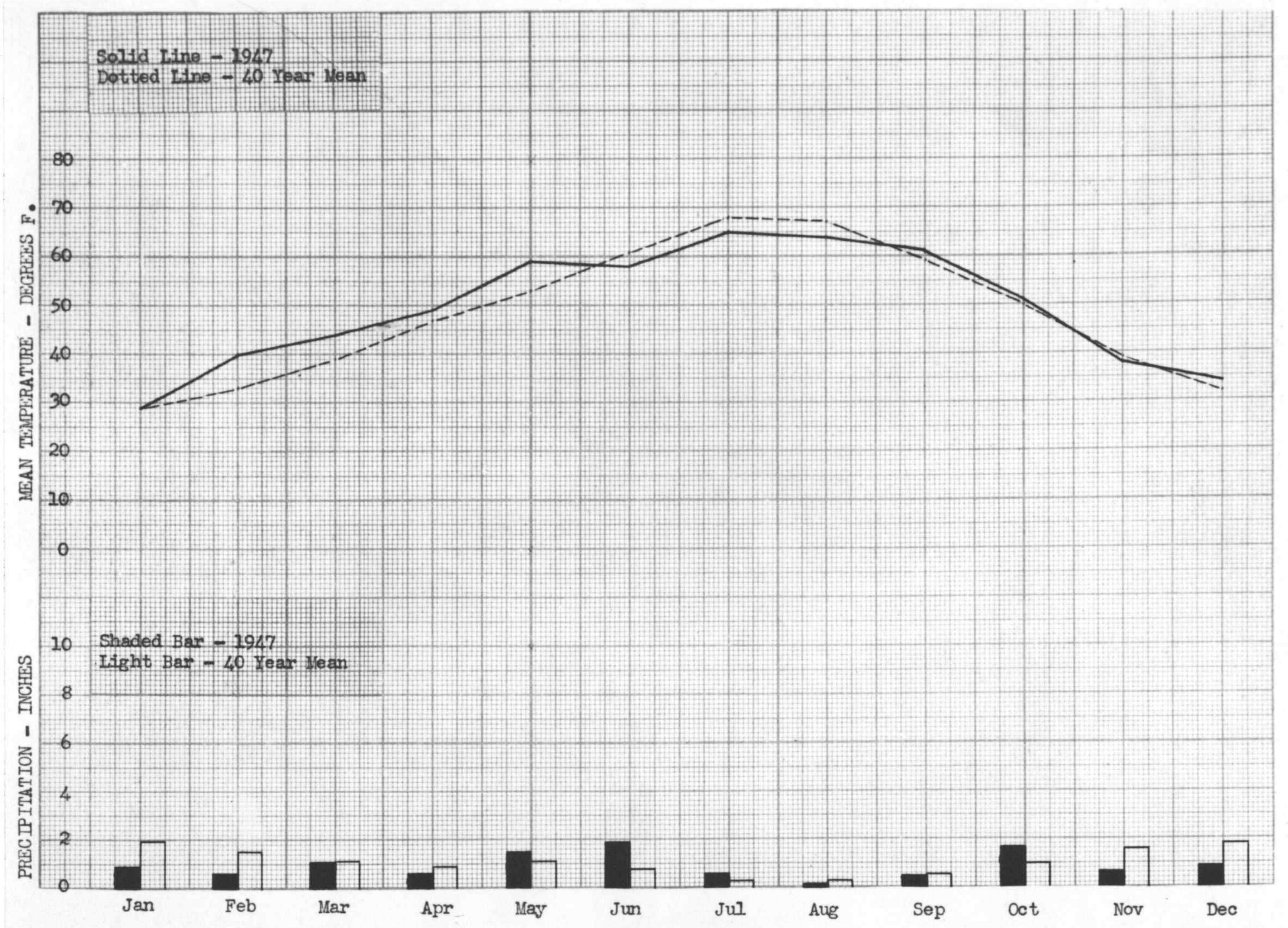


Fig. 38 Monthly Mean Temperature and Precipitation, Klamath Falls, 1947.

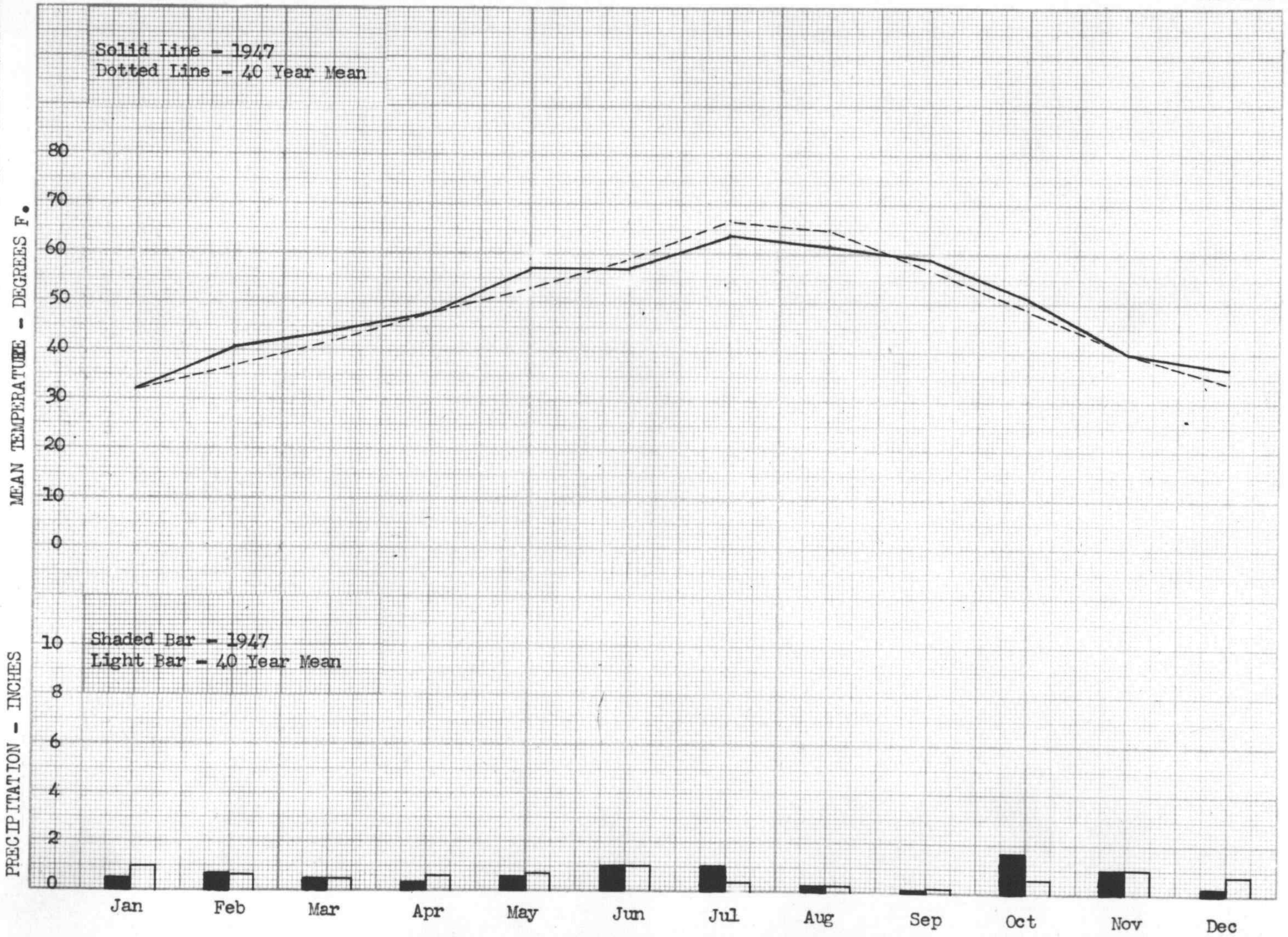


Fig. 39 Monthly Mean Temperature and Precipitation, Redmond, 1947.

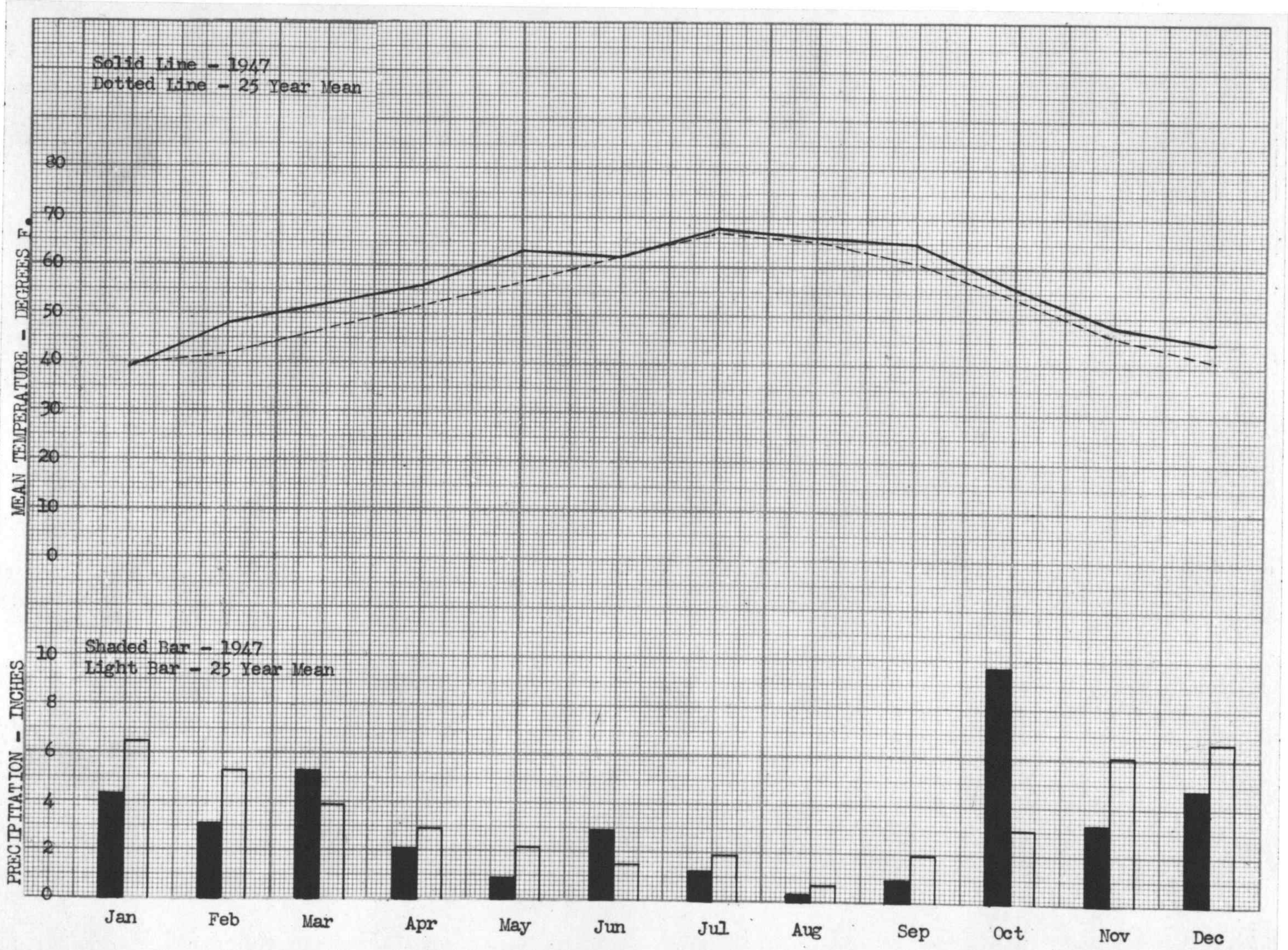
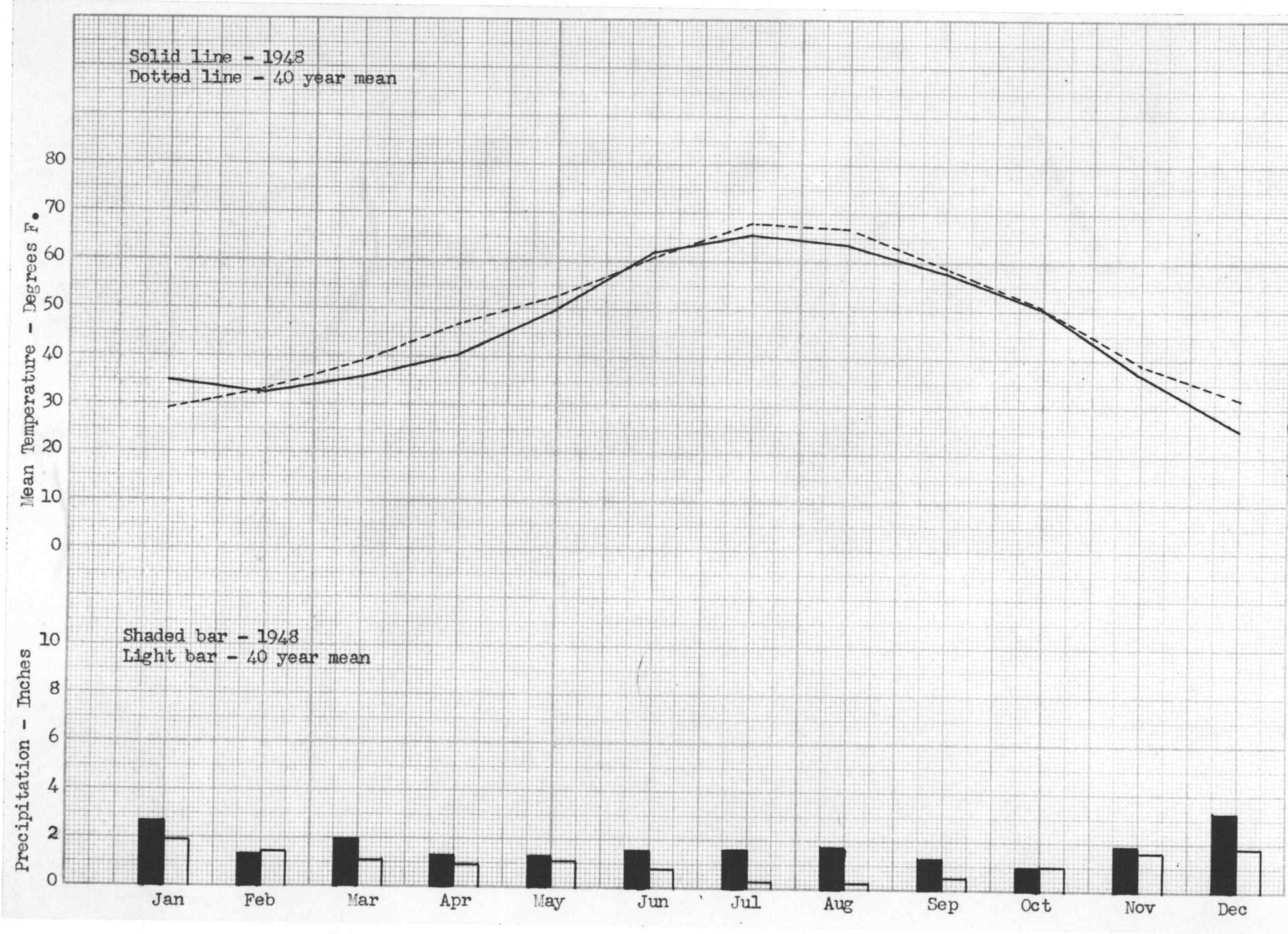
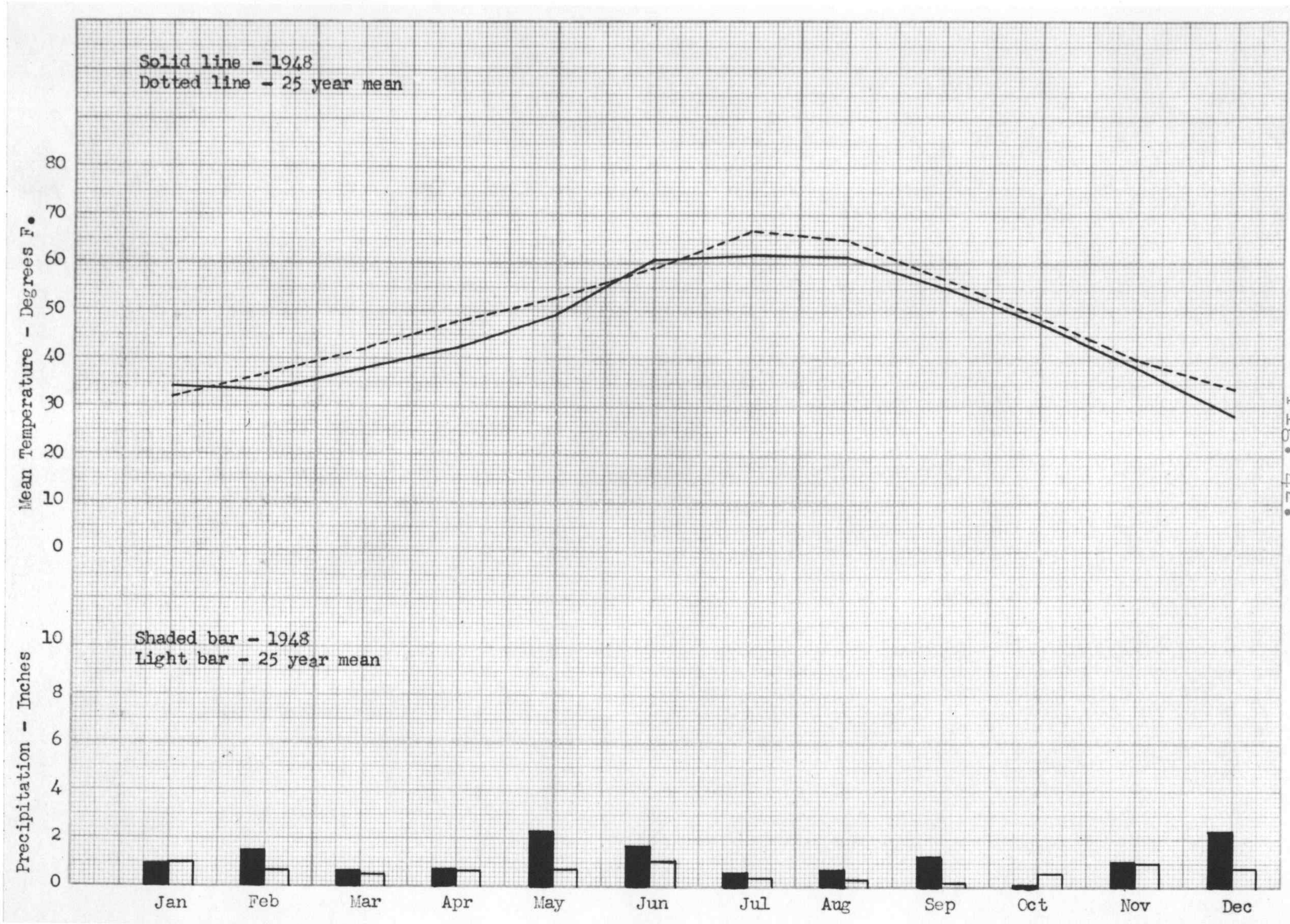


Fig. 40 Monthly Mean Temperature and Precipitation, Portland, 1947.

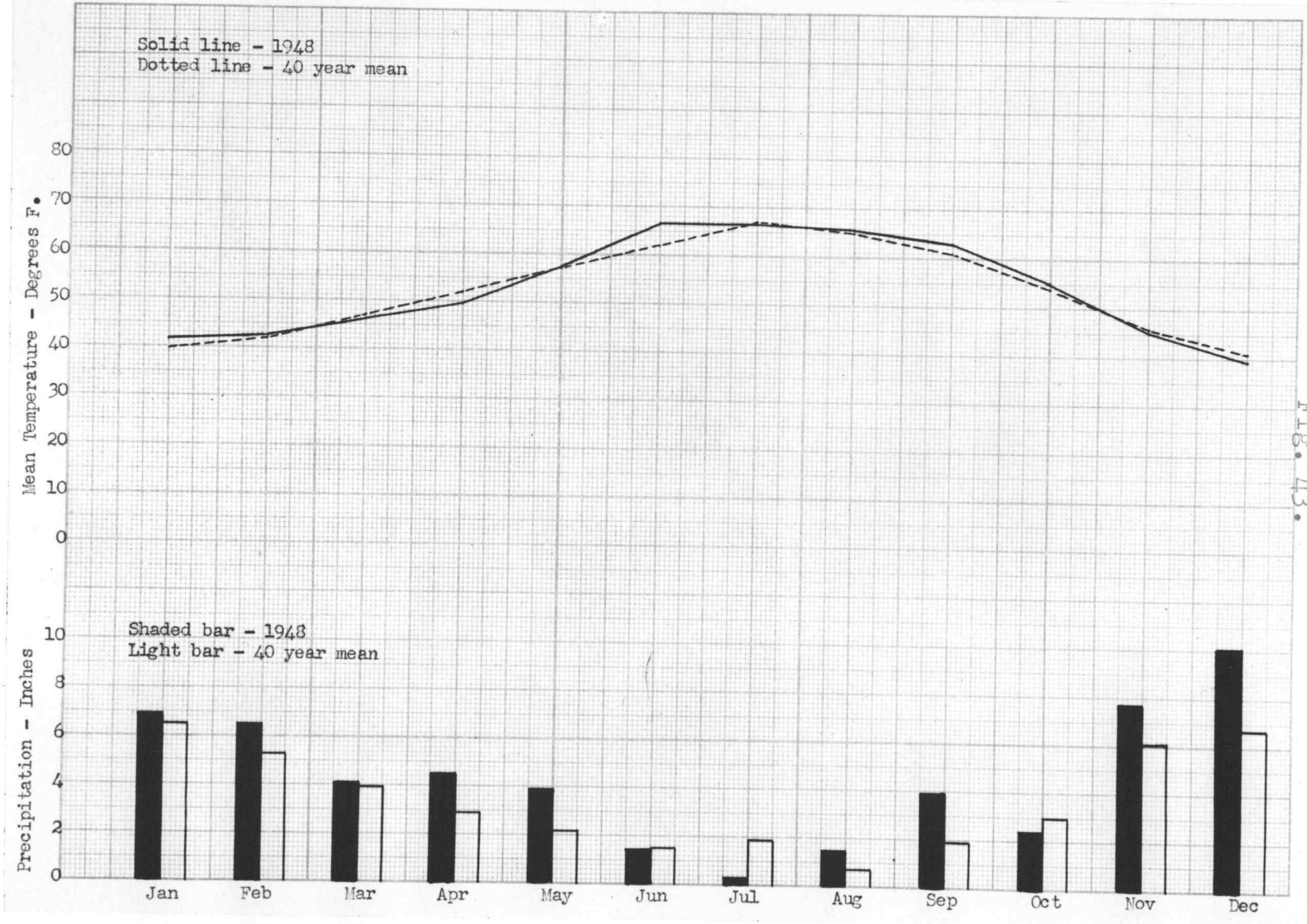


KLAMATH FALLS - 1948
Fig. 41



REDMOND - 1948

Fig. 42.



PORTLAND - 1948
Fig. 43.

KEY TO THE APHIDS OF THE FAMILY SOLANACEAE (68)

1. Root aphids.................................. 2

   Aphids on aerial portions of plant........... 4

2. Last antennal segment with distal filament elongate............*Aphis maidi-radicis* Forbes

   Last antennal segment with not more than a short distal spur.............................. 3

3. Cornicles on broad cones..... *Lachnus incertus* Schoutenden

   Cornicles lacking......*Geoica phaseoli* Passerini
   Geoica radicicola Essig

4. Aphids occurring in greenhouses.............. 5

   Aphids attacking sprouts of stored potatoes... 6

   Aphids occurring in the field................ 8

5. Wingless female with dark horseshoe-shaped mark on dorsum of abdomen.*Myzus circumflexus Buckton*

   Wingless female with immaculate body......... 6

6. A large species (pink or green) with cornicles having a distal reticulated area..... *Macrosiphum gei* Koch

   Cornicles without reticulated area........... 7

7. Antennal segment III of wingless female without sensoria............*Myzus persicae* Sulzer

   Antennal segment III of wingless female with sensoria............*Myzus solani* (Kalt.)

8. A large species (pink or green) with cornicles having a distal reticulated area..... *Macrosiphum gei* (Koch)

   Cornicles without reticulated area........... 9

9. Wingless female not black (if black, cauda not bushy)................................... 10

Wingless female dull black. Cauda "bushy" with five or more pairs of hairs.....
Aphis rumicis Linn.
Aphis solanella Theobald
Aphis solanophila Blanchard

10. Antennal tubercles prominent and converging..
Myzus persicae (Sulz.)
Myzus solani (Kalt.)

Antennal tubercles shallow and diverging..... 11

11. Wingless female with black cornicles...
Aphis gossypii Glover

Wingless female with pale cornicles....
Aphis abbreviata Patch
Aphis solanina Passerini

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