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PIERCE'S DISEASE INVESTIGATIONS

Edited by A. J. WINKLER

UNIVERSITY OF CALIFORNIA · BERKELEY, CALIFORNIA

This special report covers the investigations on Pierce's disease that were supported in part by special appropriation of the 1943 State Legislature, which made the work on the Woodlake and Lindsay plots possible, and by a special grant from University funds. The studies were a coöperative undertaking of the divisions of Entomology and Parasitology, Plant Pathology, and Viticulture.

Contributing authors of this publication are: Wm. B. Hewitt, Associate Professor of Plant Pathology and Associate Plant Pathologist in the Experiment Station, who was responsible for the pathological investigations; N. W. Frazier, Lecturer in Entomology and Assistant Entomologist in the Experiment Station, who contributed the material on the vectors and their control; J. H. Freitag, Associate Professor of Entomology and Associate Entomologist in the Experiment Station, who did the work on the host range of the virus; and A. J. Winkler, Professor of Viticulture and Viticulturist in the Experiment Station, who edited the contributions and supplied the viticultural aspects.

Many grape growers gave generous assistance during the course of this investigation, particularly those who actively coöperated in the plot work; and by Professor E. O. Essig, Chairman of the Division of Entomology and Parasitology and Professor Max W. Gardner, Chairman of the Division of Plant Pathology.

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H I L G A R D I A

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INTRODUCTION

PIERCE'S DISEASE has twice threatened the vineyards of California, once in 1884 and again in 1935. The disease—at one time called "Anaheim disease" (1),[2] (3), and "California vine disease" (12)—first appeared in about 1884 (12) in the vineyards of southern California. During the succeeding fifteen years it destroyed some 35,000 acres of excellent, productive vineyards, primarily in portions of Los Angeles, Orange, San Diego, Riverside, San Bernardino, Ventura, and Santa Barbara counties. Records further show that the disease also occurred in portions of Napa (1) and Sacramento valleys, where the damage was limited, and in the Santa Clara Valley (13), where several plantings were destroyed.

This first outbreak of Pierce's disease apparently dwindled to obscurity shortly after the turn of the century, for it is seldom mentioned in literature after that time. However, it seems reasonably certain that the disease did not just die out and reappear, but that it continued to spread in an inconspicuous manner, because attempts to reëstablish vineyards in parts of Orange and Los Angeles counties were unsuccessful. The vines died out within a few years after planting.

Evidence of the first appearance of the disease in the San Joaquin Valley was obtained in conversations with local vineyardists. It seems certain that in about 1917 a few cases occurred in vineyards near Poplar in Tulare County. This disease, or a very similar one, was observed in Tulare County in 1921 (15) and again in 1927 and 1931. Observations regarding the mysterious dying of vines were not uncommon by 1934. They indicate the early stages of spread into the San Joaquin Valley. Here the disease continued to increase and spread in an irregular pattern, for by 1938 it was clearly evident that another epiphytotic of the notorious killer of grapevines was under way. In five vineyards observed in Chowchilla just two seasons later the following percentages of vines were diseased or dead: 54, 48, 26, 18, and 90. The remains of three of these vineyards were pulled in the fall of 1940 and the others, the following season.

[1] Received for publication December 10, 1948.

[2] See "Literature Cited" at the end of this paper for complete data on citations, referred to in the text by number.

Occurrence of Pierce's disease in individual vineyards, in districts, and even as it spread over the San Joaquin Valley followed, in general, three patterns (9): first, diseased vines irregularly scattered; second, diseased vines concentrated in small localized areas without apparent association with environment, soil type, or cultural practice; and third, large numbers of diseased vines developing in portions of vineyards adjacent to alfalfa plantings and irrigated pastures—areas directly associated with the environment of the locality.

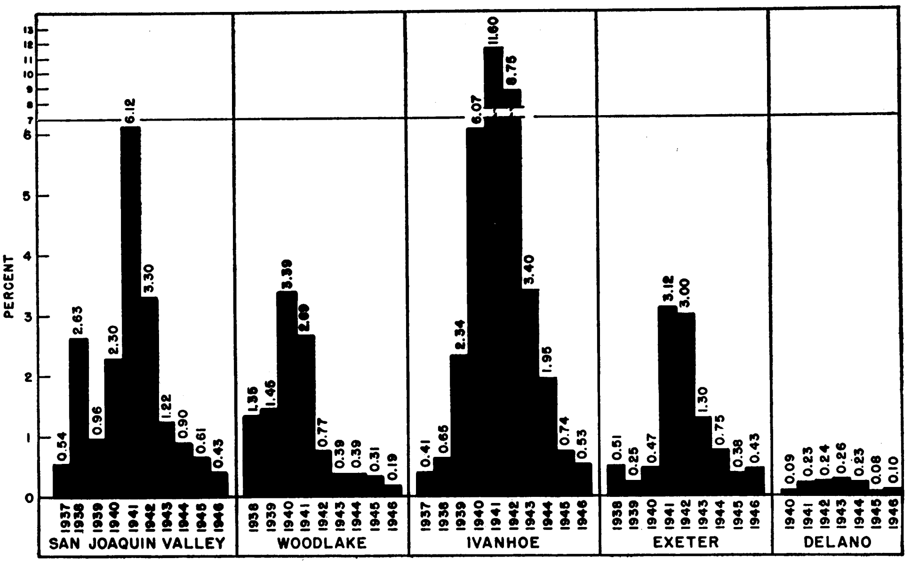

Fig. 1. Per cent of new cases of Pierce's disease each season in the San Joaquin Valley and districts in the vicinity of Woodlake, Ivanhoe, Exeter, and Delano. Percentages of vines diseased each season were calculated from data of field experimental plots and from random sampling of other vineyards in the area.

Spread of the disease appeared to be generally northward through the valley. As it progressed, it occurred first in widely scattered locations sometimes several miles apart. This was usually followed by an increase in the number and size of diseased areas or spots. The disease has usually been more severe and has persisted longer in areas where plantings of alfalfa and irrigated pastures were frequent. Conversely, it has been less intense where such crops were occasional. The disease has also occurred in some localities where the natural cover, mostly grasses, grew late into, or even throughout the summer, and in extensive districts that were nearly all planted to vineyards.

The development of Pierce's disease in the San Joaquin Valley during this last outbreak is shown in figure 1. The chart entitled "San Joaquin Valley" graphically illustrates the course of the disease over the past decade in the valley vineyards. It shows the per cent of vines developing the disease each year as computed from data gathered in vineyard test plots and other vineyards sampled at random in Madera, Fresno, Tulare, and Kern counties. The other charts show a breakdown of part of this data into the annual occurrence of Pierce's disease as it developed in the Woodlake, Ivanhoe, Exeter, and Delano areas.

The rate of increase and decrease in occurrence of the disease, and also the losses have varied with the district. The incidence of Pierce's disease was relatively low in the San Joaquin Valley up to about 1935, when it began to increase rapidly. It reached a peak there and in most of southern California about 1941. Since then the annual increment of new cases has declined. Many vineyards in the Ivanhoe area were completely destroyed during the years 1939 to 1942. The losses indicated in figure 1 for this area, although highest of all, are probably low, for they were taken from a limited number of field plots. The Delano area referred to in figure 1 comprises more than 5,000 acres, and is nearly all irrigated vineyard in which the grass is left to grow each year after July. The low incidence of disease in this area is outstanding when compared with the Ivanhoe area with its more widely diversified agriculture.

The occurrence of Pierce's disease in portions of Los Angeles County was associated with the native and ornamental flora. For example, on the grounds of the University of California at Los Angeles vines planted near both native and ornamental plants became diseased shortly after planting, even though no other grapevines grew in the area. It appears that after the early southern California epiphytotic, the virus continued in the native and cultivated vegetation of certain sections of the area.

In San Bernardino County, the occurrence of diseased vines followed a pattern similar to that in the San Joaquin Valley. Its development varied in San Diego County with each district. In Napa and Sonoma counties, it has been found most prevalent in those portions of vineyards adjacent to brush land and to stream banks with abundant natural cover. Many vineyards several hundred yards distant from such streams have also had a few irregularly scattered diseased vines and occasional areas where the diseased vines have concentrated. The incidence of Pierce's disease in Sonoma County reached a peak about 1943, and in Napa County a year later. The decline has been somewhat slower in Napa County than in Sonoma and other parts of the state.

During this last epiphytotic only a few cases of Pierce's disease appeared in the Santa Clara Valley, even though part of the region was severely affected from 1897 to 1900. Cases of the disease have been found irregularly distributed throughout nearly all of the other grape-growing districts of the state, with the exception of Livermore Valley in Alameda County, all of Contra Costa County, Coachella Valley in Riverside County, and all of Imperial County.

SYMPTOMS

Symptoms associated with Pierce's disease vary with the variety and the locality. The variations, however, are in the rate and degree to which symptoms show and not in the type. Usually in the interior valleys, symptoms show earlier in the season and are more pronounced than in the coastal regions. The symptoms of Pierce's disease have been fully described in earlier publications (1), (7), (8), (12). They are briefly summarized as follows: 1) scalding, a progressive drying of the leaf tissues while still green, usually from the margin toward the leaf petiole, followed by browning of the scalded areas; 2) dwarfing, wilting, withering, drying, and, in late season, premature coloring of the berries on part or even over the entire vine; 3) delayed foliation of a part or of the entire vine in the spring; 4) interveinal chlorotic mottling and sometimes deforming of the first 2 to 8 leaves of a shoot; 5) dwarfing of the shoot growth on a part or over the entire vine; 6) failure of the canes to mature evenly; 7) gradual dying of the root system; and 8) symptoms often show variation with age, variety, and locality, dying of the vine from 3 months to four or five years.

CAUSE

Pierce's disease is caused by a virus (6). This virus has been transmitted by grafting pieces of roots, canes, and trunk from diseased vines onto healthy vines. The virus has been experimentally spread to healthy stock by several species of sharpshooter insect vectors. It has not been transmitted to healthy stock by pruning shears or by other vineyard implements. The disease may be carried in cuttings from diseased vines and in transplanted diseased nursery stock. The same virus causes a serious and destructive disease of alfalfa known as alfalfa dwarf. It has an extensive host range that includes many grasses, perennial herbs, shrubs, and even trees.

INCUBATION PERIOD FOR SYMPTOMS IN GRAPES

Age of the vine and season of the year have caused some variation in the time required for symptoms to show after grapes have been inoculated with the Pierce's disease virus by sharpshooter leafhopper vectors or by grafting. Young vine rootings grown in pots in the greenhouse and also in the field at Davis, have shown symptoms within 8 to 12 weeks after inoculation by sharpshooter vectors. Most field-grown rootings inoculated in September or later did not show symptoms until late in May or in June of the following season. Five-year-old vines grown in the field at Davis showed symptoms within 3 to 15 months, and most of them within 12 months after inoculation.

EFFECT OF VIRUS ON GRAPEVINE TISSUES

A study of the effects of the Pierce's disease virus on the tissues of grapevines helps to explain the origin of the characteristic symptoms and, to some extent, the degeneration of diseased vines. Gum formation in wood tissues and subsequent excessive development of tyloses (growth of cells into water-conducting vessels of diseased vines) are apparently primary effects of the Pierce's disease virus (4).

Studies (4) were made of grape seedlings which had been inoculated with the Pierce's disease virus by feeding infected sharpshooters on a single leaf of each seedling. Examination showed that the water-conducting vessels were plugged with gum before external symptoms developed, and that plugging became more pronounced with the passing of time. This abnormality showed first in the tissues of the inoculated leaf, and later in the main stem of the seedling both above and below the point of leaf attachment.

A comparison was made between normal and diseased wood (4) cut in the fall of 1946 from old vines growing in vineyards. It showed that the per cent of vessels with tyloses in each annual increment produced in 1944, 1945, and 1946, were, respectively, for wood of healthy Emperor, 14.24, 9.13, 5.77; and for wood of diseased Emperor, 41.53, 53.42, and 57.80. In the healthy Emperor grape, a few tyloses were found in the wood of the current season. The numbers of tyloses were observed to increase with the age of the wood.

In diseased tissues, the numbers of vessels with tyloses were higher and the increase in numbers occurred in the reverse order. Similar differences, although not so great, were found in comparing wood from both diseased and healthy Petite Sirah and Carignane vines.

The plugging of vessels with gum and tyloses was apparently sufficient to account for the water shortage symptoms of leaf scalding and burning. Furthermore, there was more plugging of the water-conducting vessels in the Emperor and Palomino, which decline very rapidly with the disease, than in the more tolerant varieties Carignane and Petite Sirah. The anatomic changes in the xylem of affected plants (4), together with the external symptoms and the mode of virus transmission by vectors (10), suggest that the virus is closely associated with the xylem tissue.

In the phloem of healthy vines, new cork forms about July of each year. This event accounts for the normal brown or tan color of the maturing canes. In vines affected with Pierce's disease, the canes mature irregularly, with green patches left in the bark. This is one of the prominent symptoms of Pierce's disease, particularly in very susceptible varieties. Specimens of diseased vines, collected in September, 1945, showed that cork had failed to form under the green patches of the cane, and that new cork had failed to form in patches of the bark (4) in older wood from the same vines.

The cells in the cambium of healthy grape usually stop activity and develop thick walls and the firmness characteristic of dormancy about the time new cork forms in the stems. At the same time, divisions also cease in the cambium of the diseased vines, but the cells retain characteristics of active tissue—that is, the cell walls are thin and the bark will slip freely (4).

Much less starch was found in the wood of diseased vines than in comparable samples of healthy vine wood (4).

THE VECTORS

Fourteen species of leafhoppers (5) and 4 species and 6 varieties of spittlebugs (16) are known to have the ability to transmit or spread the virus from diseased to healthy vines. The leafhopper species are the green sharpshooter, *Draeculacephala minerva* Ball; the redheaded sharpshooter, *Carneocephala fulgida* Nott.; the blue sharpshooter, *Neokolla circellata* (Baker); *Helochara delta* Oman; *Carneocephala triguttata* Nott.; *Neokolla gothica* (Sign.); *N. confluens* (Uhler); *N. hieroglyphica* (Say); *Cuerna occidentalis* Oman and Beamer; *Pagaronia triunata* Ball; *P. 13-punctata* Ball; *P. furcata* Oman; *P. confusa* Oman; and *Friscanus friscanus* (Ball). All of these are contained in one leafhopper subfamily, the *Tettigoniellinae,* members of which are commonly known as sharpshooters. Recent evidence indicates that additional species of sharpshooters may also be vectors. The spittlebug species that have transmitted the virus are *Aphrophora angulata* Ball; *A. permutata* Uhler; *Clastoptera brunnea* Ball; and *Philaenus leucophthalmus* (Linn.), including the 6 varieties *leucophthalmus* (Linn.); *pallidus* (Zett.); *fabricii* V.D.; *marginellus* (Fabr.); *spumarius* (Fall.); and *impressus* DeL.

Numerous other insects have been tested and have failed to transmit the virus. The results of many tests show that the grape leafhopper, *Erythroneura elegantula* Osb. does not spread the virus.

Three Species Spread Virus. Of all the leafhopper and spittlebug species proved able to transmit the virus, only the 3 species of leafhoppers—the green sharpshooter, the redheaded sharpshooter, and the blue sharpshooter—are known to be of any importance in the actual spread of the virus in vineyards and alfalfa plantings. All other species of vectors have rarely, or never, been found in vineyards or alfalfa plantings and are, therefore, of little or no importance insofar as spread of the virus to grapes and alfalfa is concerned. Each may spread the virus, however, among its wild host plants and, along with the 3 sharpshooters named above, help to spread and maintain a virus reservoir in wild hosts throughout the state. As an aid in the recognition of the 3 important sharpshooters, a general description and color picture of each are contained in California Agricultural Experiment Station Circular 353, published in November, 1942.

Life History of the Vectors. The life cycle of sharpshooters may be divided into 3 periods: the egg; the nymphal or immature, during which the nymph passes through 5 stages of development or stadia; and the adult or mature, in which the sharpshooter has wings, and reproduction takes place.

GREEN SHARPSHOOTER

Distribution. The green sharpshooter occurs in most of the principal grape-growing areas of California; it has been found widely distributed over the state. It is commonly found in moist locations, as in marshes and bogs, along streams and ditches, and in areas wet from faulty irrigation practices. Irrigated alfalfa fields with a thinning stand of plants contain grasses that provide favorable locations for large numbers of this leafhopper. Populations have also been observed in young grainfields, in orchard covercrops, in uncultivated areas around buildings, on lawns, along roadside areas, railroads, ditches, canals, and in permanent pastures.

Life History. In the San Joaquin Valley there are 3 complete generations of green sharpshooters each year. The winter is passed in the adult stage primarily, but a few nymphs also go through the winter. In Tulare and Fresno counties, egg laying by the overwintering females begins about February 25, and the first nymphs of the first generation begin to appear about March 18. These approach the adult stage about the middle or latter half of April, depending on weather conditions. By June 1 most of the first-generation nymphs have become adults. The first-generation adults begin the depositing of eggs for the second generation about May 5; these nymphs appear about May 20, and approach the adult stage about June 25. Most of the second-generation nymphs become adults by the last of August. About July 15, the second-generation adults start laying the eggs from which the nymphs of the third generation hatch. The first nymphs of the third generation appear about July 30 and reach the adult stage about September 3. Nymphs may continue to hatch until October, and some of the later ones may not reach the adult stage until the following February or March. The dates given vary somewhat with the season. They are usually a little later in the northern than in the southern part of the San Joaquin Valley. The life history of the green sharpshooter in southern California or in coastal regions has not been studied in detail. Observations in these regions, however, indicate some variations from those made in the San Joaquin Valley.

Host Range. Although the green sharpshooter feeds on a very wide range of plants throughout the year, it prefers to feed and breed on grasses. It has been collected on more than 130 different species of plants, mostly grasses or weeds, but also a few vines, shrubs, and trees. Its commonest food and breeding plants are ripgut grass (*Bromus rigidus* Roth), foxtail fescue (*Festuca megalura* Nutt.), annual bluegrass (*Poa annua* L.), Italian ryegrass (*Lolium multiflorum* Lam.), darnel (*Lolium temulentum* L.), Bermuda grass (*Cynodon dactylon* (L.) Pers.), water grass (*Echinochola crusgalli* (L.) Beauv.), yellow bristle grass (*Setaria lutescens* (Weigel) Hubb.), and hairy crabgrass (*Digitaria sanguinalis* (L.) Scop.). Other important hosts include Johnson grass (*Holcus halepensis* L.), toad rush (*Juncus bufonius* L.), red maids (*Calandrinia menziesii* (Hook.) Torr. and Gray), neckweed (*Veronica peregrina* L.), and cockleburr (*Xanthium canadense* Mill.). Bermuda grass is the most important year-round food and breeding plant.

Feeding Habits. The green sharpshooter is probably the most important of the principal vectors over the entire state, except in the north coastal counties. It has not been found in these dry-farmed, clean, cultivated vineyards. This sharpshooter thrives in the irrigated, grass-farmed vineyards of the southern San Joaquin Valley. Since it breeds and feeds primarily on grasses, it finds ideal conditions of moisture in these vineyards and a succession of favored succulent grass hosts during the dry months of the year.

The grapevines are not favored hosts of the leafhopper. Reproduction does not take place on the vine, only in the grasses and, less often, in weeds. The green sharpshooter is found on grapes, usually in small numbers, most often during spring when the vines are growing succulently and after the cane tips have bent toward the ground. During spring—before the summer grass crop has germinated—when the vineyards are free of grass, the leafhoppers may remain on the vines for several days, but later in the season they rarely feed on a vine for more than a few hours. The green sharpshooter has been observed feeding on suckers and on the tender foliage and stem near the tips of the canes which bend toward the ground or lie on it.

Movement. Populations of the green sharpshooter remain localized within an area. There are no migratory flights. There is, however, considerable movement of a localized nature during much of the year. This movement can best be characterized by an infiltration into or throughout an area by small numbers of adults over an extended period of time rather than by a mass movement of large numbers during a short period of flight. On warm evenings—May through September in Tulare County—this flight activity occurs almost daily, beginning at sunset and continuing for about an hour or longer. The distance of flight on any one night may be measured in terms probably of feet or yards, although it is possible that some individuals may travel a mile or more. During the cool months of the year the movements of green sharpshooter populations are limited, localized, and slow. In the late fall they tend to seek the shelter of early germinated broad-leaved weeds, or clumps of perennial grasses, such as Johnson or Bermuda, or grasses and weeds growing under trees, bushes, or vines, or grasses that have germinated under old plant debris. During late winter they move to the winter and spring annual grasses and weeds in which, starting in late February, they begin to deposit eggs.

REDHEADED SHARPSHOOTER

Distribution. The redheaded sharpshooter occurs in all of the principal grape-producing areas of northern California, especially in the San Joaquin Valley. In southern California it has been found as far south as Corona. The redheaded sharpshooter in general is found under much the same conditions as the green sharpshooter, but is not so dependent on moisture and succulence of host plants. It favors open growth of low, sparse, exposed grasses and weeds, such as those found in sandy, alkaline, or poor soils. It is commonly found around the margins of receding, overflow pools along streams, in beds of drying streams, along irrigation canals, roadsides, alkaline sinks, and at the outer exposed margins of denser plant growth, such as margins of alfalfa stands or vineyard avenues and borders.

Life History. In Tulare and Fresno counties, where the life history of the redheaded sharpshooter has been studied, there are 4 generations a year. The approximate dates on which the first eggs hatch and the first nymphs become adults are March 18 and April 15 for the first generation, May 14 and June 12 for the second generation, July 5 and August 2 for the third generation, and August 15 and September 12 for the fourth generation. The dates for the different generations will vary somewhat from year to year.

Host Range. The redheaded sharpshooter, like the green sharpshooter, also breeds and feeds on a very large number of grasses and certain weed hosts. It has been found on over 75 species of plants, principally annuals. The more important include Bermuda grass (*Cynodon dactylon* (L.) Pers.), salt grass (*Distichlis stricta* (Torr.) Rydb.), foxtail fescue (*Festuca megalura* Nutt.), hairy crabgrass (*Digitaria sanguinalis* (L.) Scop.), red maids (*Calandrinia menziesii* (Hook.) Torr. and Gray), common purslane (*Portulaca oleracea* L.), redstem filaree (*Erodium cicutarium* L'Her.), and puncture vine (*Tribulus terrestris* L.). Bermuda grass is an excellent host most of the year. Wherever it occurs, it is the most important of all food and breeding plants for this leafhopper.

Feeding Habits. In the spread of Pierce's disease to grapes it is probable that the redheaded sharpshooter plays an important part in the San Joaquin Valley, especially in the raisin-grape districts, where it thrives on the Bermuda grass, red maids, hairy crabgrass, and common purslane. In the sandy loam soil of this area, these plants are usually abundant and seldom too rank. In table-grape districts where a grass cover is grown during the summer, the leafhoppers are found primarily around the vineyard margins, in the avenues, or in the vineyard areas where the plant growth is sparse and low. The Bermuda and other grasses growing on the shoulders of roads and at pavement edges often support untold numbers of redheaded leafhoppers.

In its feeding habits on grapevines the redheaded sharpshooter is similar to the green sharpshooter. Grapevines are not a favored food host; feeding is apparently limited to short periods on suckers, foliage, or shoots of vines that are near to the ground or on it. No reproduction takes place on the vine. Both species of sharpshooters may temporarily feed on grapes as they pass through vineyards in search of preferred grasses and weeds; or when they are already in a vineyard on a grass cover that is turned under; or when other vineyard operations, such as sulfuring, disturb them in the cover and cause them to fly up on the vines. During evening flights and other movements, individuals will settle on the low foliage of the vine and remain there, perhaps overnight, or, more often, only a few minutes. When the vines are in early succulent growth, the leafhoppers feed for a longer period than when the vines have started to mature in the summer and fall.

Movement. There are no migratory movements of the redheaded sharpshooter. Like the green sharpshooter, their movements or flights are local, day-by-day flights of individuals rather than mass flights. In this respect, their activity is greater than that of the green sharpshooter, and they will spread themselves over an area more rapidly, traveling farther in a given length of time. The period of greatest activity occurs from May into September. The flights take place daily, when weather permits, for about an hour and a half, just after sunset. Distances traveled in any evening are usually the number of feet to a neighboring plant, but a mile or more may be reached.

Unlike the green sharpshooter, which normally breeds on the long-succulent plants growing in moist soil, the redheaded sharpshooter prefers to lay its eggs in the stunted, sparse type of growth found in dry, poor, or sandy types of soil. These hosts have matured and begun to dry by the time the nymphs have reached the adult winged stage. The adults then soon leave in search of more favorable food and breeding plants. The redheaded sharpshooter thus apparently tends to be more continually on the move than the green sharpshooter. During the winter months it moves to the young, early germinated filaree and grasses, and throughout the winter it continually seeks the smaller, well-spaced plants on well-drained soil.

BLUE SHARPSHOOTER

Distribution. The blue sharpshooter occurs throughout most of the grape-producing areas of California. It is very common and often very abundant, especially in canyons and along valley streams in the coastal fog belt. In the interior valleys it likewise is found primarily in the heavy growths along river channels.

Life History. In Napa, Alameda, and Tulare counties, where the life history of the blue sharpshooter has been studied, there is only one generation a year. Some differences occur in the dates between the three areas. The approximate dates when the first eggs are hatched and the adult winged stage is attained by the first nymphs are respectively: in Tulare County, April 17 and June 1; in Alameda County, April 1 and June 7; and in Napa County, May 10 and July 7. Eggs are laid by the overwintered females during much of the six-week period prior to the appearance of the first nymphs. The overwintered adults continue to lay eggs until their death. By the time the first nymphs have reached the adult stage, most of the overwintered adults have died, but often some will survive and oviposit for considerably longer periods. Thus, reproduction is continuous over one long generation each year, and nymphs may be found until late fall. The nymphs become adults during summer and fall, and these overwinter and produce the following year's generation.

Host Range. The blue sharpshooter, unlike the green and the redheaded sharpshooters, typically infests perennial plants—especially vines, shrubs, and trees. The most important food and breeding plants include willow (*Salix* spp.), creek nettle (*Urtica gracilis* Ait.), California blackberry (*Rubus vitifolius* C. & S.), European grape (*Vitis vinifera* L.), California wild grape (*Vitis californica* Benth.) and its wild hybrids; blue elderberry (*Sambucus glauca* Nutt.), and California mugwort (*Artemisia vulgaris* L.). However, the blue sharpshooter has been collected from over 150 species of plants. Often when the populations are very abundant, individuals may be found on every species of plant present, including weeds and woody vines, shrubs, trees, and, more rarely, ferns and grasses. The blue sharpshooter is often very abundant on numerous ornamental plants around homes in cities as well as in rural areas.

Feeding Habits. The blue sharpshooter is the most important vector in the spread of Pierce's disease to grapes in the coastal fog belt from Mendocino County to San Diego County. It finds the grape an excellent host plant, and often breeds in very large numbers. In some vineyards, it is not uncommon to find more than 500 blue sharpshooters per vine. The leafhoppers start to move into the vineyards shortly after the buds have broken in the spring, and may remain continuously present until the vines go into dormancy in late fall. They feed predominantly on the younger foliage and tips of canes, and the presence of either the adults or the ivory-colored nymphs may be readily detected. During late summer the adults begin to leave the vineyards and move to other hosts—such as brush and brambles and dooryard ornamentals.

In the San Joaquin Valley during the summer months, the blue sharpshooter is rather closely confined to the thickets and brush along streams and river channels. Only rarely have a few individuals been found on cultivated grapes at this time of the year, and on such occasions the grapes were adjacent to stream channels where the blue sharpshooter was abundant. In winter they may either remain largely in the breeding area or spread out toward the nearby low hills. They have been found only rarely on orange trees and on weeds growing in foothill orange groves.

Movement. There is some evidence of a limited migratory tendency by the blue sharpshooter. These leafhoppers prefer to feed on succulent growing tips of shoots or new foliage, so that during the course of the year populations often shift to new hosts. During the winter months very few wild hosts in the northern California valleys produce any new growth suitable for the blue sharpshooter. However, many rural homes have yards and gardens which contain different kinds of ornamental shrubs, trees, and herbs, many of which are suitable winter hosts. Populations will often overwinter on them in large numbers. In other places, however, either all or a part of a population may fly to nearby hills where suitable hosts are available. Distances traveled may not be more than ¼ to 2 or more miles.

MODE OF VECTOR FEEDING IN PLANT TISSUES AND VIRUS TRANSMISSION

Studies of the mode of vector feeding (10) show that adults of *Draeculacephala minerva, Neokolla circellata, Carneocephala fulgida,* and nymphs of the former two, all seek the xylem tissue in the process of feeding. When feeding upon leaves, the insects were able to reach the xylem from either the upper or the lower side of the leaf blade. Out of 110 feeding punctures made by viruliferous adults of *D. minerva* on healthy and diseased grape and alfalfa, 88.2 per cent ended in the xylem, 2.7 per cent reached the phloem, and 9.1 per cent entered parenchyma only. Seventy per cent of the feeding punctures that reached the xylem passed through the phloem. After entering the plant, many of the punctures branched in several directions.

Experiments have shown (10) that sharpshooters *D. minerva* and *N. circellata* transmit Pierce's disease to grape only when they are able to feed in xylem tissue. The percentages of plants infected after viruliferous leafhoppers were fed on different portions of the plant were: "whole plant, grape 91.6, alfalfa 75.0; whole stem, grape 80.0, alfalfa 80.0; exposed xylem strip, grape 60.4, alfalfa 90.0; phloem strip kept separate from xylem after feeding, grape 0.0; and the phloem strip replaced in contact with xylem after feeding, grape 0.0."

Other experiments reported in the same paper (10) indicate that the virus moves upward very rapidly in alfalfa stems, and that this movement may be associated with the movement of water in the xylem elements. Other experiments (4) show that the Pierce's disease virus may in a few instances move up or down very rapidly from the point of inoculation in grape, but in most instances this movement in the tissue has been relatively slow.

HOST RANGE OF VIRUS

The finding that Pierce's disease and alfalfa dwarf were caused by the same virus (9) first suggested that the virus had a wide host range. This has now been confirmed, and the number of plants experimentally infected includes 73 species belonging to 20 families. The infected plants range from annuals to perennials, and vary from grasses and weeds to vines, shrubs, and trees. A total of 34 species belonging to 17 families has been found to be naturally infected with the virus.

The grasses and clovers are among the plants found most susceptible to the virus. Symptoms have not been detected on any of the 24 species of grasses commonly found in cultivated areas, although this family of plants is known to include the best sources of virus for the sharpshooter vectors. Common vineyard grasses, such as Bermuda, foxtail, Italian rye, hairy crab, Johnson, and water grass have proved to be susceptible. In addition to being excellent sources of virus, the grasses are favorite breeding places and food plants for the green and the redheaded sharpshooters.

Seventeen species of clovers have been experimentally infected with the virus, and the majority of these developed definite symptoms. Among the clovers infected were white sweet, yellow, Ladino, crimson, and red.

Perennial plants, such as shrubs, vines, and trees occurring along stream banks or in ornamental home gardens are susceptible to the virus and are important sources of natural infection. This has often been illustrated by the fact that vineyards planted adjacent to stream banks and ornamentals have suffered severe losses through the movement of insects from such areas into the vineyard.

The three important vectors of Pierce's disease virus were collected during various seasons of the year and in different habitats, and were tested for natural infectivity. The insects were collected in vineyards, irrigated pastures, alfalfa fields, ornamental gardens, roadside areas, ditch banks, and natural breeding areas, such as bogs and the banks of streams. The results of these tests indicate that three vectors carry the virus during all seasons of the year, and are naturally infective in all of their various habitats.

RAINFALL AND PIERCE'S DISEASE

In the investigation of Pierce's disease control the relation of a number of factors to its spread has been considered. Of these factors, rainfall has had a

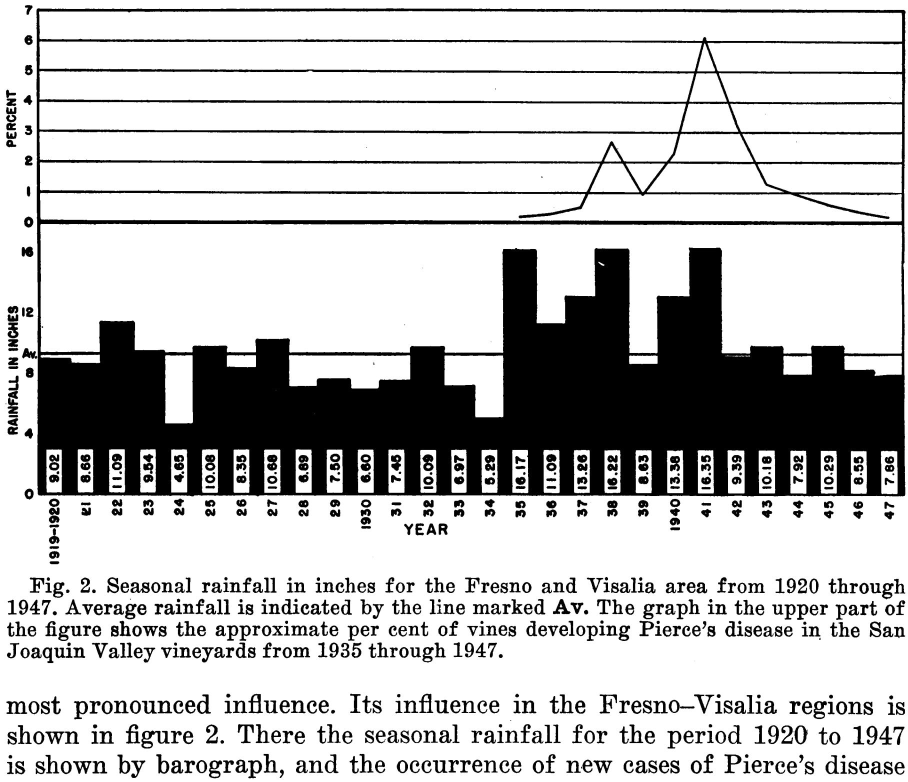

Fig. 2. Seasonal rainfall in inches for the Fresno and Visalia area from 1920 through 1947. Average rainfall is indicated by the line marked **Av.** The graph in the upper part of the figure shows the approximate per cent of vines developing Pierce's disease in the San Joaquin Valley vineyards from 1935 through 1947.

most pronounced influence. Its influence in the Fresno–Visalia regions is shown in figure 2. There the seasonal rainfall for the period 1920 to 1947 is shown by barograph, and the occurrence of new cases of Pierce's disease by graph.

The graphs of figure 2 indicate that during the years 1920 to 1934 the mean rainfall for this region was 13.2 per cent below normal. Although Pierce's disease was known to be present in the region during this period, there were very few new cases. The wettest wet period on record for the region was during the years 1935 to 1941, when the mean rainfall averaged 54.9 per cent above normal. The occurrence of new cases of Pierce's disease increased rapidly to a peak in 1941. Again, during the years 1942 to 1947, when the mean rainfall dropped to 6.2 per cent below normal, the occurrence of new cases of the disease decreased markedly each year.

There was a strikingly similar relation of rainfall to occurrence of Pierce's disease in the Anaheim outbreaks. From 1878, when the Anaheim weather station was established, to 1883 the mean rainfall was 34.7 per cent below normal; there were no reports of diseased vines. The season of 1883–1884 was unusually wet, with a rainfall of 226 per cent of normal. Many vines died in 1885, but the bulk of the destruction occurred in 1886 (12). In the light of present information, the majority of infections must have taken place in 1884 and 1885. This outbreak of the disease dwindled in 1885 to 1887, when the rainfall was 17.4 per cent below normal. However, in the years 1888 to 1891, when the mean rainfall was 50.7 per cent above normal, a second epiphytotic followed and many vines died in the years 1891 to 1893. The next ten years

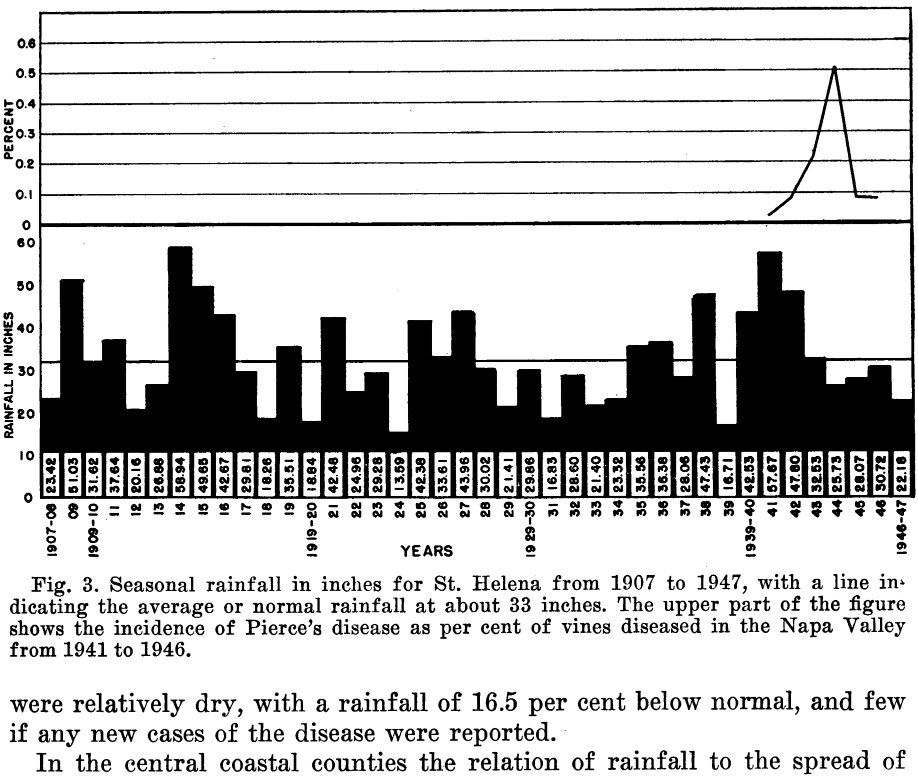

Fig. 3. Seasonal rainfall in inches for St. Helena from 1907 to 1947, with a line indicating the average or normal rainfall at about 33 inches. The upper part of the figure shows the incidence of Pierce's disease as per cent of vines diseased in the Napa Valley from 1941 to 1946.

were relatively dry, with a rainfall of 16.5 per cent below normal, and few if any new cases of the disease were reported.

In the central coastal counties the relation of rainfall to the spread of Pierce's disease was as definite as in the interior, but there was a lag of one to three years in the building up of the disease. The relation of rainfall to the present epiphytotic in the Napa Valley is shown in figure 3.

Although Pierce's disease has been known to be present in certain areas of the Napa Valley since 1887, it did not reach epiphytotic proportions there until 1941. The overnormal rainfall of 1914 to 1916 apparently was not enough, nor of sufficient duration, to start an epiphytotic, or the virus was not well established in native and cultivated host plants. If there were cases of the disease, they were too limited to be recorded. The spread may have been stopped effectively before it got under way by the very dry period beginning with the winter of 1916–1917. During 1917 to 1937, when the rainfall was 11.4 per cent below normal, few cases of disease occurred. The rainfall for 1938 was 46 per cent above normal and that for 1940 to 1942 was 55 per cent above normal.

In 1941 there was a sharp increase in new cases of Pierce's disease. The increase continued through the next two years, and reached a peak in 1944. Since 1942 the rainfall has been 14 per cent below normal, and the disease dropped off very sharply in 1945 and 1946 (11).

The behavior of the disease in the Santa Clara Valley during the outbreak of 1898–1899 (2) was similar to that of the Napa Valley in recent years. An epiphytotic started with the very wet period 1889 to 1895, but the peak was not reached until 1898 to 1899 during a dry period that started in 1896 and extended to 1900.

Several factors may have caused the lag in spread in the coastal areas, compared with the very rapid spread in the interior following excessive rainy

Table 1

PER CENT OF VINES DEVELOPING PIERCE'S DISEASE IN ROGUED AND UNROGUED 10-ACRE VINEYARD PLOTS

Plot number	Variety	Treatment	Per cent of vines diseased each year						
			1937	1938	1939	1940	1941	1942	1943
1	Emperor	Rogued	0.14	0.02	0.02	0.17	0.51	1.97	0.46
2	Emperor	Rogued	0.43	0.23	0.13	1.66	3.10	2.41	....
3	Emperor	Rogued	....	....	0.25	0.15	2.47	5.72	1.55
4	Emperor	Rogued	....	....	....	1.09	2.02	3.61	0.93
6	Emperor	Unrogued	....	....	0.49	0.54	1.46	4.34	0.73
7	Emperor	Unrogued	0.96	0.60	0.08	0.48	3.24	1.56	....
8	Emperor	Unrogued	0.20	0.60	0.66	3.85	8.97	....	....
9	Emperor	Unrogued	0.15	0.72	1.30	8.30	14.12	....	....
10	Malaga	Rogued	0.33	0.06	0.06	0.06	1.71	0.92	0.36
11	Thompson seedless	Rogued	....	....	10.90	4.06	0.96	2.16	....

periods. Of these factors, the following appear to be the most important: 1) the more rapid and greater response of the herbaceous annual host plants of the interior; 2) the development of the sharpshooters in the wet periods; and 3) the slower progress of the disease in the cooler coastal areas.

The relation of rainfall to spread of Pierce's disease, as indicated above, is a reasonable explanation for the declining spread in the recent epiphytotic. It also explains why the disease, although known to be present in both the San Joaquin and Napa valleys, did not spread in these regions before the recent epiphytotics.

EXPERIMENTS IN CONTROL

In the early investigations of Pierce's disease, the systematic removal of diseased vines from vineyards appeared to be a practical approach to possible control. Roguing, it was thought, would remove diseased vines which were a source of the virus; then healthy stock could be replanted. The practice would at least help to maintain vineyard stands.

Test plots of about 10 acres each were first established in Tulare County in 1937 and later in Fresno County. From time to time additional plots were included or established plots discontinued, as advisable. It was planned that diseased vines were to be removed from the rogued plots twice each season—once in the spring and again in the fall. After the diseased vines were marked,

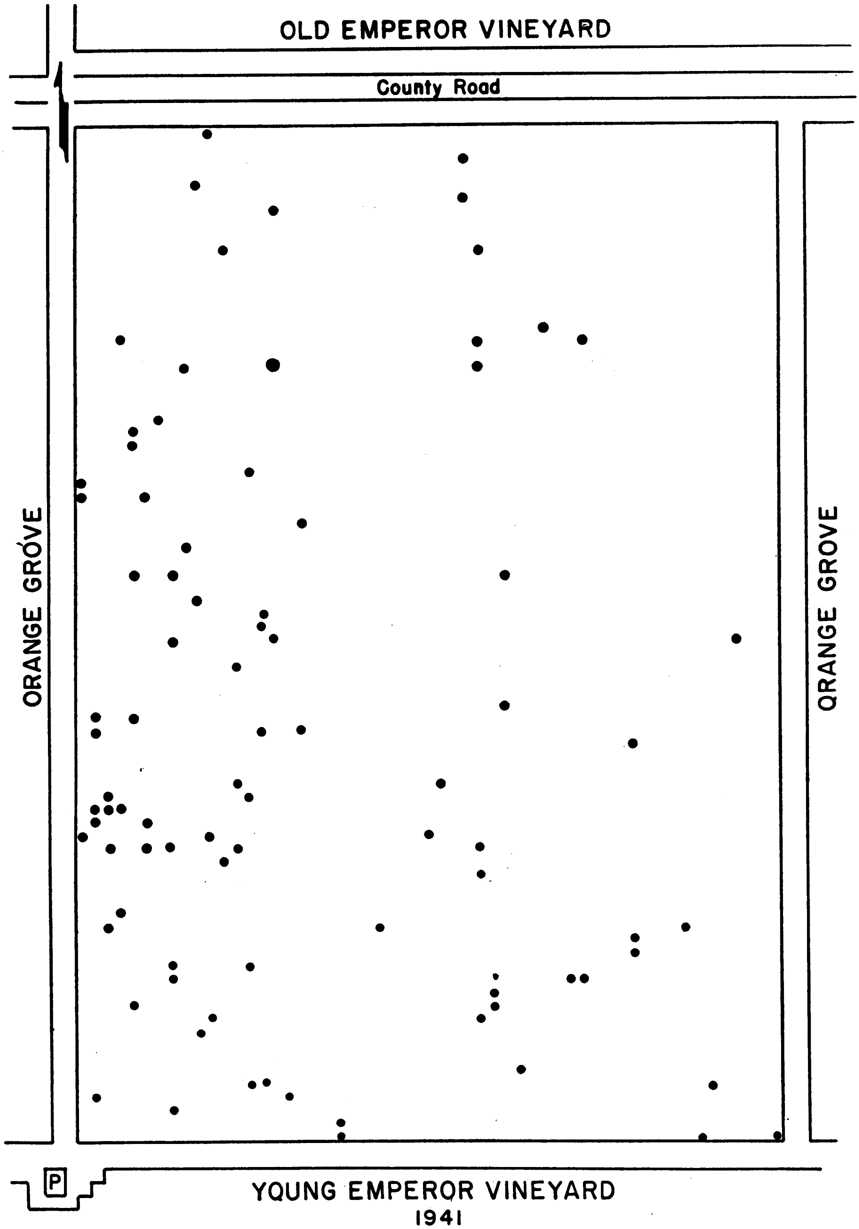

Fig. 4*A* to *F*, inclusive. Distribution of new vines showing symptoms of Pierce's disease each year from 1941 through 1946, in 10 acres of a 15-year-old Emperor vineyard. Locations of diseased vines are indicated by dots. The vineyard was bordered on the east by a young orange grove, west by an old orange grove, north by an old Emperor vineyard, and south by a young Emperor vineyard. *A*, new vines showing symptons for 1941. **P** indicates site of pump house.

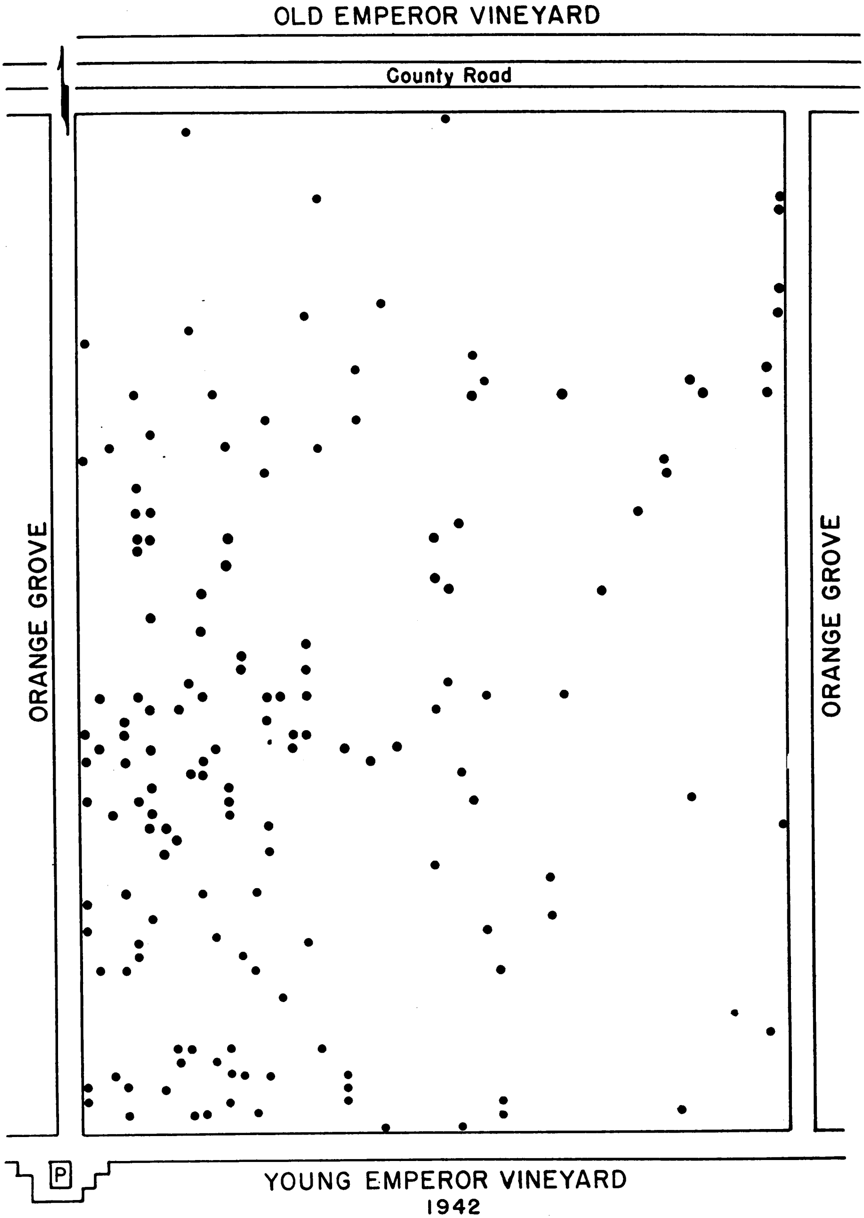

Fig. 4*B*. New vines showing symptoms of Pierce's disease in 1942.

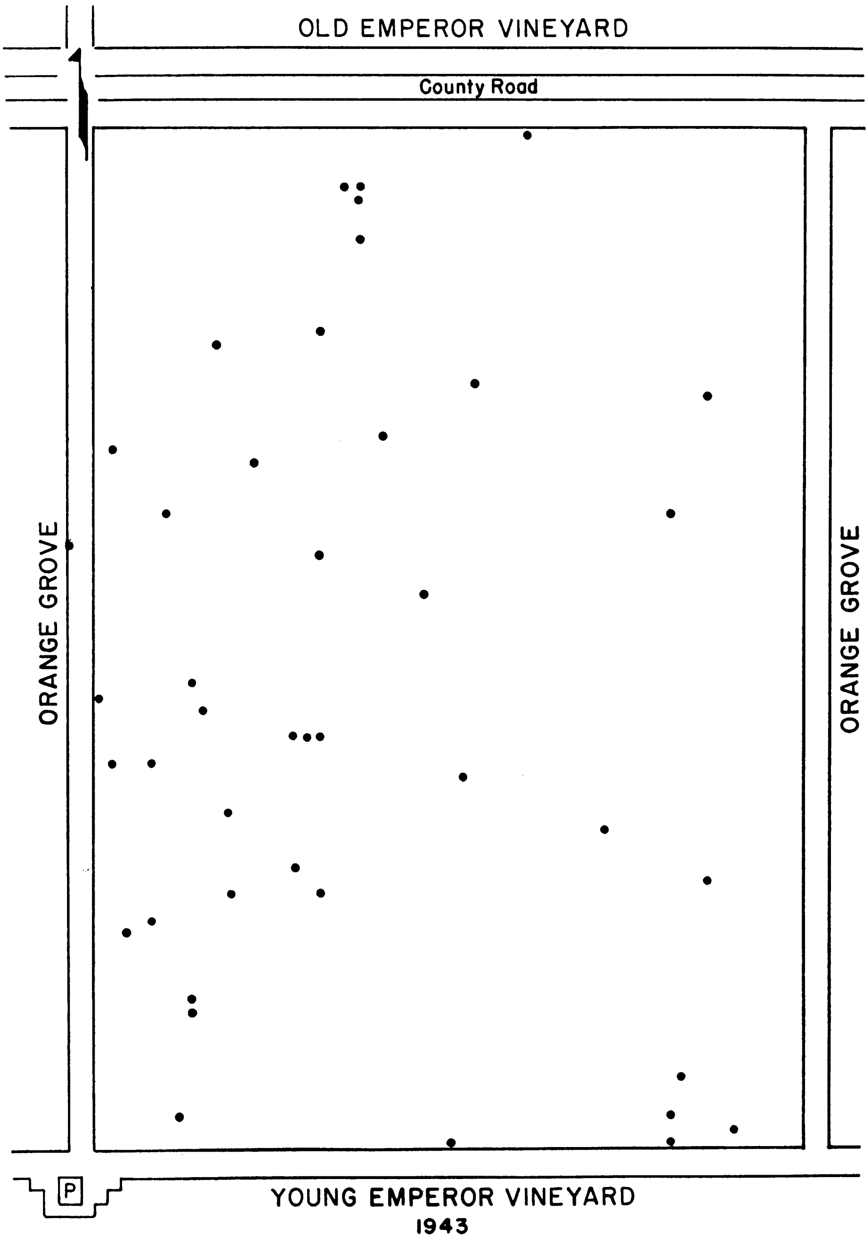

Fig. 4*C*. New vines showing symptoms of Pierce's disease in 1943.

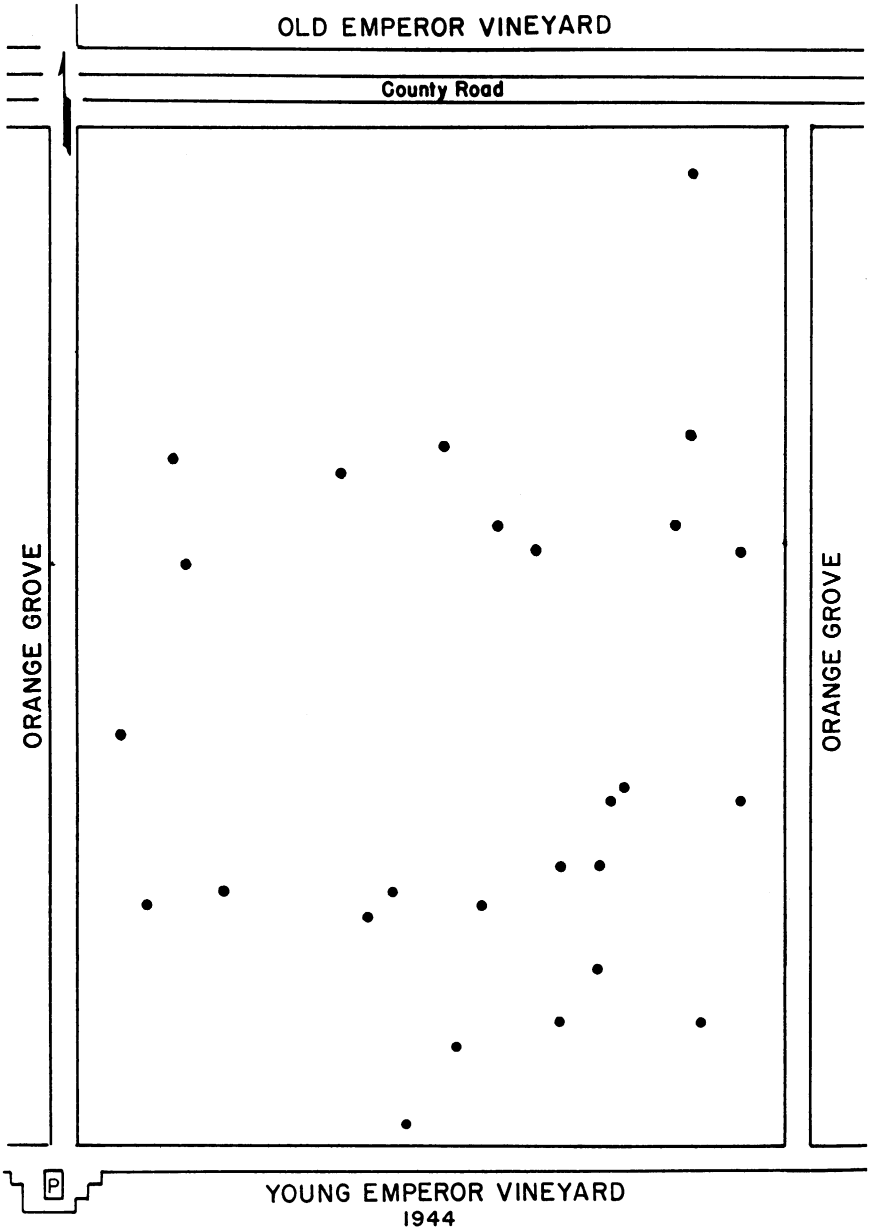

Fig. 4*D*. New vines showing symptoms of Pierce's disease in 1944.

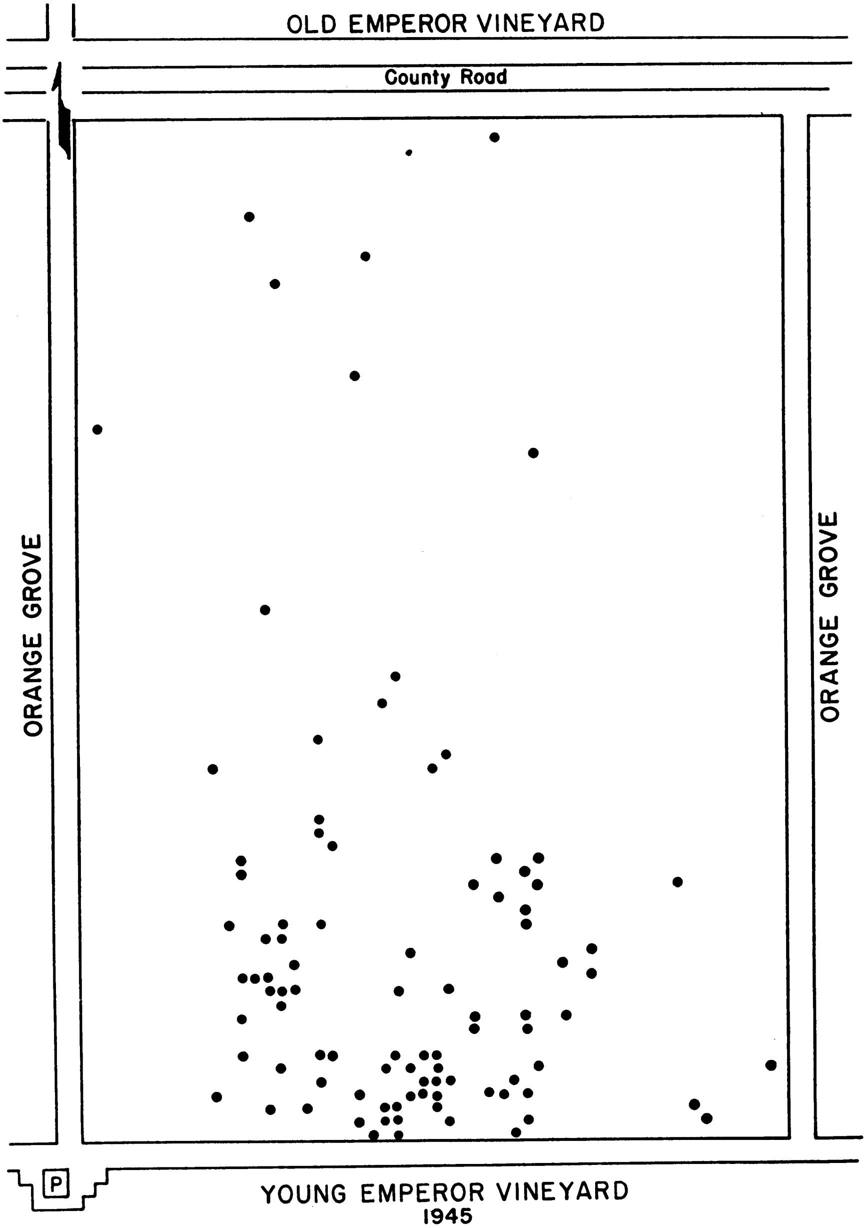

Fig. 4*E*. New vines showing symptoms of Pierce's disease in 1945.

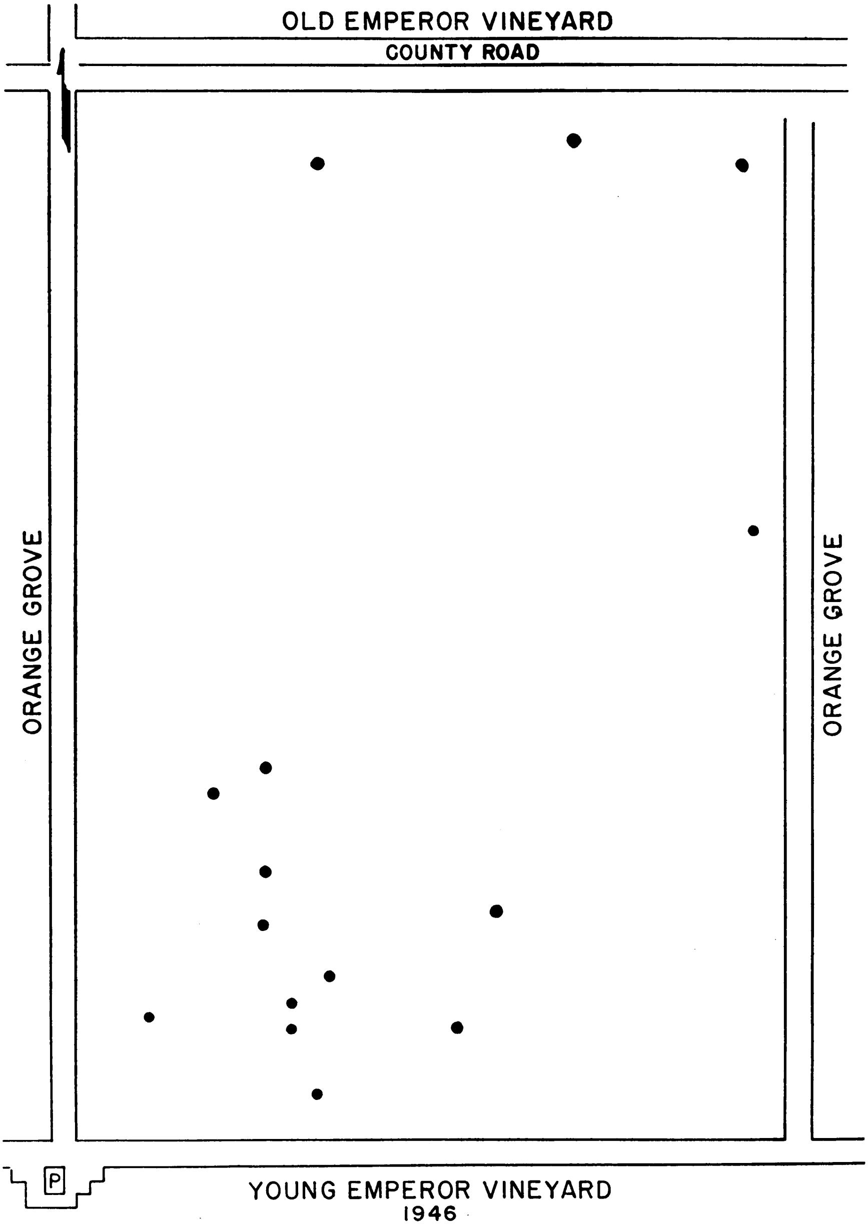

Fig. 4*F*. New vines showing symptoms of Pierce's disease in 1946.

removal was the responsibility of the coöperating vineyardist; some growers rogued the diseased vines regularly, others irregularly. The occurrence of disease in some of these plots through 1943 is shown in table 1. During 1940, new cases of Pierce's disease increased in rogued plot No. 2, and in all plots unrogued. In the following season, 1941, the numbers of diseased vines increased in all of the plots, irrespective of treatment.

The distribution of diseased vines in these 10-acre plots followed a pattern characteristic of the occurrence of Pierce's disease in most of the valley vineyards. Diseased vines were usually scattered irregularly over the plots, although in some seasons relatively large numbers were found concentrated in a section of one or more plots. When concentrated numbers of diseased vines recurred in subsequent seasons, they were often in a different section of the plot or vineyard.

Seasonal variability in the location of newly diseased vines in one of the plots is illustrated in figure 4. During 1941 and 1942, diseased vines were concentrated along the west side; in 1945 a similar concentration showed in the southern part of the plot. These areas—at times called "hot spots"—showed in rogued and unrogued plots alike. Their distribution in rogued plots indicates that the diseased vines in these vineyards were not the important source of virus spread.

The rapid increase in the number of new cases of the disease after 1940, and their irregular distribution in both rogued and unrogued plots indicates that roguing had no effect on the spread of Pierce's disease in vines. True, vine stands were more complete in the rogued plots, but this occurred because the diseased vines had been removed and the spaces planted to healthy stock. It was therefore evident that the 10-acre plots were too small for roguing to influence the spread of the disease.

In the spring of 1943, two large plots were established: to test roguing further; to test possible vector-control practices as a means of combating Pierce's disease; and to study vector populations and movement in relation to the occurrence and spread of Pierce's disease.

One plot was in a typical vineyard area near Woodlake in Tulare County. It consisted of nearly 1,000 acres, of which 793 were in vineyard. The area also included irrigated and dry pastures, alfalfa, peaches, plums, walnuts, citrus, other occasional crops, and waste land. The other plot, near Lindsay, consisted of 240 acres, all in vineyard. For convenience of records, each plot area was divided into quarter sections and these, in turn, into approximate 10-acre blocks, as illustrated in the plot maps shown in figures 5 and 6. Maps of each 10-acre piece were prepared to show the spaces for each of the 352,582 individual vines of the Woodlake and Lindsay plots.

Diseased vines in the vineyards were mapped twice each season, once in May and again in September. These map records show the condition of the vineyards at the time the plots were established and, progressively, the diseased vines found at each semi-annual mapping. From 1943 to 1945 the diseased vines were sawed off at the time of each mapping and the stumps removed later. The records of dead, missing, and replanted vines in the initial mapping in 1943 indicate the previous history of Pierce's disease in these vineyards. These records are summarized in table 2.

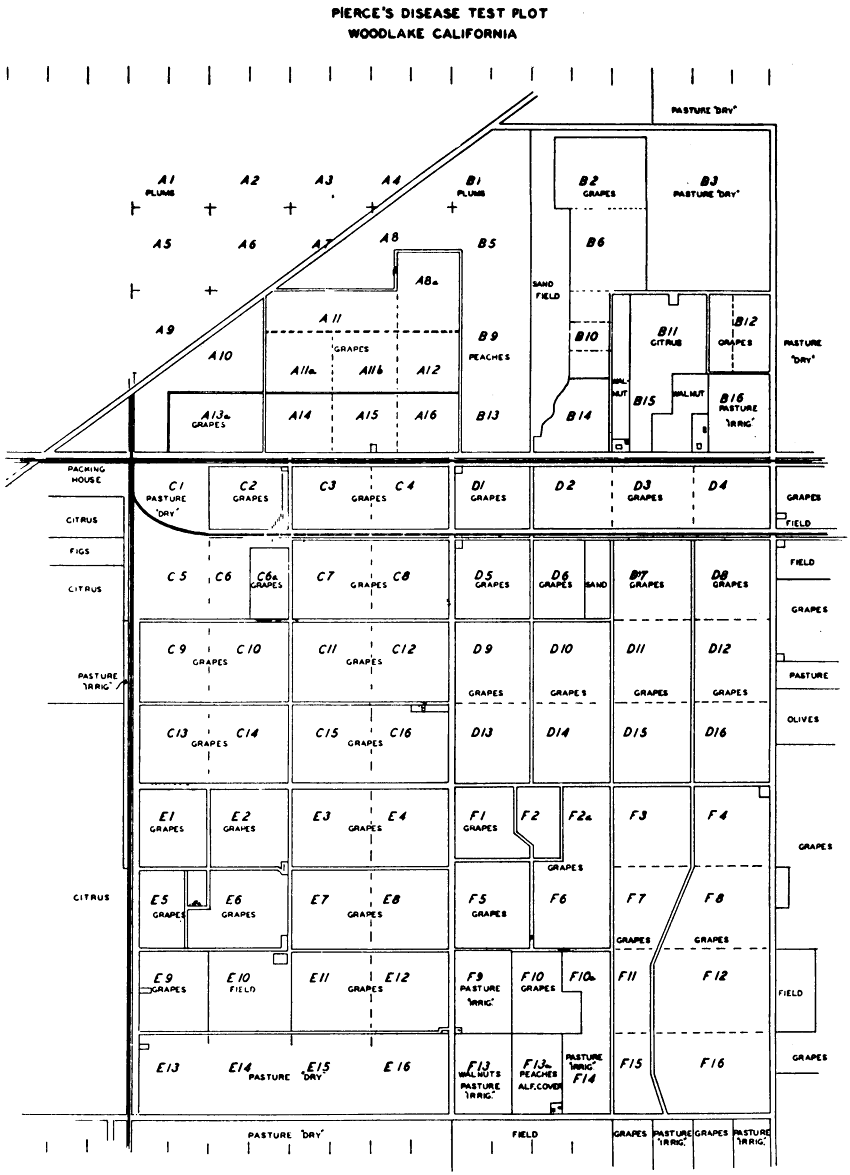

Fig. 5. Test plot area, with sections indicated and numbered for Pierce's disease control, near Woodlake in Tulare County. The double lines indicate the roadways and vineyard avenues, the heavy broken lines, railroad tracks and the southwest corner of block C-2 panel and swamp area.

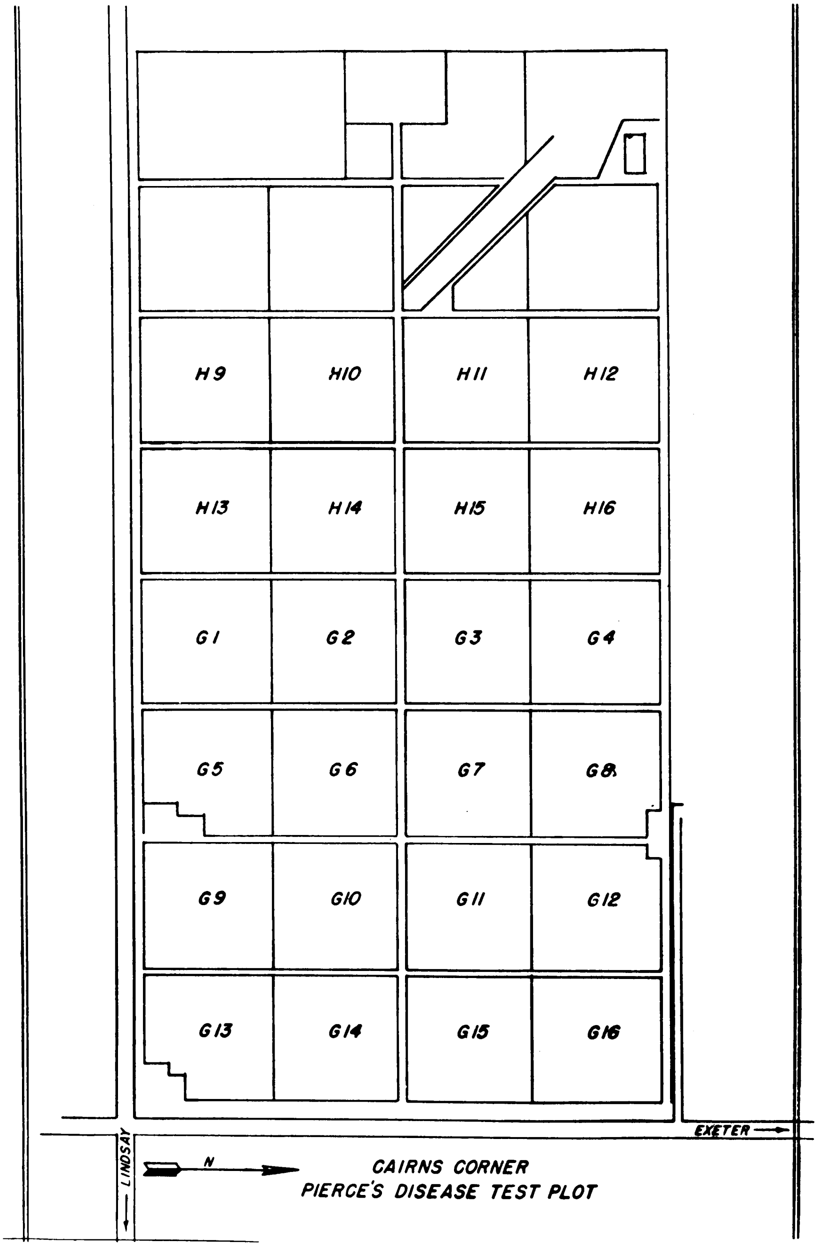

Fig. 6. Arrangement of 10-acre blocks in the Pierce's disease control test plot area near Lindsay.

Nearly all of the grapes in the two plots were of the Emperor variety. The plot also had a few acres of Red Malaga and Ribier which are equally susceptible to the disease. Vines of these varieties usually die in the season following the first symptoms of Pierce's disease. Most of the vineyards in the Woodlake plot had not been rogued before the plot was established. Therefore, the diseased vines found in this plot in the spring of 1943 represented, for the most part, an accumulation of the previous two years. In estimating the previous history of disease in the vineyards, the vines dead and missing, and the age of replanted vines could be used, even though the growers, for the most part, had been irregular in replacing the vines. The history of the occurrence of Pierce's disease in the Woodlake plot was estimated from the first season

Table 2

THE NUMBER OF DISEASED, DEAD, MISSING AND REPLANTED VINES IN EACH QUARTER-SECTION BLOCK OF THE WOODLAKE AND LINDSAY PLOTS IN THE SPRING OF 1943

	Woodlake plot						Lindsay plot	
	A	B	C	D	E	F	G	H
Vines with Pierce's disease	63	109	117	285	401	371	3,085	535
Dead vines	9	219	34	204	50	109	97	11
Missing vines	57	424	1,088	1,130	1,129	1,318	102	134
Replanted vines, new	695	1,239	1,856	1,196	2,128	1,343	3,777	986
age 1 year	385	34	466	647	572	1,018	.....	253
age 2 years	172	759	684	720	538	671	.....	126
age 3 years	184	454	433	539	347	215	.....	4

records. This is shown in table 2, and is illustrated over the caption Woodlake in figure 1. The greatest number of diseased vines occurred in 1940 and 1941, and the incidence of disease has since declined. The development of Pierce's disease in the Lindsay plot was similarly estimated for blocks G and H. This is also shown in table 2.

The semi-annual records of the occurrence of Pierce's disease in each 10-acre plot are tabulated in table 3 and summarized in table 4. Each quarter section and the summaries for both the Woodlake and Lindsay plots are graphically illustrated in the top part of figure 7.

An infection period is best represented by combining the new cases of diseased vines mapped in the fall with those found the next spring. Spring symptoms—delayed foliation, dwarfing, leaf mottling, and deformity—show in vines which have carried the infection over the winter.

The occurrence of Pierce's disease in the large experimental plots on an infection period basis, taken from table 4, is graphically illustrated in the lower part of figure 7. These barographs show the per cent of vines diseased in each fall-spring period for the entire Woodlake plot, and for each quarter section in the plot and for block G in the Lindsay plot. Block H of the Lindsay plot was not always mapped in the spring; the accumulation of disease for the season was tabulated in each fall mapping. The difference between the annual incidence of disease and that for the fall-spring period, shown in figure 7, is slight.

The barographs showing the incidence of disease clearly illustrate its course in the plot areas. Although some variations show in the individual sections, it is evident that the incidence of disease declined in all of the plot areas since the initiation of the experiment.

A comparison was made of the annual occurrence of diseased vines in the Woodlake and Lindsay plots, figure 7, with the percentage of vines developing disease in the San Joaquin Valley, figure 1, in 10-acre vineyard plots, table

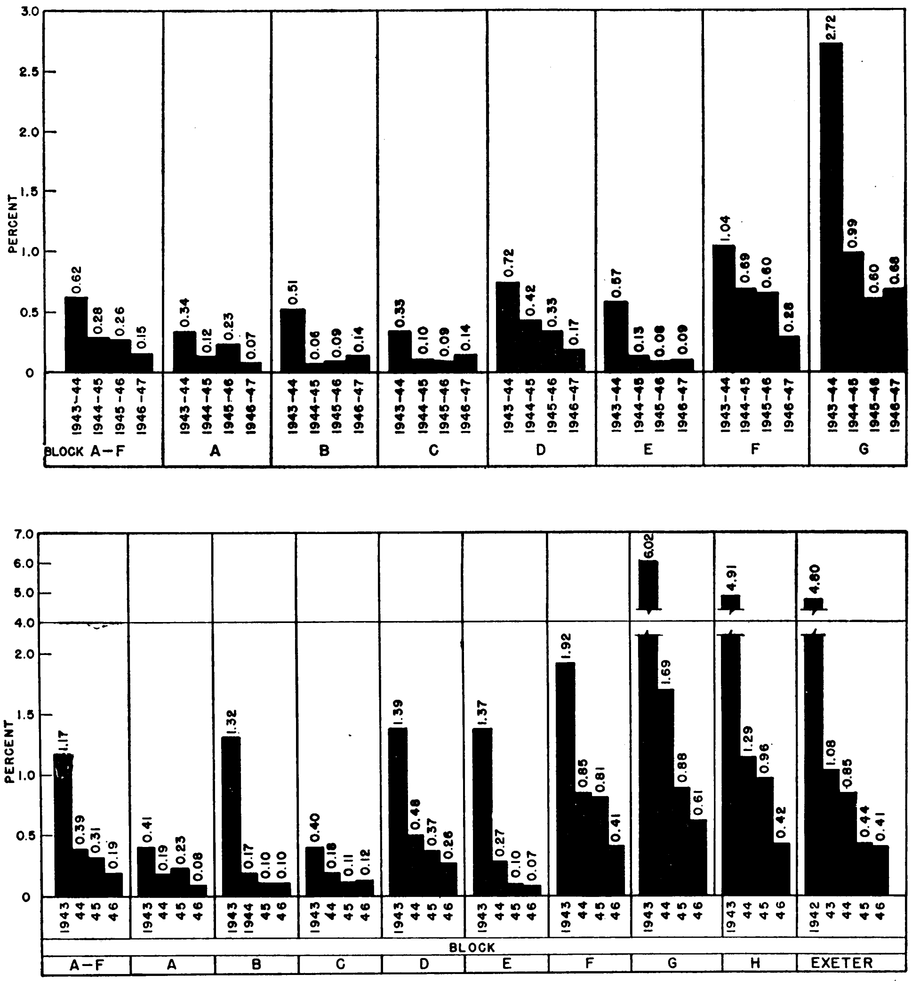

Fig. 7. Development of Pierce's disease in the Woodlake and Lindsay test plots. Barographs show the per cent of vines developing Pierce's disease for each period indicated; A to F, for the entire Woodlake plot; A, B, C, D, E, and F, for each quarter-section area of the Woodlake plot; G to H, for the Lindsay plot; and a group of 19 separate vineyards, totaling 362 acres, located within the vicinity of Exeter. Top series of barographs show the per cent of vines becoming diseased each year. Bottom series show the per cent of vines becoming diseased during an infection period, the fall of one season combined with the spring of the following sesaon. (See text.)

Table 3

NUMBER OF DISEASED VINES REMOVED EACH SPRING AND FALL FROM 1943 THROUGH 1945, AND THE NUMBER OF DISEASED VINES FOUND IN 1946 IN THE VINEYARDS OF THE PIERCE'S DISEASE CONTROL TEST PLOTS NEAR WOODLAKE (A TO F) AND LINDSAY (G, H)

Block	Vine spaces	1943			1944			1945			1946			1947
		Spring	Fall	Total	Spring	Fall	Total	Spring	Fall	Total	Spring	Fall	Total	Spring
A-8a	2,814*	8	9	17	6	3	9	3	3	6	0	0	0	..
A-11	2,979	1	2	3	0	1	1	2	0	2	0	2	2	0
A-11a	4,160	1	1	2	10	2	12	1	7	8	0	2	2	1
A-11b	3,281	4	1	5	2	1	3	0	38	38	0	0	0	0
A-12	3,864	20	20	40	6	5	11	1	0	1	1	7	8	0
A-13a	6,177	0	6	6	6	1	7	0	3	3	0	2	2	0
A-14	4,513	2	8	10	6	11	17	4	9	13	0	5	5	0
A-15	3,433	3	3	6	0	1	1	0	6	6	3	1	4	0
A-16	4,229	24	33	57	3	3	6	2	2	4	2	2	4	0
Totals	.....	63	83	146	39	28	67	13	68	81	6	21	27	1

* Block A-8a pulled in the fall of 1945.

Block	Vine spaces	1943			1944			1945			1946			1947
		Spring	Fall	Total	Spring	Fall	Total	Spring	Fall	Total	Spring	Fall	Total	Spring
B-2	3,320	0	3	3	0	0	0	1	2	3	0	0	0	1
B-6	1,654	15	0	15	0	0	0	0	0	0	1	1	2	0
B-10	222	0	0	0	0	0	-0	0	1	1	0	0	0	1
B-10a	348	0	1	1	0	0	0	0	0	0	0	0	0	1
B-12	765	4	8	12	4	0	4	1	2	3	2	1	3	2
B-12a	1,660	38	20	58	5	1	6	2	2	4	0	3	3	1
B-14a	2,679	46	6	52	7	2	9	0	0	0	0	4	4	2
B-14b	746	6	4	10	0	0	0	0	0	0	0	0	0	0
Totals	.....	109	42	151	16	3	19	4	7	11	3	9	12	8

Table 3—*Continued*

Block	Vine spaces	1943			1944			1945			1946			1947
		Spring	Fall	Total	Spring	Fall	Total	Spring	Fall	Total	Spring	Fall	Total	Spring
C-2	3,052	0	4	4	0	0	0	0	0	0	0	1	1	0
C-3	3,876	0	4	4	6	3	9	1	2	3	1	3	4	0
C-4	3,885	0	0	0	1	1	2	2	0	2	0	11	11	0
C-6a	720	0	0	0	0	0	0	0	0	0	0	0	0	0
C-7	3,323	15	7	22	4	1	5	0	2	2	1	1	2	2
C-8	3,381	8	4	12	12	1	13	0	5	5	1	9	10	1
C-9	4,005	5	23	28	2	9	11	0	2	2	0	2	2	0
C-10	3,988	1	6	7	1	1	2	1	6	7	3	5	8	3
C-11	4,176	28	9	37	10	3	13	1	5	6	0	4	4	1
C-12	3,989	10	13	23	11	4	15	2	5	7	0	4	4	5
C-13	3,657	5	9	14	2	3	5	3	5	8	0	4	4	2
C-14	3,588	3	2	5	0	2	2	0	2	2	1	3	4	3
C-15	4,048	12	5	17	4	1	5	4	4	8	0	1	1	0
C-16	3,587	30	15	45	8	1	9	3	0	3	0	4	4	0
Totals	.....	117	101	218	61	30	91	17	38	55	7	52	59	17

Block	Vine spaces	1943			1944			1945			1946			1947
		Spring	Fall	Total	Spring	Fall	Total	Spring	Fall	Total	Spring	Fall	Total	Spring
D-1	2,681	27	8	35	10	3	13	6	0	6	5	1	6	1
D-2	2,226*	0	88	88	0	0	0	0	0	0	0	0	0	0
D-3	5,140	3	4	7	5	8	13	5	2	7	0	3	3	1
D-4	4,887	9	32	41	0	10	10	2	3	5	1	2	3	1
D-5	4,438	10	14	24	12	1	13	0	2	2	0	6	6	0
D-6	1,069	14	26	40	9	1	10	0	8	8	0	0	0	0
D-7	2,904†	1	5	6	7	9	16	8	0	8	1	0	1	0
D-8	4,727	116	9	125	22	8	30	21	13	34	11	17	28	2
D-9	3,552	11	9	20	0	0	0	0	0	0	0	0	0	0
D-10	4,318	16	7	23	1	1	2	2	2	4	0	0	0	1
D-11	2,970‡	3	1	4	2	5	7	1	1	2	1	1	2	0
D-12	4,950	112	44	156	31	13	44	12	18	30	30	19	49	7
D-13	3,619	34	14	48	9	28	37	9	10	19	2	1	3	2
D-14	4,400	27	16	43	9	16	25	9	26	35	6	8	14	1
D-15	3,147	12	1	13	2	3	5	2	0	2	0	1	1	0
D-16	5,170	140	26	166	14	29	43	24	20	44	21	8	29	5
Totals	.....	535	304	839	133	135	268	101	105	206	78	67	145	21

* Block D-2 pulled in the fall of 1943.
† Number of vines in block D-7 for 1944 through 1946 was changed to 1,970.
‡ Number of vines in block D-11 changed to 1,978.

Table 3—*Continued*

Block	Vine spaces	1943			1944			1945			1946			1947
		Spring	Fall	Total	Spring	Fall	Total	Spring	Fall	Total	Spring	Fall	Total	Spring
E-1	3,608	36	13	49	7	2	9	0	1	1	2	2	4	6
E-2	4,301	30	26	56	5	3	8	0	0	0	1	2	3	1
E-3	3,946	26	5	31	4	4	8	2	3	5	0	0	0	0
E-4	3,684	28	13	41	14	10	24	2	1	3	0	3	3	1
E-5	2,100	23	6	29	1	2	3	1	3	4	1	3	4	1
E-5a	570	4	5	9	1	0	1	0	2	2	0	0	0	1
E-6	4,426	34	12	46	4	4	8	6	4	10	0	5	5	2
E-7	4,089	46	16	62	5	1	6	0	0	0	0	1	1	2
E-8	3,915	67	12	79	10	4	14	0	1	1	0	1	1	0
E-9a	685	0	0	0	0	0	0	1	2	3	0	1	1	0
E-9b	842	0	0	0	0	0	0	0	2	2	0	0	0	0
E-9c	1,286	5	24	29	1	1	2	0	2	2	0	0	0	1
E-11	4,182	50	15	65	10	4	14	0	6	6	0	2	2	0
E-12	3,928	52	20	72	9	6	15	1	3	4	1	3	4	2
Totals	.....	401	167	568	71	41	112	13	30	43	5	23	28	17

Block	Vine spaces	1943			1944			1945			1946			1947
		Spring	Fall	Total	Spring	Fall	Total	Spring	Fall	Total	Spring	Fall	Total	Spring
F-1	1,983	34	6	40	6	7	13	9	6	15	2	6	8	0
F-2	1,880	18	12	30	2	6	8	3	13	16	1	3	4	2
F-2a	1,987	2	4	6	6	1	7	7	2	9	1	1	2	0
F-3	2,992*	11	46	57	..	..	..	..	..	..	..	..	..	..
F-4	3,635	69	28	97	19	10	29	10	13	23	9	2	11	4
F-5	3,327	32	16	48	10	13	23	5	17	22	2	5	7	1
F-6	6,805	25	10	35•	29	7	36	30	9	39	5	3	8	9
F-7	3,050*	0	3	3	..	..	..	..	..	..	..	..	..	..
F-8	4,736	90	47	137	8	20	28	11	15	26	16	3	19	2
Thompson F-10	1,302	32	21	53	50	12	62	11	0	11	18	20	38	0
Emperor F-10	3,175	33	16	49	41	0	41	25	22	47	2	10	12	4
F-11	2,293*	2	2	4	..	..	..	..	..	..	..	..	..	..
F-12	6,724	243	50	293	54	18	72	43	47	90	33	9	42	8
F-15	1,369*	0	2	2	..	..	..	..	..	..	..	..	..	..
F-16	6,175	113	19	132	22	8	30	32	9	41	8	13	21	11
Totals	.....	704	282	986	247	102	349	186	153	339	97	75	172	41

* Blocks pulled in the fall of 1943.

Table 3—*Concluded*

Block	Vine spaces	1943			1944			1945			1946			1947
		Spring	Fall	Total	Spring	Fall	Total	Spring	Fall	Total	Spring	Fall	Total	Spring
G-1	4,455	86	68	154	76	15	91	12	11	23	6	13	19	6
G-2	4,455	165	66	231	39	25	64	16	14	30	7	15	22	11
G-3	4,293	98	44	142	46	9	55	18	14	32	9	7	16	8
G-4	4,289	98	51	149	71	13	84	21	20	41	8	13	21	18
G-5	4,183	188	119	307	42	40	82	25	29	54	23	27	50	12
G-6	4,455	215	34	249	34	28	62	16	18	34	9	12	21	12
G-7	4,293	195	95	290*	26	17	43	19	15	34	13	6	19	5
G-8	4,216	231	51	282	53	21	74	20	17	37	11	15	26	21
G-9	4,400	179	83	262	9	23	32	15	10	25	11	12	23	6
G-10	4,400	343	34	377	42	7	49	27	5	32	13	15	28	22
G-11	4,240	248	78	326	62	11	73	15	15	30	5	16	21	24
G-12	4,205	152	25	177	40	14	54	18	7	25	7	15	22	12
G-13	4,089	223	121	344	66	30	96	40	24	64	16	20	36	7
G-14	4,235	271	89	360	55	17	72	27	12	39	15	15	30	23
G-15	4,081	204	47	251	107	31	138	30	13	43	3	13	16	12
G-16	4,081	189	26	215	61	24	85	36	21	57	9	36	45	14
Totals	.....	3,085	1,031	4,116	829	325	1,154	355	245	600	165	250	415	213

Block	Vine spaces	1943			1944			1945			1946			1947
		Spring	Fall	Total	Spring	Fall	Total	Spring	Fall	Total	Spring*	Fall	Total	Spring
H-9	4,455	1	163	164	10	33	43	20	12	32	..	24	24	..
H-10	4,455	37	130	167	7	65	72	20	12	32	..	17	17	..
H-11	4,293	119	141	260	21	38	59	34	25	59	..	9	9	..
H-12	4,293	62	145	207	13	53	66	20	21	41	..	17	17	..
H-13	4,455	82	117	199	4	33	37	16	13	29	..	23	23	..
H-14	4,455	54	170	224	15	51	66	18	11	29	..	8	8	..
H-15	4,293	82	81	163	14	24	38	28	10	38	..	18	18	..
H-16	4,201	98	216	314	13	50	63	53	22	75	..	31	31	..
Totals	.....	535	1,163	1,698	97	347	444	209	126	335	..	147	147	..

* Vines not examined in the spring of 1946.

Table 4

SUMMARY OF THE NUMBER OF DISEASED VINES MAPPED* EACH SPRING AND FALL FROM 1943–1947; PER CENT OF DISEASED VINES FOUND EACH YEAR AND THE TOTAL VINE SPACES IN THE PIERCE'S DISEASE CONTROL TEST PLOTS NEAR WOODLAKE (BLOCKS A–F) AND LINDSAY (BLOCKS G–H) IN TULARE COUNTY

Block	Vine spaces†		1943				1944				1945				1946				1947
	1943	1944	Spring	Fall	Total	Per cent	Spring	Fall	Total	Per cent	Spring	Fall	Total	Per cent	Spring	Fall	Total	Per cent	Spring
A......	35,450	35,450	63	83	146	0.41	39	28	67	0.19	13	68	81	0.23	6	21	27	0.08	1
B......	11,394	11,394	109	42	151	1.32	16	3	19	0.17	4	7	11	0.10	3	9	12	0.10	8
C......	49,275	49,275	117	101	218	0.44	61	30	91	0.18	17	38	55	0.11	7	52	59	0.12	17
D......	60,198	56,046	535	304	839	1.39	133	135	268	0.48	101	105	206	0.37	78	67	145	0.26	21
E......	41,562	41,562	401	167	568	1.37	71	41	112	0.27	13	30	43	0.10	5	23	28	0.07	17
F......	51,433	41,729	704	282	986	1.92	253	102	355	0.85	186	153	339	0.81	97	75	172	0.41	41
Totals.	249,312	235,456	1,929	979	2,908	1.17	573	339	912	0.39	334	401	735	0.13	196	247	443	0.19	105
G......	68,370	68,370	3,085	1,031	4,116	6.02	829	325	1,154	1.69	355	245	600	0.88	165	250	415	0.61	213
H......	34,900	34,900	535	1,163	1,698	4.91	97	347	444	1.27	209	126	335	0.96	...‡	147	147	0.42	....
Totals.	103,270	103,270	3,620	2,194	5,814	5.63	926	672	1,598	1.55	564	371	935	0.90	....	397	562	0.54	318

* Diseased vines were sawed off at the time of mapping and the stumps removed later in the spring and fall of each year from 1943–1945, while they were only recorded for 1946.
† Vine spaces for 1945 and 1946 are the same as those listed for 1944, except Block A which dropped to 32,636 for 1946.
‡ Vines not examined in the spring of 1946.

1, and in separate districts within the valley, figure 1. This shows that the decline of disease in the plots was similar to that occurring in other sections of the valley, and of the same magnitude.

EFFECT OF ROGUING ON THE INCIDENCE OF DISEASE

This paper showed earlier that roguing had no apparent influence on the development and spread of Pierce's disease in 10-acre vineyard plots. The percentage of vines developing disease each year in representative rogued

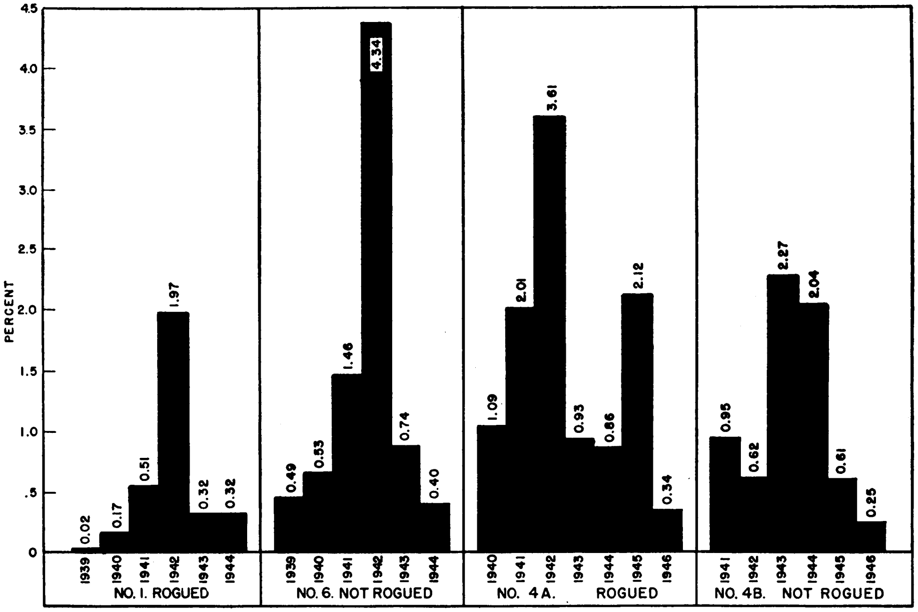

Fig. 8. Per cent of vines developing Pierce's disease each year in two separate pairs of 10-acre Emperor vineyard plots. Numbers 1 and 6 were separated only by a vineyard avenue and Numbers 4A and 4B by a county road. Numbers 1 and 4A were rogued twice each year, once in the spring and again in the fall. Numbers 6 and 4B were unrogued.

and unrogued vineyards is illustrated in figure 8. The incidence of disease was variable in all plots. Plots No. 1 and No. 6 joined. In 1942 a large number of diseased vines developed in a section of plot No. 6. This spot of diseased vines had no apparent relation to previous cases of the disease. In rogued plot No. 4A the incidence of disease was high in 1942 and 1945, while in plot No. 4B, which was not rogued, the incidence was high in 1943 and 1944. This variation indicates that the practice of roguing out diseased vines did not materially influence the spread of disease in these 10-acre plots.

The Woodlake plot and block G of the Lindsay plot were rogued twice each season from 1943 to 1945, at the same time the diseased vines were mapped. The upper half of figure 7 shows the per cent of vines rogued from the several blocks of these vineyards each year, and the lower half of figure 7, the occurrence of disease on an infection-period basis. Block H was not rogued, whereas the other blocks were. The development of Pierce's disease in block H followed a pattern very similar to that of the other plots.

The chart marked Exeter in the upper half of figure 7, shows the occurrence of Pierce's disease in 19 separate Emperor vineyards, totaling 362 acres, which were located in the vicinity of Exeter. These numbers differ from those in figure 1, which represent a random sample of all varieties and vineyards in the Exeter district. These 19 Exeter vineyards were rogued twice each year from 1942 through 1945. In 1946 they were rogued only once. The manner of roguing was similar to that employed in the Woodlake and Lindsay plots.

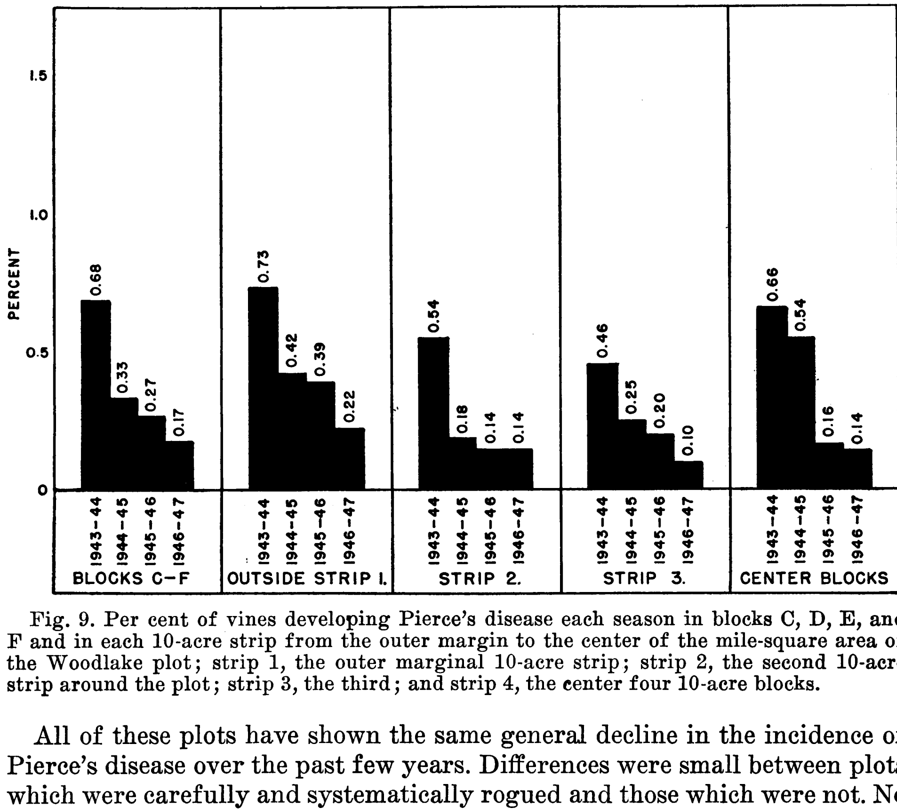

Fig. 9. Per cent of vines developing Pierce's disease each season in blocks C, D, E, and F and in each 10-acre strip from the outer margin to the center of the mile-square area of the Woodlake plot; strip 1, the outer marginal 10-acre strip; strip 2, the second 10-acre strip around the plot; strip 3, the third; and strip 4, the center four 10-acre blocks.

All of these plots have shown the same general decline in the incidence of Pierce's disease over the past few years. Differences were small between plots which were carefully and systematically rogued and those which were not. No apparent differences could be attributed to the practice of removing diseased vines. Furthermore, it appears that the spread of Pierce's disease in a district was general, that diseased grapevines were not the primary or principal source of virus, and that the general spread of the virus was into the vineyards from outside sources.

SPREAD OF DISEASE INTO VINEYARDS

Knowledge of the distances over which Pierce's disease naturally spreads is of importance, particularly in relation to certain control possibilities. As discussed earlier, the disease developed freely over small 10-acre plots. Spread of the disease into the Woodlake plot area was considered. Blocks C, D, E, and F of the Woodlake plot constituted a mile-square area under reasonably clean culture that was rogued twice each season. If the distance of ½ mile had any influence on the spread of the disease, then there should have been a decrease in the incidence of diseased vines from the margins of the area to its center. The data showing the number and per cent of diseased vines in the

Table 5

NUMBER AND PER CENT OF VINES DEVELOPING PIERCE'S DISEASE EACH FALL-SPRING PERIOD IN THE MILE-SQUARE AREA OF THE WOODLAKE PLOT, AND IN 10-ACRE STRIPS FROM THE OUTER MARGINS TO THE CENTER

Plot area	Total vine spaces		Diseased vines							
	1943	1944	Fall, 1943–spring, 1944		Fall, 1944–spring, 1945		Fall, 1945–spring, 1946		Fall, 1946–spring, 1947	
	Number	Number	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Blocks C–F..........	202,468	188,611	1,372	0.68	625	0.33	513	0.27	324	0.17
Outside strip......1	76,391	......	561	0.73	322	0.42	299	0.39	167	0.22
Strip..............2	53,793	45,825	293	0.54	84	0.18	65	0.14	66	0.14
Strip..............3	50,432	......	235	0.46	126	0.25	102	0.20	53	0.10
Center blocks......4	12,873	......	83	0.66	69	0.54	21	0.16	18	0.14

Table 6

NUMBER AND PER CENT OF VINES DEVELOPING PIERCE'S DISEASE EACH FALL-SPRING PERIOD IN AREAS OF THE WOODLAKE AND LINDSAY PLOTS UNDER DIFFERENT CULTURAL PRACTICES

Treatment	Total vine spaces		Diseased vines							
	1943	1944	Fall, 1943–spring, 1944		Fall, 1944–spring, 1945		Fall, 1945–spring, 1946		Fall, 1946–spring, 1947	
	Number	Number	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Clean culture by										
Oil*...............	46,384	......	245	0.53	61	0.13	33	0.07	44	0.09
Tillage, area 1*.....	40,920	......	130	0.32	38	0.09	41	0.10	64	0.15
Tillage, area 2......	21,001	......	149	0.71	150	0.37	102	0.25	42	0.19
Tillage, area 3......	33,895	31,969	205	0.60	160	0.50	122	0.38	77	0.24
Tillage, area 4......	21,270	......	247	1.16	152	0.71	150	0.70	52	0.24
Grass cover										
Block A............	35,450	32,636†	122	0.34	41	0.12	74	0.23	22	0.06
Block G...........	68,370	......	1,860	2.72	680	0.99	410	0.60	463	0.68
Block H...........	34,900	......	1,260	3.61	556	1.59	126‡	0.36	147§	0.42

* Oil and clean-tillage areas are outlined in the description of figure 10.
† Number of vine spaces for 1946 and 1947.
‡ Diseased vines for the fall of 1945 only.
§ Diseased vines for the year 1946.

area, and by 10-acre strips from the margins to the center, are presented in table 5 and shown graphically in figure 9.

These data do not show a decrease in the incidence of disease from the margin to the center of the plot for any individual season, nor for the entire period of the experiment. It is then evident that the disease must have spread in this area over distances greater than ½ mile.

CLEAN CULTURE VS. SUMMER GRASS COVER

It is the practice in many of the frequently irrigated vineyards in the San Joaquin Valley to allow summer grasses to grow freely after midsummer. Many of these grasses are annuals, but they have been found to be susceptible to Pierce's disease virus and to be symptomless carriers. Furthermore, these same grasses are preferred hosts of the vectors found most important in spreading the virus in the valley vineyards. Clean culture was therefore tested as a possible means of reducing the incidence of Pierce's disease.

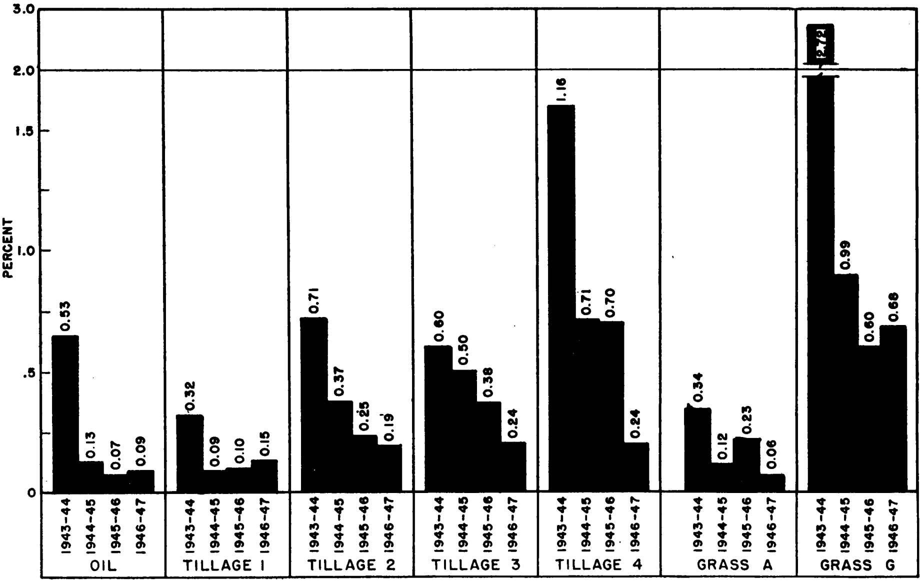

Fig. 10. Per cent of vines diseased each season in blocks of vines in the Woodlake and Lindsay plots under different cultural practices: oil consisted of blocks C 15–16, E 1–8, and E 11–12; tillage 1, blocks C 2–4 and C 7–14; tillage 2, blocks D 13–14, F 1, 2, 2a, 5, and 6; tillage 3, blocks D 3, 4, 7, 8, 11, 12, 16; tillage 4, blocks F 4, 8, 12, 16; grass A, all vineyards in block A; and grass G, all vineyards in block G.

From 1943 through 1945, most of the vineyards and other lands in Blocks C, D, and F of the Woodlake plot were clean tilled by disc and harrow. The ground was tilled as frequently as practice would permit in an effort to keep down vector populations and to prevent any vector breeding in the cover. Blocks C 15 and 16, and E 1, 2, 3, 4, 5, 5a, 6, 7, 8, 11, and 12, were similarly cleaned by frequent oil sprays. Vineyards in blocks A, B, and the entire Lindsay plot, blocks G and H, were maintained with summer grass cover. The incidence of disease in these areas is shown in table 6 and figure 10. The per cent of vines diseased in each area declined over the entire period of the experiment. Figures 5 and 6 show the limits of areas as defined herewith and also under figure 10: oil culture area consisted of blocks C 15, 16; E 1–8 and E 11–12; tillage area 1, blocks C 2–4 and C 7–14; tillage area 2, blocks D 13–14, F 1, 2, 2a, 5, and 6; tillage area 3, blocks D 3, 4, 7, 8, 11, 12, 15, 16, and tillage area 4, blocks F 4, 8, 12, 16; and grass areas were A and G.

In the area under clean culture by oil, disease declined consistently throughout 1945, but picked up slightly in the 1946 infection period. This slight rise, however, is not significant. Similar results also show for the clean-tillage area 1, just north of the oiled area. In other blocks of vines, including the grass areas, occurrence of the disease declined similarly over the entire period.

The 10-acre block No. 4 A, in figure 8, was also clean tilled by cultivation from 1942 through 1945. The incidence of disease in this plot was inconsistent and apparently not influenced by clean tillage.

EFFECT OF CLEAN TILLAGE AND SUMMER GRASS ON FRUIT DEVELOPMENT

Along with the control test plot work on Pierce's disease in 1942 to 1945, a number of tests were made to determine the influence of clean tillage and summer grass on the time of maturing and coloring of grapes. Information on these vineyard practices was of interest in conjunction with possible measures which might influence the rate of spread of Pierce's disease.

During the seasons of 1942 and 1943 no significant difference in the development and ripening of Emperor grapes in Tulare County could be assigned to clean tillage in contrast to the usual practice of growing a summer grass covercrop. The slightly higher degree Balling of the fruit of the clean-tilled plots and the larger berries of most of the covercrop lots are not significant.

The data of tables 7 and 8 are supported by the results for twelve pairs of comparisons, between clean-tilled and covercropped vineyards in 1945.

Although there was no significant difference in the measurements, it is the general opinion of most growers practicing clean tillage in recent years that the quality of fruit from such plots was inferior to that of fruit from plots farmed to summer grass. Data to support this opinion are lacking, but the rather uniform agreement among growers cannot be ignored. The growers' opinion regarding quality is not in conflict with the data of the table, since it refers largely to keeping quality, especially of the stems.

The stems of fruit from clean-tillage plots are supposed to lack keeping quality. It is our opinion that, should it be worth while to practice weed control, the present weakness of stems under this system of culture can be overcome by appropriate modification in fertilizer and irrigation practices. The proper adjustment of irrigation alone should greatly improve the stems.

Where clean tillage was in force throughout the year, as in the plots where the weeds were controlled with oil, there was more vine growth. This response of the vines was subject to control through the judicious application of water and fertilizers.

SHARPSHOOTER POPULATION AND PIERCE'S DISEASE*

The green and the redheaded sharpshooters *Draeculacephala minerva* and *Carneocephala fulgida* are the most important vectors of the Pierce's disease virus in the San Joaquin Valley where the Woodlake and Lindsay plots were

* The comparisons between sharpshooter populations and incidences of Pierce's disease and the conclusions indicated under the heading are tentative. Additional investigation may provide a more accurate basis of data interpretation and thus alter to some degree the conclusions presented herein.

located. Beginning in 1943 on the Woodlake plot, and in 1944 on Section G of the Lindsay plot, samples of sharpshooter populations were taken six or more times a year. Each sample consisted of 100 sweeps of an insect net made in 50

Table 7

EFFECT OF CLEAN TILLAGE COMPARED WITH SUMMER COVERCROP IN ADJACENT VINEYARD BLOCKS ON THE FRUIT OF EMPEROR IN TULARE COUNTY, 1942

Year and vineyard	Treatment	Degree Balling	Weight of berry, grams	Per cent acidity	Per cent colored, by inspection
1942:					
Cosart	Clean tillage	18.0	4.76	.37	86.2
	Grass cover	17.0	4.54	.35	87.5
List-McGee	Clean tillage	17.8	4.20	.47	63.3
	Grass cover	18.0	5.02	.47	77.0
Sexton	Clean tillage	16.6	4.57	.41	58.3
	Grass cover	16.4	4.84	.48	43.0
El Festino	Clean tillage	15.4	4.60	.52	46.6
	Grass cover	14.8	4.50	.57	30.0
Williams	Clean tillage	17.2	4.43	.36	85.0
	Grass cover	17.0	5.18	.35	79.0
1943:					
Williams and Milton	Clean tillage	17.0	4.8	.45	59.6
	Covercrop	15.1	6.4	.45	44.6
Sexton	Clean tillage	15.4	5.7	.43	54.1
	Covercrop	15.0	6.2	.55	38.9

Table 8

COMPARISON OF THE EFFECT OF WEED CONTROL AND SUMMER GRASS ON FRUIT DEVELOPMENT AND MATURING

	Under weed control	Under grass culture	Difference
Weight of cluster, grams	635.0	629.0	6.0
Weight of berry, grams	5.00	5.34	0.34
Color by berry count, per cent	64.5	60.8	3.7
Balling degree	16.6	16.3	0.3
Acidity, per cent	0.45	0.44	0.01

sweeps over the ground in-between the vineyard rows, and 50 sweeps about the borders of each block. The former were designated as block samples, and the latter as border samples.

The seasonal vector population samples for each 10-acre block of the Woodlake plot and section G of the Lindsay plot are shown in table 9. Summaries of the blocks by quarter sections A, B, C, D, E, F, and G are shown in table 10; and summaries of the vector population samples for the entire Woodlake plot,

Table 9

SUMMARY OF SEASONAL SHARPSHOOTER POPULATION SAMPLES TAKEN IN EACH 10-ACRE BLOCK IN THE WOODLAKE AND LINDSAY TEST PLOTS

Plot section	Year	Number of samples	Average number of sharpshooters per sample						
			Draeculacephala		*Carneocephala*		Total sharpshooters		
			Adults	Nymphs	Adults	Nymphs	In vineyard	In borders	Per sample
A-8a	1943	6	2.83	0.16	2.99	0	4.32	1.66	5.98
A-11	1943	6	0.99	0	1.49	0	1.82	0.66	2.48
	1944	6	4.00	0.66	18.83	0	0.5	23.00	23.5
	1945	6	0.66	0	3.00	0	0.66	3.00	3.66
	1946	6	0.17	0.17	1.00	0	0.84	0.50	1.34
A-11a	1943	6	0	0	0	0	0	0	0
	1944	6	4.16	0.5	14.00	0	3.66	15.00	18.65
	1945	6	0.5	0	10.5	0	0.83	10.16	11.00
	1946	6	0	0	5.33	0	0	5.33	5.33
A-11b	1943	6	0.32	0	1.33	0	0.66	0.99	1.65
	1944	6	17.66	1.16	4.66	0	17.5	6.00	23.5
	1945	6	0.33	0	0.33	0	0.66	0	0.66
	1946	6	0	0	3.33	0	0.50	2.83	3.33
A-12	1943	6	1.83	0.82	9.82	0.83	5.65	7.65	13.30
	1944	6	9.5	8.16	0.83	1.16	19.33	0.33	19.66
	1945	6	0.5	0	3.33	0	0.83	3.00	3.83
	1946	6	0	0	0.17	0	0.17	0	0.17
A-13	1943	6	0.50	0	36.83	0.99	4.16	34.16	38.32
	1944	6	5.33	2.66	40.00	0.83	12.5	36.33	48.83
	1945	6	0	0	2.66	0	0	2.66	2.66
	1946	6	0.17	0	0.17	0	0.34	0	0.34
A-14	1943	6	5.16	0	19.5	0	0	24.66	24.66
	1944	6	2.83	0.16	12.83	0	4.33	11.5	15.83
	1945	6	0.16	0	2.83	0	0.16	2.83	3.00
	1946	6	0	0	0.17	0	0	0.17	0.17
A-15	1943	6	8.83	0	23.99	2.5	11.16	24.16	35.32
	1944	6	2.33	0.16	26.83	0.5	2.83	27.00	29.83
	1945	6	0.33	0	5.16	0	0	5.5	5.5
	1946	6	0	0	7.00	0.33	0	7.33	7.33
A-16	1943	6	2.00	0.33	37.16	0.83	1.16	39.16	40.32
	1944	6	11.00	3.00	24.33	3.5	5.83	36.00	41.83
	1945	6	0.66	0.16	16.33	0.83	0.66	17.33	18.00
	1946	6	0	0	10.67	1.83	0.17	12.33	12.33
B-2	1943	6	0.5	0	17.00	0.16	1.66	16.00	17.66
	1944	6	2.33	0	10.16	3.33	1.33	14.5	15.83
	1945	6	0.33	0	2.83	0	0.33	2.83	3.61
	1946	6	0	0	0	0	0	0	0
B-6	1943	6	0.16	0	19.16	0	2.16	17.16	19.32
	1944	6	3.16	1.5	15.66	5.16	8.5	17.00	25.5
	1945	6	0.16	0	0.83	0	0.5	0.5	1.00
	1946	6	0	0	1.00	0	0	1.00	1.00

Table 9—*Continued*

Plot section	Year	Number of samples	Average number of sharpshooters per sample						
			Draeculacephala		*Carneocephala*		Total sharpshooters		
			Adults	Nymphs	Adults	Nymphs	In vineyard	In borders	Per sample
B-12	1943	6	7.49	0	33.99	4.16	7.66	37.98	45.64
	1944	6	24.00	2.33	54.33	30.33	22.5	88.5	111.00
	1945	6	25.83	3.83	20.00	26.83	17.5	59.00	76.5
	1946	6	46.16	6.50	32.33	4.49	24.32	65.16	89.48
B-14	1943	6	1.49	0	7.99	5.83	2.82	12.49	15.31
	1944	6	2.33	0	6.00	4.16	3.66	8.83	12.5
	1945	6	0.5	0	0.33	0	0.83	0	0.83
	1946	6	0.34	0	1.00	0	0.34	1.00	1.34
C-2	1943	6	1.00	0	35.99	0	3.66	33.33	36.99
	1944	6	1.33	0	10.66	0	1.00	11.00	12.00
	1945	6	0.66	0.33	2.66	0	2.16	1.5	3.66
	1946	6	0.17	0	0	0	0.17	0	0.17
C-3	1943	6	1.00	0	2.00	0	1.00	2.00	3.00
	1944	6	3.33	0.5	1.33	0	5.16	0	5.16
	1945	6	1.16	0	12.33	0	1.83	11.66	13.5
	1946	6	0	0	0	0	0	0	0
C-4	1943	6	0.16	0	3.49	0.33	0.16	3.82	3.98
	1944	6	4.16	0.16	21.16	0	1.66	23.83	25.49
	1945	6	0.5	0	6.00	11.66	0.5	17.66	18.16
	1946	6	0.17	0	0	0	0.17	0	0.17
C-6	1943	6	2.16	0	20.33	2.33	15.16	9.66	24.82
	1944	6	2.00	0	5.5	5.83	1.33	12.00	13.33
	1945	6	0.5	0	5.83	0.5	0.83	6.00	6.83
	1946	6	0.17	0	20.83	3.00	3.17	20.83	24.00
C-7	1943	6	5.49	0	13.16	0	4.16	14.49	18.65
	1944	6	1.66	0	7.16	0.16	5.16	3.83	9.00
	1945	6	0.16	0	1.5	0	1.00	0.66	1.66
	1946	6	1.50	0.17	12.33	2.33	10.33	6.00	16.33
C-8	1943	6	6.16	1.33	15.99	0.49	5.32	18.65	23.97
	1944	6	0.33	0	10.33	0	2.00	8.66	10.66
	1945	6	0.66	0	1.16	0	1.83	0	1.83
	1946	6	1.67	0.17	23.00	4.33	12.17	17.00	29.17
C-9	1943	6	0.49	0	14.82	15.33	0.32	30.32	30.64
	1944	6	0.83	0	3.16	0	0.16	3.83	4.00
	1945	6	0.33	0	1.66	0.66	0.16	2.5	2.66
	1946	6	5.16	0	0.67	0	5.33	0.50	5.83
C-10	1943	6	1.00	0	7.00	3.33	0	11.33	11.33
	1944	6	0.5	0	6.5	0	0	7.00	7.00
	1945	6	0.5	0	0.66	0	0.33	0.83	1.16
	1946	6	1.17	0.17	1.00	0.17	1.00	1.51	2.51
C-11	1943	6	5.16	0	24.83	0	1.83	28.16	29.99
	1944	6	4.5	0.5	12.16	0.16	4.00	13.33	17.33
	1945	6	0.5	0	3.83	0	4.33	0	4.33
	1946	6	1.00	0.17	11.16	2.17	4.33	10.17	14.50

Table 9—*Continued*

Plot section	Year	Number of samples	Average number of sharpshooters per sample						
			Draeculacephala		*Carneocephala*		Total sharpshooters		
			Adults	Nymphs	Adults	Nymphs	In vineyard	In borders	Per sample
C-12	1943	6	4.83	0	27.00	0	2.5	29.33	31.83
	1944	6	4.00	0	13.66	0.5	5.83	12.33	18.16
	1945	6	3.83	0	4.66	0	3.83	4.33	8.5
	1946	6	2.17	0.66	16.32	3.50	6.49	16.16	22.65
C-13	1943	6	0.99	0	31.16	0	0.32	31.83	32.15
	1944	6	0.5	0	3.66	0	1.16	3.00	4.16
	1945	6	0	0	3.83	0	0	3.83	3.83
	1946	6	0.66	0.17	2.00	0	1.00	1.83	2.83
C-14	1943	6	0.99	0	31.16	0	0.32	31.83	32.15
	1944	6	0.5	0	3.66	0	1.16	3.00	4.16
	1945	6	0	0	3.83	0	0	3.83	3.83
	1946	6	0	0	0.83	0	0	0.83	0.83
C-15	1943	6	0.33	0	8.66	0	0.66	8.33	8.99
	1944	6	0	0	12.33	0	0.66	11.66	12.33
	1945	6	0	0	7.33	0	0	7.33	7.33
	1946	6	0	0	0	0	0	0	0
C-16	1943	6	0.66	0	28.16	0	0.49	28.33	28.83
	1944	6	0.66	0	16.83	0	5.33	12.16	17.5
	1945	6	0	0	7.33	0	0	7.33	7.33
	1946	6	0	0	0	0	0	0	0
D-1	1943	6	3.82	0.16	20.66	39.32	5.48	58.48	63.96
	1944	6	1.83	0	4.5	0	1.83	4.5	6.33
	1945	6	1.00	0	0.83	0	1.33	0.5	1.83
	1946	6	0	0	3.67	0	0.50	3.17	3.67
D-3	1943	6	0.66	0	9.66	0	1.49	8.83	10.32
	1944	6	0.66	0	14.33	0	3.5	11.5	15.00
	1945	6	0	0	0.16	0	0	0.16	0.16
	1946	6	0.17	0	0.83	0	1.00	0	1.00
D-4	1943	6	0.5	0	8.66	0	0.83	8.33	9.16
	1944	6	0.16	0	18.00	0	2.5	15.66	18.16
	1945	6	0.33	0	0.83	0	0.5	0.5	1.16
	1946	6	0.83	0	0.34	0	0.17	1.00	1.17
D-5	1943	6	5.66	0	14.5	5.5	10.66	15.00	25.66
	1944	6	1.16	0.16	12.83	0	1.00	13.16	14.16
	1945	6	1.00	0	0.33	0	1.33	0	1.33
	1946	6	0	0	0.17	0	0.17	0	0.17
D-7	1943	6	4.5	0	10.16	0	6.00	8.66	14.66
	1944	6	0.66	3.33	1.66	1.66	6.33	1.00	7.33
	1945	6	1.00	0	2.33	0	2.33	1.00	3.33
	1946	6	0.60	0	2.66	0	0.33	2.83	3.16
D-8	1943	6	4.82	0	13.32	0	6.82	11.32	18.14
	1944	6	4.83	0	8.5	0.16	6.16	7.33	13.5
	1945	6	3.00	0	16.33	1.33	5.00	15.66	20.66
	1946	6	0.17	0	0	0	0.17	0	0.17

Table 9—*Continued*

Plot section	Year	Number of samples	Average number of sharpshooters per sample						
			Draeculacephala		*Carneocephala*		Total sharpshooters		
			Adults	Nymphs	Adults	Nymphs	In vineyard	In borders	Per sample
D-9	1943	6	4.82	0	13.32	0	6.82	11.32	18.15
	1944	6	4.83	0	8.5	0.16	6.16	7.33	13.5
	1945	6	3.00	0	16.33	1.33	5.00	15.66	20.66
	1946	6	0.34	0	6.00	2.33	1.34	8.33	8.67
D-10	1943	6	4.00	0	26.66	0	6.16	24.54	30.66
	1944	6	2.83	0	16.33	0	6.33	12.83	19.16
	1945	6	2.83	0	2.5	0	3.00	2.33	5.33
	1946	6	0.17	0	28.16	0	0.50	27.83	28.33
D-11	1943	6	1.00	0	21.99	0	4.66	18.33	22.99
	1944	6	1.5	0	12.33	0	0.5	13.33	13.83
	1945	6	0.5	0	3.83	0	1.16	3.16	4.33
	1946	6	0	0	0	0	0	0	0
D-12	1943	6	3.5	0	5.49	0	3.83	5.16	8.99
	1944	6	1.16	0	3.5	0.16	4.83	0	4.83
	1945	6	2.00	0	1.00	0.16	2.5	0.66	3.16
	1946	6	0	0	0	0	0	0	0
D-13	1943	6	4.49	0.16	22.66	0	4.65	22.66	27.31
	1944	6	0.83	0	2.16	0	1.66	1.33	3.00
	1945	6	1.66	1.33	1.66	0.16	3.00	1.83	4.83
	1946	6	0.83	0	1.33	0	1.66	0.50	2.16
D-14	1943	6	4.16	0.16	14.83	0	4.15	15.00	19.15
	1944	6	3.5	0	8.66	0	4.33	7.83	12.16
	1945	6	1.33	0	0.5	0	1.16	0.66	1.83
	1946	6	0.66	0	0	0	0.66	0	0.66
D-15	1943	6	0.16	0	17.48	0	1.32	16.33	17.65
	1944	6	0.16	0	4.83	0	0	5.00	5.00
	1945	6	0.5	0	0.33	0	0.83	0	0.83
	1946	6	0	0	0	0	0	0	0
D-16	1943	6	4.33	2.00	1.66	0	7.16	0.83	7.99
	1944	6	0.16	0	1.83	0	1.66	0.33	2.00
	1945	6	1.83	0	0.5	0	1.66	0.66	2.33
	1946	6	0	0	0	0	0	0	0
E-1	1943	6	0	0	2.16	0	0	2.16	2.16
	1944	6	0	0	10.00	2.66	0	12.66	12.66
	1945	6	0	0	0.33	0	0	0.33	0.33
	1946	6	0	0	0	0	0	0	0
E-2	1943	6	3.83	0	14.16	0	5.99	12.00	17.99
	1944	6	0.83	0	16.5	0	0.5	16.83	17.33
	1945	6	0	0	0	0	0	0	0
	1946	6	0	0	0	0	0	0	0
E-3	1943	6	0.33	0	8.66	0	0.83	8.16	8.99
	1944	6	0	0	21.83	0	0	21.83	21.83
	1945	6	0	0	0	0	0	0	0
	1946	6	0	0	0	0	0	0	0

Table 9—*Continued*

Plot section	Year	Number of samples	Average number of sharpshooters per sample						
			Draeculacephala		*Carneocephala*		Total sharpshooters		
			Adults	Nymphs	Adults	Nymphs	In vineyard	In borders	Per sample
E-4	1943	6	0.16	0	4.66	0	2.49	2.33	4.82
	1944	6	3.33	0	13.5	0	7.83	9.00	16.83
	1945	6	1.16	0	0.16	0	1.32	0	1.33
	1946	6	0.17	0	0	0	0.17	0	0.17
E-5	1943	6	4.16	0	46.32	0.16	4.52	46.16	50.64
	1944	6	0	0.16	22.66	0	1.16	21.66	22.83
	1945	6	0	0	2.44	0	0	2.44	2.44
	1946	6	0	0	0	0	0	0	0
E-6	1943	6	2.5	0	4.16	0	0.83	5.83	6.66
	1944	6	0.66	0	7.00	0	0.5	7.15	7.66
	1945	6	0.33	0	0.33	0	0	0.66	0.66
	1946	6	0	0	0	0	0	0	0
E-7	1943	6	1.83	0	25.33	0	1.33	25.83	27.16
	1944	6	0.16	0	12.33	0	0.83	11.66	12.5
	1945	6	0.5	0	4.16	0	2.00	2.66	4.66
	1946	6	0	0	0	0	0	0	0
E-8	1943	6	3.16	0	15.82	0	3.66	15.32	18.98
	1944	6	0.66	0.5	11.66	0.16	1.16	11.83	13.00
	1945	6	1.33	0	6.5	0	2.83	5.00	7.83
	1946	6	0	0	0	0	0	0	0
E-9	1943	6	3.49	0	20.82	0	2.99	21.32	24.31
	1944	6	5.83	1.00	39.66	40.33	4.66	82.16	86.83
	1945	6	12.5	0	2.66	0	2.33	12.83	15.16
	1946	6	0.33	0.17	1.17	0	1.67	0	1.67
E-11	1943	6	1.5	0.66	72.16	2.16	2.99	73.49	76.48
	1944	6	0	0	22.16	0	0.83	21.33	22.16
	1945	6	0.5	0	82.66	0	3.00	80.16	83.16
	1946	6	0.17	0	0	0	0.17	0	0.17
E-12	1943	6	0.99	0	136.66	3.33	0.82	140.16	140.98
	1944	6	3.66	0	36.00	0	2.83	36.83	39.66
	1945	6	0	0	31.33	0	0.83	30.5	31.33
	1946	6	1.83	0	2.17	0	0.66	3.34	4.00
F-1	1943	6	4.16	0.33	26.33	0.83	12.32	19.33	31.65
	1944	6	3.66	0.16	25.66	0	9.66	19.83	29.5
	1945	6	1.83	0	0.33	0	1.83	0.33	2.16
	1946	6	1.17	0	12.66	0.33	0.83	13.33	41.16
F-1a	1943	6	12.99	0.33	122.33	1.16	15.98	120.16	146.81
	1944	6	5.66	0	17.00	0	13.33	9.33	22.66
	1945	6	2.33	0	1.5	0	2.16	1.66	3.82
	1946	6	3.83	0	5.33	0	1.33	7.83	9.16
F-2	1943	6	6.83	0.83	17.32	4.00	12.65	16.32	28.97
	1944	6	11.33	0	5.5	0	12.32	4.5	16.83
	1945	6	4.83	0.83	2.33	0	5.33	2.66	7.13
	1946	6	3.00	0	8.50	0	1.33	10.17	11.50

Table 9—*Continued*

Plot section	Year	Number of samples	Average number of sharpshooters per sample						
			Draeculacephala		*Carneocephala*		Total sharpshooters		
			Adults	Nymphs	Adults	Nymphs	In vineyard	In borders	Per sample
F-4	1943	6	2.16	0	52.66	3.66	9.32	49.16	54.48
	1944	6	0.33	0	2.5	0	1.66	1.16	2.83
	1945	6	3.5	0	2.00	0	3.5	2.00	5.5
	1946	6	0	0	0	0	0	0	0
F-5	1943	6	17.33	1.16	21.66	0.16	19.15	21.16	39.31
	1944	6	5.16	3.00	20.16	0.16	5.33	23.16	28.5
	1945	6	16.5	0	3.5	0	2.5	17.5	20.00
	1946	6	2.33	0	3.34	0.17	0.84	5.00	5.84
F-6	1943	6	11.00	4.16	31.00	0	21.16	24.00	45.16
	1944	6	1.00	0	12.16	0	1.83	11.33	13.16
	1945	6	2.33	0	0.33	0	1.00	1.66	2.66
	1946	6	1.33	0	1.33	0	2.00	0.66	2.66
F-8	1943	6	1.99	0.16	36.00	1.66	7.65	32.16	39.81
	1944	6	0.16	0	3.66	0	1.16	2.66	3.83
	1945	6	2.5	0.33	7.00	0	6.33	3.5	9.83
	1946	6	0	0	2.17	0	2.17	0	2.17
F-10	1943	6	14.5	1.33	27.49	14.16	10.66	46.82	57.48
	1944	6	32.83	1.83	5.33	0	7.33	32.66	40.00
	1945	6	9.66	1.16	2.5	0	1.83	11.5	13.33
	1946	6	25.66	2.00	0.33	0	5.00	22.99	27.99
F-12	1943	6	4.5	0.16	11.16	0	9.99	5.83	15.82
	1944	6	1.5	0.16	6.33	0	2.33	5.66	8.00
	1945	6	4.83	0.16	1.83	0	5.00	1.83	6.83
	1946	6	0.17	0	0.50	0	0.67	0	0.67
F-16	1943	6	9.16	1.16	42.49	0.66	18.31	35.16	53.47
	1944	6	11.5	0	17.00	0	13.33	15.16	28.5
	1945	6	0.5	1.5	1.66	0	2.16	1.5	3.66
	1946	6	0.50	0	0	0	0.50	0	0.50
G-1	1944	6	4.83	5.00	13.83	6.16	5.33	24.5	29.83
	1945	6	0.83	0.33	0.16	0.83	2.16	0	2.16
	1946	6	0.33	0	0	0	0.33	0	0.33
G-2	1944	6	2.5	0	3.66	1.16	2.66	4.66	7.33
	1945	6	0.5	0	0.33	0	0.83	0	0.83
	1946	6	1.50	0	0	0	1.50	0	1.50
G-3	1944	6	0.83	0.16	0	0.16	1.16	0	1.16
	1945	6	0.83	0	0.16	0	1.00	0	1.00
	1946	6	1.17	0	0	0	1.17	0	1.17
G-4	1944	6	0.83	0.33	0	0	1.16	0	1.16
	1945	6	1.83	0.33	0	0	2.16	0	2.16
	1946	6	0.33	0	0	0	0.33	0	0.33
G-5	1944	6	2.83	0.33	0	0	3.16	0	3.16
	1945	6	0.33	0	0	0	0.33	0	0.33
	1946	6	0.33	0	0	0	0.35	0	0.33

Table 9—*Concluded*

Plot section	Year	Number of samples	Average number of sharpshooters per sample						
			Draeculacephala		*Carneocephala*		Total sharpshooters		
			Adults	Nymphs	Adults	Nymphs	In vineyard	In borders	Per sample
G-6	1944	6	9.83	0.16	0	0	10.00	0	10.00
	1945	6	0.33	0	0	0	0.33	0	0.33
	1946	6	0.17	0	0	0	0.17	0	0.17
G-7	1944	6	0.5	0.16	0	0	0.66	0	0.66
	1945	6	0.33	0	0.5	0	0.33	0.5	0.83
	1946	6	0.17	0	0	0	0.17	0	0.17
G-8	1944	6	2.00	0.16	1.00	0	0.83	1.33	3.16
	1945	6	2.16	1.33	0	0	3.33	0.16	3.5
	1946	6	0.66	0	0	0	0.66	0	0.66
G-9	1944	6	5.66	0.16	0.16	0	6.00	0	6.00
	1945	6	13.83	10.5	0.33	0.5	25.16	0	25.16
	1946	6	0.17	0	0	0	0.17	0	0.17
G-10	1944	6	1.00	0.33	0	0	1.33	0	1.33
	1945	6	0.66	0	0	0	0.66	0	0.66
	1946	6	0.17	0	0	0	0.17	0	0.17
G-11	1944	6	6.33	0.33	0	0	6.66	0	6.66
	1945	6	0.33	0	0	0	0.33	0	0.33
	1946	6	0.17	0	0	0	0.17	0	0.17
G-12	1944	6	18.33	4.33	0.16	0	22.83	0	22.83
	1945	6	15.33	15.00	0	0	30.33	0	30.33
	1946	6	0.17	0	0	0	0.17	0	0.17
G-13	1944	6	6.5	0.5	1.16	0.16	7.00	1.33	8.33
	1945	6	2.5	1.33	0	0	3.83	0	3.83
	1946	6	0	0	0	0	0	0	0
G-14	1944	6	8.00	2.33	5.16	0	9.83	5.66	15.5
	1945	6	3.33	0	0.33	0	3.66	0	3.66
	1946	6	0	0	0	0	0	0	0
G-15	1944	6	2.00	1.16	0.16	0	3.33	0	3.33
	1945	6	0.66	0	0	0	0.66	0	0.66
	1946	6	0.66	0	0	0	0.66	0	0.66
G-16	1944	6	26.16	2.33	0	0	28.5	0	28.5
	1945	6	0.16	0	0	0	0.16	0	0.16
	1946	6	0.17	0	0	0	0.17	0	0.17

sections A to F, inclusive, A and B, and sections C to F, are shown in table 11. The totals of the sharpshooter population samples presented in table 11 are shown graphically in figure 11. The number of sharpshooters represents an

Table 10

SUMMARY OF THE SEASONAL SHARPSHOOTER POPULATION SAMPLES TAKEN IN EACH QUARTER-SECTION BLOCK OF THE WOODLAKE AND LINDSAY TEST PLOTS

Plot section	Year	Number of samples	Average number of sharpshooters per sample						
			Draeculacephala		*Carneocephala*		Total sharpshooters		
			Adults	Nymphs	Adults	Nymphs	In vineyard	In borders	Per sample
A	1943	54	2.51	.15	14.79	.57	3.23	14.80	18.02
	1944	48	7.1	2.06	17.79	.75	8.30	19.39	26.70
	1945	48	.39	.02	5.52	.10	.47	5.55	6.03
	1946	48	.02	.04	3.48	.27	.25	3.56	3.81
B	1943	24	2.41	....	19.5	2.54	3.58	20.87	24.45
	1944	24	7.93	.96	21.54	10.74	9.00	32.20	41.20
	1945	24	6.7	.96	5.99	6.71	4.78	15.58	20.36
	1946	24	11.90	1.62	11.37	.33	6.37	18.85	25.22
C	1943	84	2.61	.1	18.85	1.61	2.6	20.57	23.17
	1944	84	1.8	.08	9.46	.44	2.49	9.33	11.82
	1945	84	.76	.02	4.12	.92	1.17	4.68	5.83
	1946	90	.92	.10	6.00	1.04	2.94	5.12	8.06
D	1943	84	3.28	.18	16.38	3.21	5.17	17.88	23.05
	1944	84	1.4	.25	8.14	.14	2.94	6.97	9.92
	1945	84	1.28	.09	2.4	.12	1.73	2.11	3.86
	1946	84	.25	....	3.03	.16	.39	3.05	3.44
E	1943	66	1.98	.06	31.92	.5	2.39	32.07	34.46
	1944	78	1.57	.13	20.19	3.51	2.82	21.65	24.47
	1945	78	1.37	....	11.03	....	2.05	10.37	12.41
	1946	84	.22	.01	5.68	1.15	4.20	2.86	7.06
F	1943	60	10.03	.86	40.51	2.65	15.36	38.69	54.05
	1944	60	7.31	.51	11.53	.01	6.81	12.54	19.36
	1945	60	4.88	.39	2.29	....	3.15	4.40	7.55
	1946	60	3.75	.20	3.41	.04	1.41	5.99	7.40
G	1943*	..	....	....	......	....	....	......	......
	1944	96	6.13	1.11	1.57	.48	6.87	2.33	9.29
	1945	96	2.81	1.80	.11	.08	4.77	.04	4.81
	1946	96	.39	....	......	....	.39	......	.39

* No samples for 1943.

average number per sample for the total number of samples taken during the season.

The number of vectors obtained by sampling in each 10-acre block varied with the block and also with the season. The totals for the 10-acre blocks combined into quarter-section units, A, B, C, D, E, F, and G, as shown in table 10 and figure 11, are more consistent. The sharpshooters in section A increased in 1944 over 1943 but declined in 1945 and 1946; in section B they remained

Table 11

SUMMARY OF SEASONAL SHARPSHOOTER POPULATION SAMPLES TAKEN EACH YEAR IN THE ENTIRE WOODLAKE PLOT, BLOCKS A TO F; BLOCKS A AND B, AND C TO F

Plot section	Year	Number of samples	Average number of sharpshooters per sample						
			Draeculacephala		*Carneocephala*		Total sharpshooters		
			Adults	Nymphs	Adults	Nymphs	In vineyard	In borders	Per sample
A to F.........	1943	372	3.82	.23	23.56	1.96	5.36	24.22	29.58
	1944	378	3.6	.5	13.53	1.63	4.70	14.67	19.26
	1945	378	2.00	.15	5.15	.67	1.95	6.09	8.00
	1946	396	1.59	.17	4.66	.63	2.50	4.55	7.05
A and B........	1943	78	2.47	.10	16.25	1.17	3.33	16.67	20.00
	1944	72	7.38	1.69	19.04	4.09	8.53	23.65	32.20
	1945	72	2.5	.33	5.68	2.30	1.90	8.90	10.80
	1946	72	3.90	.57	6.31	.15	2.20	8.73	10.93
C, D, E, and F	1943	295	4.17	.27	29.47	2.17	5.89	30.20	36.09
	1944	306	2.71	.22	12.24	1.06	3.60	12.45	16.14
	1945	306	1.86	.11	5.01	.28	1.94	5.33	7.26
	1946	324	1.13	.08	4.61	.64	2.33	4.13	6.46

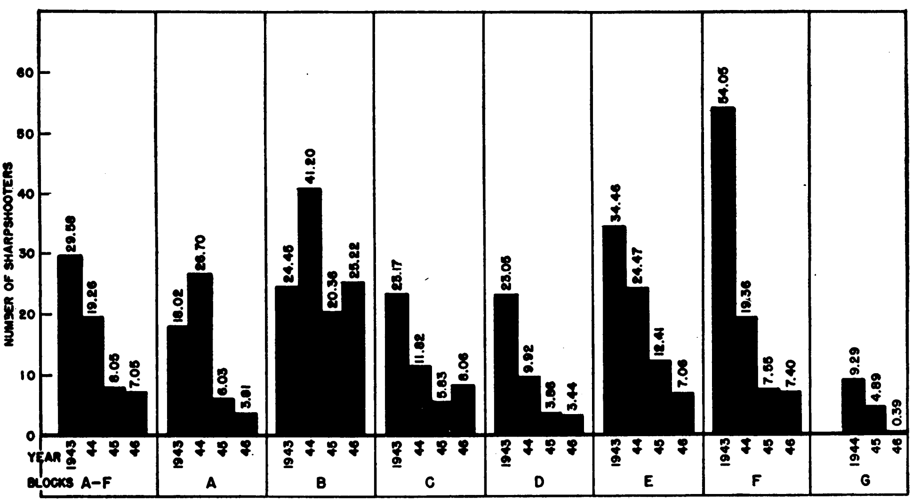

Fig. 11. Average number of sharpshooters collected per sample in the Woodlake and Lindsay plots for the seasons 1943 to 1946.

fairly high; in section C they declined from 1943 through 1945 and increased slightly in 1946; in sections D, E, F, and G they declined from 1943 through 1946; and in sections D and F for 1945 and 1946 the populations remained about the same.

Sample populations of *D. minerva* and *C. fulgida* taken in each 10-acre block were compared with the corresponding percentages of diseased vines for the same and also for following infection periods. The results of these comparisons are shown in table 12; none of them is statistically significant. This is not out of line because the incidence of disease, as well as the population samples, for the 10-acre block was variable.

The average number of sharpshooter vectors per sample for each quarter section of the Woodlake plot was compared with the per cent of vines develop-

Table 12

CORRELATION COEFFICIENT BETWEEN THE AVERAGE NUMBER OF SHARPSHOOTER VECTORS PER SAMPLE PER SEASON AND THE PER CENT OF VINES DEVELOPING PIERCE'S DISEASE FOR THE SAME AND FOR EACH SUBSEQUENT SEASON

Block	Number of comparisons	1943 sharpshooters compared with Pierce's disease for:			1944 sharpshooters compared with Pierce's disease for:		1945 sharpshooters compared with Pierce's disease for:
		Fall, 1943–spring, 1944	Fall, 1944–spring, 1945	Fall, 1945–spring, 1946	Fall, 1944–spring, 1945	Fall, 1945–spring, 1946	Fall, 1945–spring, 1946
A	8	0.4034	0.0455	−0.3517	−0.0621	−0.1987	−0.3494
B	4*	0.9030	0.8027	0.9831	0.8185	0.9964	0.6262
C	13	−0.1470	0.0395	−0.0339	−0.1114	−0.1537	−0.2782
D	14	−0.0474	−0.1055	−0.1870	−0.2796	0.0051	0.2481
E	11	0.0951	0.0027	0.2532	−0.0916	0.4284	0.3229
F	10	0.0155	−0.0632	0.0313	0.0250	−0.0514	0.0982
G	16	....	....	....	−0.0053	−0.0681	−0.1732

*At the 5 per cent level with only 4 comparisons a correlation coefficient of 0.950 is required for significance.

ing Pierce's disease in the same section for the corresponding infection period. These comparisons are shown in table 13. A high correlation coefficient approaching the theoretical value for significance was obtained for comparisons in plot sections C, E, and F. That for section D exceeded the requirement for significance at the 5 per cent level.

Figure 11 graphically illustrates the average number of sharpshooters per sample for each quarter section of the Woodlake plot and for section G of the Lindsay plot. This is done in such a way that it may be compared with figure 7 showing the per cent of vines developing Pierce's disease in each section for corresponding infection periods. The average vector populations shown by the samples and the percentage of vines diseased decreased generally over the plot and in similar proportions.

Samples of sharpshooter populations of the 10-acre blocks in the plots were inconsistent and did not correlate with the per cent of vines diseased. The averages of samples for quarter-section areas of the Woodlake plot, however, compared favorably with the amount of disease, and suggest a positive relationship. Furthermore, a comparison of barograph figures 7 and 11 shows a close relationship between the vector samples taken and the incidence of disease.

Table 13

CORRELATION COEFFICIENT BETWEEN THE AVERAGE NUMBER OF SHARPSHOOTERS PER SAMPLE AND THE PER CENT OF VINES DEVELOPING PIERCE'S DISEASE IN EACH QUARTER-SECTION AREA OF THE WOODLAKE PLOT

	Section A		Section B		Section C		Section D		Section E		Section F	
	Sharp-shooters	Diseased vines	Sharp-shooters	Diseased vines	Sharp-shooters	Diseased vines	Sharp-shooters	Diseased vines	Sharp-shooters	Diseased vines	Sharp-shooters	Diseased vines
	number	*per cent*	*number*	*per cent*	*number*	*per cent*	*number*	*per cent*	*number*	*per cent*	*number*	*per cent*
Year 1943	18.20	0.34	24.45	0.51	23.17	0.33	23.05	0.72	34.46	0.57	54.05	1.04
Year 1944	26.70	0.12	41.20	0.06	11.82	0.10	9.92	0.42	24.47	0.13	19.36	0.69
Year 1945	6.03	0.23	20.36	0.09	5.83	0.09	3.86	0.33	12.41	0.08	7.55	0.60
Year 1946	3.81	0.07	25.22	0.14	8.06	0.14	3.44	0.17	7.06	0.10	7.40	0.28
Sum	54.74	0.76	111.23	0.80	48.88	0.66	40.27	1.64	78.40	0.88	88.36	2.61
Mean	13.68	0.19	27.80	0.20	12.22	0.16	10.07	0.41	19.60	0.22	22.09	.65
Sum of squares	1095.01	0.188	3345.82	0.291	775.51	0.147	656.44	0.833	1990.12	0.358	3407.97	1.996
$\frac{\text{Square of sum}}{n}$	749.12	0.144	3093.03	0.160	597.31	0.190	405.42	0.672	1536.64	0.194	1951.87	1.703
Sum of mean square	345.89	0.044	252.79	0.131	178.20	0.038	251.02	0.161	453.48	0.164	1456.10	0.293
Correlation coefficient*	0.1666		−0.3389		0.9300		0.9516		0.8247		0.8967	

* With only 4 comparisons a correlation coefficient of 0.950 is required for significance at the 5 per cent level.

SHOOT MANAGEMENT AND THE SPREAD OF PIERCE'S DISEASE

Early observations by Frazier on the activities and feeding habits of the principal vectors in the interior valley indicated that these leafhoppers preferred to remain relatively near to the ground. On the basis of these observations, attempts were made to keep the vine shoots in a number of vineyards 3 to 7 feet above the ground during the growing season to determine what effect this might have on the incidence of the disease.

Two methods were used to keep the vine shoots off the ground: one, used by several growers, consisted in cutting the shoots back; the other, used in the test plots, consisted in throwing the shoots over the top of the trellis or arbor. The only figures on the relation of shoot management to the occurrence of Pierce's disease presented (see table 14) are those obtained with the canes at 7 feet. This is the highest type of support used at present; it represents the upper limit of practicability.

Table 14

PER CENT OF ALMERIA VINES DEVELOPING PIERCE'S DISEASE EACH SEASON WITH VARIED SHOOT MANAGEMENT—SHOOTS ALLOWED TO GROW FREELY (SHOOTS DOWN) AND SHOOTS KEPT UP ON 7-FOOT ARBOR (SHOOTS UP)

Number of acres and type of cane management	Year of treatment					
	1940	1941	1942	1943	1944	1945
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
80 acres shoots down	0.027	0.335	.....	.....	.....	.....
60 acres shoots down	.....	.....	0.419	0.254	0.315	0.179
20 acres shoots up	.....	.....	0.525	0.460	.....	.....
(20 acres) each alternating 4 rows						
shoots down	.....	.....	.....	.....	0.363	0.217
shoots up	.....	.....	.....	.....	0.484	0.242

These results do not show any correlation between this type of shoot management—even though the shoots were kept 7 feet above the ground—and the incidence of Pierce's disease. The results with the shoots at lower levels, either from cutting back or from throwing over the trellis, were similarly negative.

Although the cutting of the shoots had no effect on the incidence of the disease, its effect on the fruiting of the vines was deleterious. This effect is illustrated by figures obtained on leaf removals (cutting the shoots back) for 1943. Such items as percentage of leaves removed, crop in pounds, and number of clusters for both the 1943 and 1944 crops for Aramon and Emperor appear in table 15.

These figures show an increasing retardation in maturation and in color development, and a reduction in cluster and berry weight as the leaf removals were increased beyond 20 per cent. However, the influence of leaf removals was most pronounced in the year following the removals. This was largely due to the reduction both in the number and size of the clusters. In the Aramon there was a reduction of 20 and 49 per cent in the number of berries per cluster, and 0 and 49 per cent in number of clusters to a vine, respectively, as a result of the removal of 20 and 50 per cent of the leaves of these vines about July first of the previous year. The reduction in crop amounted to 31 and 76 per cent, respectively.

Table 15

EFFECT OF LEAF REMOVALS ON THE FRUITING OF ARAMON AND EMPEROR AT DAVIS

Leaves removed	Crop	Number of clusters	Cluster weight	Number of berries	Berry weight	Per cent colored	Balling degree	Per cent acidity
per cent	*kilos*		*grams*		*grams*			
Aramon, 1943								
None	16.5	50	328	80	4.18	100	21.4	.65
10	16.2	49	326	81	4.05	96	18.8	.66
20	15.7	50	314	84	3.74	98	19.8	.64
40	14.9	48	310	81	3.82	92	17.0	.67
50	14.7	51	290	76	3.79	90	17.0	.76
Same vines, 1944								
None	19.3	47	410	91	4.50	98	19.9	.52
None	16.1	50	342	79	4.32	100	18.9	.60
None	14.0	46	305	70	4.35	100	19.5	.53
None	8.1	38	214	49	4.31	100	19.9	.56
None	4.6	24	190	47	4.27	100	19.9	.54
Emperor, 1943								
None	14.6	25	588	111	5.35	93	17.8	.54
10	11.0	22	514	103	5.00	88	16.2	.54
20	13.9	27	519	100	5.26	74	15.4	.51
40	15.3	30	513	108	4.73	63	14.0	.54
50	12.2	30	405	116	4.70	37	12.6	.60
Same vines, 1944								
None	10.7	27	400	90	4.52	91	19.1	.58
None	10.1	25	403	96	4.23	97	19.3	.58
None	10.9	24	446	105	4.28	95	19.1	.60
None	6.9	19	377	89	4.25	88	18.7	.61
None	3.7	19	189	45	4.20	94	19.0	.56

In the Emperor there was a reduction of 0 and 53 per cent in number of berries per cluster and 0 and 29 per cent in number of clusters to a vine, respectively, with the removal of 20 and 50 per cent of the leaves of these vines in the previous season. The reduction in crop amounted to 0 and 65 per cent, respectively.

VECTOR CONTROL

Sharpshooter populations in vineyards, alfalfa fields, irrigated pastures, and other breeding areas can be controlled with insecticides. The three most effective materials are DDT, HCN, and pyrethrum. DDT gives excellent results. It kills the sharpshooters present at the time of application, and leaves a residue which kills any nymphs hatching from eggs, and other sharpshooters moving into the treated area for several weeks after the treatment. Because of its poisonous residue, however, DDT used for sharpshooter control is greatly limited. It cannot be recommended on pastures or on alfalfa that is used for dairy stock feed, or in vineyards after blossoming until the crop has been harvested. HCN, used as calcium cyanide dust, and pyrethrum kill the insects present at the time of the application and leave no toxic residue. Nymphs hatching from eggs and reinfesting adults must be killed with additional treatments. Cyanide is a poison and is hazardous to use. To attempt effective seasonal control of sharpshooters with either HCN or pyrethrum would necessitate a number of applications, which would be costly. No program of insecticide applications has been worked out to give seasonal control of sharpshooters, and there is no evidence at hand to indicate whether or not any such program of sharpshooter control would be reflected in appreciable control of Pierce's disease.

SUMMARY

Two epiphytotics of Pierce's disease have occurred in California's vineyards. The first developed between 1880 and 1900, and was centered in southern California vineyards. The second, which was more widely distributed in the state, started about 1935 and has now declined.

The development and spread of this disease during the latter epiphytotic followed three general patterns: 1) diseased vines occurred in an irregular, scattered manner; 2) diseased vines concentrated in localized areas in vineyards and districts without apparent association with environment; and 3) diseased vines grouped in areas directly associated with alfalfa, irrigated pastures, and similar places.

Cases of Pierce's disease have been irregularly distributed throughout nearly all of the grape-growing regions of the state.

The rate of increase or decrease of the disease, and the losses it has incurred have varied from district to district. The incidence of Pierce's disease in the San Joaquin Valley was low up to 1935, when it increased rapidly to a peak in 1941. Since then, the annual occurrence of new cases has declined. The incidence of disease in north Sonoma County reached a peak about 1943 and in Napa County about 1944.

The outbreaks of Pierce's disease were very closely correlated with rainfall. During the years 1917 to 1934, when the mean annual rainfall for the Fresno–Visalia area was 10.6 per cent below normal, and when Pierce's disease was known to be present in this area, there were few new cases. During the years 1935 to 1941, the wettest wet period on record for this area, when the mean annual rainfall averaged 53.8 per cent above normal, the occurrence of Pierce's disease increased rapidly to a peak in 1941. During the years 1942 to 1947, when the mean annual rainfall dropped to 6.2 per cent below normal, the occurrence of Pierce's disease decreased markedly each year. The earlier outbreaks of Pierce's disease were similarly associated with periods of above-normal rainfall.

The symptoms of Pierce's disease of the grape are as follows: 1) leaf scalding and later drying of the entire leaf, which usually starts after midseason; 2) wilting, withering, drying, and premature coloring of the berries on part of the vine or on the entire vine; 3) delayed foliation of a part of the vine or of the entire vine; 4) interveinal chlorotic mottling of the lower leaves (usually leaves 2 to 8) of the shoots; 5) dwarfing of the shoot growth of a part of the vine or of the entire vine; 6) failure of the canes to mature evenly; 7) gradual dying of the root system; and 8) death of the vine.

All European and American varieties of grape grown commercially in California are susceptible to Pierce's disease and show the symptoms in varying degrees. Some varieties appear more tolerant than others.

Pierce's disease of grapes is caused by a virus. This virus has been transmitted by insect vectors and by grafting. The disease may also be spread to a limited extent in cuttings made from diseased vines. The time from the introduction of the virus into the vine until symptoms show, varies from 3 to 15 months.

Insect vectors constitute the principal means of natural spread. The virus causing Pierce's disease of the grape and alfalfa dwarf can be transmitted by 14 species of sharpshooters and 4 species of spittlebugs. However, only 2 species of sharpshooters are of major importance in the San Joaquin Valley. These are the green sharpshooter, *Draeculacephala minerva* (Ball), and the redheaded sharpshooter, *Carneocephala fulgida* Nott. The green sharpshooter has 3, and the redheaded sharpshooter 4 generations a year. Grapes are not normal host plants of these insects, but are occasionally fed on.

In the coastal regions the blue sharpshooter, *Neokolla circellata* (Baker), is the important spreader of the virus. It feeds and breeds on grapevines. Other leafhoppers and spittle insect vectors are either localized in limited areas or are restricted by host plant preference so that they are unimportant in the spread of the virus to grape.

The virus has a wide host range which includes plants of 73 species in 20 families, ranging from grasses to shrubs. Insect vectors collected in vineyards, alfalfa fields, roadside areas, ditch banks, bogs, and other such natural breeding areas have been shown to carry the virus.

In districts of the San Joaquin Valley, where dwarf-infested alfalfa plantings have been common, the vineyards have contained a higher percentage of diseased vines and have shown a higher annual incidence of Pierce's disease than vineyards located in other districts. In the coastal regions the spread of Pierce's disease is associated with environmental conditions favorable to the blue sharpshooter.

Vineyard plots varying in size from 10 to over 600 acres show that the removal of diseased vines at least twice each year did not significantly influence the occurrence of new cases of Pierce's disease. But the practice of removing diseased vines at least once a year and replanting with healthy stock has maintained the stands and kept vineyards in production.

Roguing experiments indicate that diseased vines are not a principal source of the virus which is spread to grapevines. In general the virus spread to vineyards comes from outside sources.

The occurrence of new cases of Pierce's disease was not influenced by cultivation or oil sprays to control weeds as carried out in the Woodlake and other plots.

Averages of the samples of sharpshooter populations in 10-acre blocks of the Woodlake and Lindsay plots were not statistically correlated with the percentages of vines showing Pierce's disease in the same or subsequent seasons. Averages of samples for quarter sections of the plots, however, compared favorably with the per cent of vines developing disease during the same infection period. Furthermore, the yearly trends of the average of samples of vector populations in quarter sections of the plots compare favorably with those showing the per cent of vines which developed disease in the same area, indicating a positive relationship.

The following practices did not influence the occurrence of new cases of Pierce's disease: 1) cutting the shoots in midsummer at 36 inches above the ground; 2) keeping all of the shoots 36 inches above the ground; and 3) keeping all of the shoots on top of a 7-foot arbor. Removal of shoots in midsummer at 36 inches above the ground injured the vines and reduced the crop.

Sharpshooters in vineyards, alfalfa fields, irrigated pastures and other breeding areas may be controlled with insecticides. Each of the insecticides tested in the field—DDT, HCN, and pyrethrum—has certain limitations to practical and economical use. No effective program has been worked out to give seasonal control of sharpshooters, and there is no evidence to indicate whether or not any such program of sharpshooter control would be reflected in appreciable control of Pierce's disease.

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