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THE ECOLOGY OF THE PRINCIPAL SUMMER WEED HOSTS OF THE BEET LEAFHOPPER IN
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The Ecology of the Principal Summer Weed Hosts of the Beet Leafhopper in the San Joaquin Valley, California[1]

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INTRODUCTION

The beet leafhopper (*Eutettix tenellus* (Baker)) is the only known vector of the virus of curly top, which in California causes losses each year to two major crops, sugar beets and tomatoes, as well as to other crops, such as garden beets, spinach, and cucurbits, and to many ornamentals. In some years the losses are serious.

The symptoms and effects of curly top have been discussed by a number of investigators. Carsner and Stahl (*2*)[3] discussed the disease in beets and reviewed the early literature, McKay and

[1] Submitted for publication September 10, 1942.
[2] The authors are indebted to William C. Cook and Eubanks Carsner, who made suggestions during the course of these studies and criticized the manuscript; to Dr. Cook also for assistance in the field; and to J. C. Chamberlin, George T. York, and the late Gillette Amidon, each of whom helped with one season's survey.
[3] Italic numbers in parentheses refer to Literature Cited, p. 36.

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Dykstra (*9*) described the disease in tomatoes, Carsner (*1*) described it in beans, and Severin (*13*) and Severin and Henderson (*16*) described it in minor crops and other plants.

The Bureau of Entomology and Plant Quarantine and the Bureau of Plant Industry cooperated in an effort to determine (1) the location and size of the areas of weed hosts of the beet leafhopper, (2) to what extent these areas persist from year to year on the same ground, (3) how much fluctuation there is in the acreages, and (4) the factors that influence the increase or decrease of these host plants, with the view of determining what might be done to reduce the acreages.

A part of the resulting information, particularly that on the winter and spring hosts and on the hold-over hosts that bridge the gap between summer and winter annuals, was given in a previous bulletin (*11*), together with some information on the summer hosts, such as their relation to winter annuals in the successions and also in relation to the original types of vegetation.

The present bulletin deals with the summer hosts, indicating what they are and why they are important in the beet leafhopper and curly top problem. It also deals with the acreages of summer hosts, and with the fluctuations in acreages, and shows how these are influenced by the present use of the land and other factors. Finally there is a discussion of the relations of the summer hosts to winter annuals, particularly the competition with winter annuals as influenced by rainfall. This information forms a basis for an understanding of the major factors which produce and maintain large acreages of host plants and is necessary for an intelligent application of control measures. Such measures are discussed only insofar as they are based on the preceding information and the principles set forth.

The first surveys were begun in 1931 and continued through 1937, and all statements concerning distribution and abundance of these plants apply to this period. The quantitative data obtained from the surveys have been supplemented by extensive observations by both authors in California and by the junior author in Idaho (*10*) and other States. Thus, while the information presented on abundance and distribution is limited to the San Joaquin Valley, the principles and the broad conclusions may be stated to apply throughout the semiarid region where the weed hosts occur.

CLIMATE AND TOPOGRAPHY OF THE SAN JOAQUIN VALLEY

The San Joaquin Valley is a flat plain roughly 50 miles wide and 250 miles long, extending approximately northwest by southeast, in the central part of California (fig. 1). The valley is bounded on three sides by mountains. It is cut off from the humid coastal region by the Coast Range except at the northern end, where the Sacramento River flows through a broad gap to the Pacific Ocean. As a result, the climate of the valley is arid and warm, but the moderating influence of the ocean is felt through this gap. This influence is greatest in the northern end and gradually decreases southward, so there is a gradient of temperature and rainfall extending from north to south. Stockton, in the northern end, has a mean annual temperature of 59.7° F. and a mean annual rainfall of 13.99 inches. The comparable figures for Bakersfield, in the southern end, are

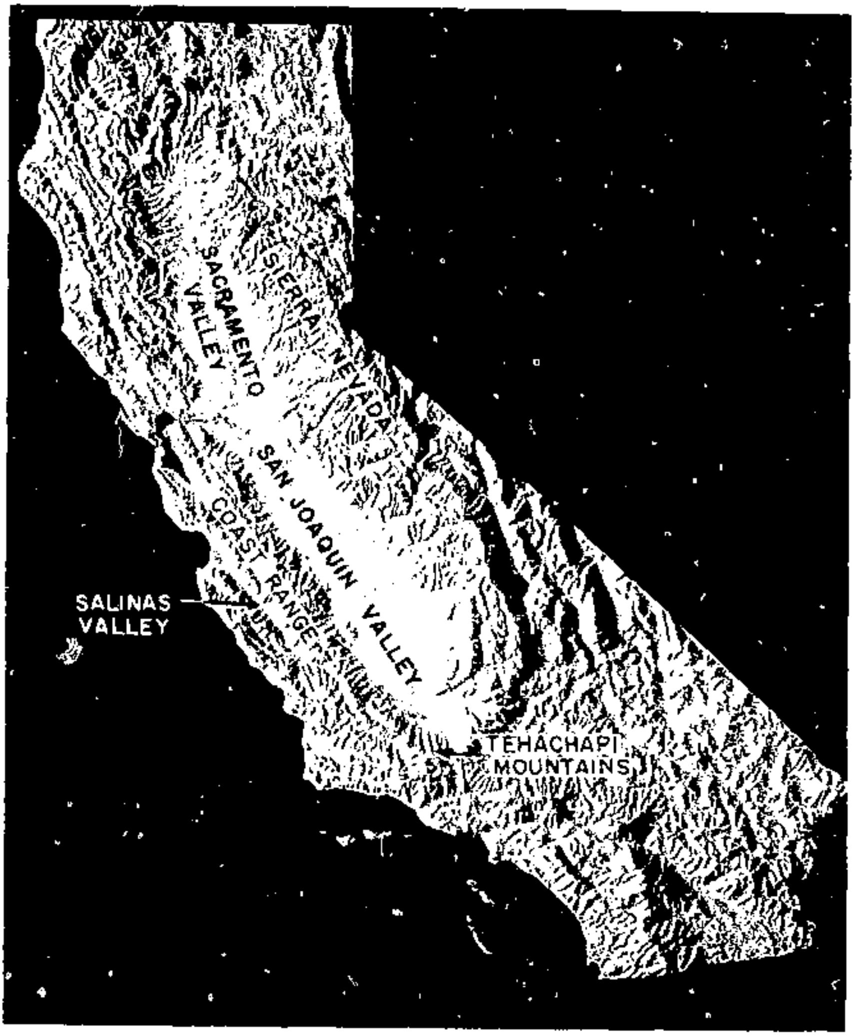

FIGURE 1.—Relief map of California.

[illegible] F. and 5.08 inches of rainfall. On the west side of the valley the climatic gradient is interrupted locally by the influence of the [illegible] Pacheco Pass near the middle and through Cholame Pass near the southern end of the valley. There is another gradient extending from east to west, the western foothills of the Sierra Nevada being wetter and cooler than the eastern foothills of the Coast Range. [illegible] that falls in the valley comes in the winter months, and the [illegible] summer months are practically rainless.

The cultivated districts of the San Joaquin Valley lie mostly in the northern and eastern portions. To the west, adjacent to the foothills of the Coast Range, there is a strip of uncultivated plains which begins in the vicinity of Los Banos and gradually becomes wider as it extends southward.

The vegetation of the valley, as it is at present, was mapped and discussed in detail and related to the original types in a previous publication (*11*).

LIFE HISTORY OF THE BEET LEAFHOPPER

The general life history of the beet leafhopper in California was worked out by Severin (*14*, *15*), whose findings have been confirmed and extended by investigators of the Bureau of Entomology and Plant Quarantine.

In the San Joaquin Valley the beet leafhopper passes the winter in the adult stage, and one or two generations develop in the spring on the plains and foothills of the west side, on host plants which form a part of the winter-annual cover. When these annuals dry in April or May, extensive movements of leafhoppers to other weeds and cultivated crops occur. It is at this time that the leafhoppers cause their greatest damage to crops by transmitting the curly top disease. During the summer the insect breeds for several generations on annual weeds and on sugar beets, and the overwintering generation is produced on these plants in the fall. Large numbers of leafhoppers of this generation move back to the plains and foothills of the west side of the valley and survive there on any available green plants until the fall rains come and germination of winter annuals takes place.

All the wild plants that are of importance as breeding hosts of the leafhopper in the San Joaquin Valley are annuals and form a part of the plant cover on the lands that are not continuously well cultivated. These annuals fall into two classes that are distinct as to the time of year when they make their greatest growth. The "winter annuals" are the plants that begin growth from seed in the fall, grow through the winter, make their greatest growth in spring, and mature and dry before the hot summer begins. The "summer annuals" begin growth in the spring from seed, make their greatest growth in the summer, and mature late in the summer or in the fall. It is only by seasonal shifts from winter-annual hosts to summer annuals in the spring, and back again in the fall, that the leafhopper is able to survive in abundance in the San Joaquin Valley.

TERMS USED

To avoid confusion it seemed desirable in this bulletin to restrict the use of certain terms.

The term "weed host" designates plants that are hosts of the beet leafhopper and are commonly known as weeds in cultivated districts and on grazing lands.

"Weed-host area" is used to signify the tract of land on which weed hosts are growing. If a particular kind of weed host is meant, the specific name is substituted for the general term—for instance, "Russian-thistle area." By "area" here is meant the particular or individual tract of land, and this term refers to the space occupied rather than to the plant cover. "Stand" refers only to the plant cover, that is, the aggregation of plants on the particular tract of land in a given season. Since the weed hosts dealt with are annuals, there is a new stand each year but the weed-host area may persist. Thus, a Russian-thistle area which persists on the same ground for 3 years may have varying stands of 90, 50, and 10 percent. "Site" designates the particular tract after the stand has been removed. Thus if Russian-thistle has disappeared from a tract of land it is no longer referred to as a Russian-thistle "area" but instead as a Russian-thistle "site."

"Locality" is used to include all the areas in a given neighborhood. Thus a locality may consist of only a single large weed-host area, but it more often consists of many small areas with intervening tracts with crops or with other kinds of plant cover. The actual extent of all the areas in such a locality is expressed in acres and referred to as "acreage" of a particular weed host. All the localities considered have been divided into two groups and designated as the "eastern group" and the "western group."

The terms "idle" and "abandoned," as applied to lands in this paper, are discussed later in the section dealing with present use of the land (p. 14), and "fallow" is discussed in the section on what becomes of weed-host areas (p. 20).

METHODS

The abundance and distribution of the summer host plants were determined by two types of surveys, one detailed and covering practically all the particular geographical unit, and the other based on transects from 3 to 6 miles apart.

Detailed Surveys

Estimates of the abundance of weeds in selected places considered to be of primary importance because of their proximity to winter-breeding grounds were made by traveling all roads and trails in an automobile, measuring one side of each weed-host area with the speedometer and estimating the other dimensions. The normal division of farm land into quarters and eighths of a square mile greatly improved the accuracy of these estimates. On grazing land, which is not normally divided into parts smaller than 1 square mile, the usual methods of making estimates were supplemented by cross-country cruising.

In making these surveys, weed-host areas covering less than 5 acres were ignored. Such areas are usually found in barnyards, and along ditchbanks, fence rows, and roads. To test the importance of small patches, 7 square miles were surveyed in detail by an observer on foot. Four hundred and sixty-five acres of weed hosts occurred as large tracts, and 51 acres, or approximately 10 percent, as small patches. Scattered stands were ignored, since in localities badly infested by weed hosts a few individuals can be found anywhere. In estimating abundance it was necessary to draw a more or less arbitrary line as to what stands should be recorded, and in these surveys any stand covering less than 10 percent of the soil area was omitted. Scattered stands and numerous small patches may give an exaggerated impression of the abundance of weed hosts. For instance, a strip 4⅛ feet wide and 2 miles long by the side of the road, which actually contains only 1 acre, is often more conspicuous than a 10-acre block.

Transect Surveys

In that portion of the San Joaquin Valley which was not surveyed in detail an estimate of weed-host acreages was obtained from transects spaced 3 to 6 miles apart. The total length along the road on both sides of all weed-host areas was determined by the automobile speedometer. No record was kept of the depth of weed-host areas, as it was assumed that the length of all weed-host areas bore the same relation to the total length of transects as the actual acreage of weed hosts bore to the total acreage of the tract through which the transects were made.

This method will theoretically give accurate estimates of weed-host acreages provided enough transects are made to give an adequate sample of the locality. In theory, transects should be equidistant from one another and should run in a straight line across the general pattern of zonation, since irrigated districts are usually composed of a central, well-farmed area, and an outlying, poorly farmed portion. In practice, however, roads were not always available at the desired spacing in spite of the fact that any usable trail was followed. Except in a few cases the same transects were followed every year so that if any bias was present the estimates would at least be comparable from year to year.

Both methods of surveying therefore yielded only approximate acreages, and only large differences had any significance when comparisons were being made.

THE SUMMER HOST PLANTS AND THEIR RELATIVE IMPORTANCE [4]

Severin (*15*) published a list of 45 species of weeds in which the beet leafhopper deposited eggs under natural conditions in the cultivated districts of California. His list includes 11 species of *Atriplex*, 4 of *Chenopodium*, 3 of *Amaranthus*, 2 of *Malva*, and 1 each of 25 other genera belonging to several diverse families. Severin states that on many of these plants leafhoppers cannot develop to the winged stage and that the most favorable host plants in the cultivated districts are members of the family Chenopodiaceae.

Investigations by the Bureau of Entomology and Plant Quarantine have substantiated Severin's findings but have further restricted the number of important breeding hosts. Of the numerous species of Chenopodiaceae in California, many are such poor hosts that very little breeding occurs on them. For instance, nymphs can be found only occasionally on species of *Suaeda*. Other species of Chenopodiaceae, such as *Atriplex tularensis* Coville and *A. parishii* S. Wats., are good hosts but are either so restricted in distribution or abundance, or both, in the San Joaquin Valley that they are not considered to be of any importance in building up populations that are of economic significance. Arrowscale (*A. phyllostegia* (Torr.) S. Wats.), redscale (*A. rosea* L.), smotherweed (*Bassia hyssopifolia* (Pall.) Kuntze), and three species of *Chenopodium*, namely, *C. album* L.,

[4] Data on the relative merits of various plants as summer breeding hosts are abstracted from unpublished investigations by W. C. Cook, G. T. York, H. E. Wallace, and F. R. Lawson, all of the Bureau of Entomology and Plant Quarantine.

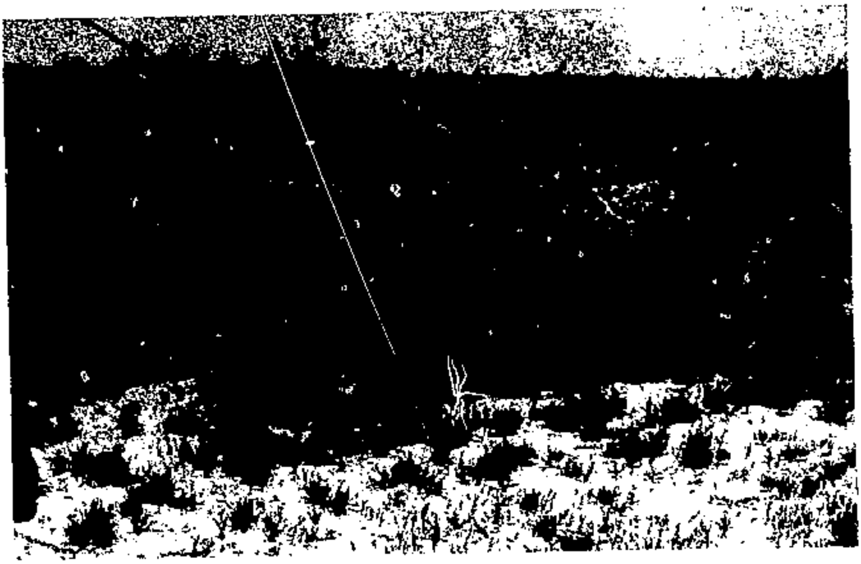

FIGURE 2.—Young plants of Russian-thistle growing in a vineyard. In the background are old plants of the previous year lodged against the vines. Near Turlock, Calif., June 1933.

C. leptophyllum Moq., and *C. murale* L., may produce fair populations in the summer, but these species mature and dry so early in the season that an overwintering generation of leafhoppers is not produced. The leafhoppers that are bred on these plants must move to later-maturing hosts if they are to survive.

Australian saltbush (*Atriplex semibaccata* R. Br.) and three species of mustard, namely, *Brassica kaber* var. *pinnatifidum* (Stokes) Wheeler, *B. campestris* L., and *B. nigra* (L.) Koch, produce such small numbers of leafhoppers that they cannot be considered important breeding hosts.

There are only three species of good breeding hosts that are abundant and that mature sufficiently late in the season to produce the overwintering generation of leafhoppers. These are Russian-thistle (*Salsola pestifer* A. Nels.) (fig. 2), bractscale (*Atriplex serenana* A. Nels.) (fig. 3), and fogweed (*A. expansa* S. Wats.) (fig. 4). Russian-thistle is the most important of these. The two species of *Atriplex* often dry too early in the season to produce a fall population, and, in addition, the numbers of leafhoppers produced on them are usually lower than on Russian-thistle. Compared with the other two, fogweed is a poorer host. Russian-thistle, however, does not dry early, except locally, produces high populations, and during the period 1931-37 was the most abundant. In addition, this species occurs abundantly in localities near the spring breeding grounds of the leafhopper, and losses in the transfer from summer to winter hosts are relatively low.

There is one other important source of summer and fall populations of the leafhopper, and that is sugar beets. Under some conditions the insect breeds abundantly on this crop, but under present practices, in the San Joaquin and Sacramento Valleys, beets that

FIGURE 3.—A young plant of bractscale in the foreground growing in a nearly bare spot. In the background is a dense stand of bractscale. Near Lemoore, Calif., April 16, 1941.

FIGURE 4.—Young plants of fogweed. Near Stratford, Calif., April 16, 1941.

might contribute populations to the spring breeding ground are mostly harvested too early in the season to enable leafhoppers on them to survive until the winter annuals begin their growth.

GEOGRAPHICAL LOCATION OF SUMMER WEED-HOST AREAS IN RELATION TO SPRING BREEDING GROUNDS AND CROPS

Figure 5 shows the principal spring and summer breeding grounds of the beet leafhopper in their relation to one another. Summer breeding grounds, as shown in figure 5, are a composite formed as follows: All the areas of each of the three weed hosts were plotted on the same map for all years from 1931 to 1937, inclusive, and then a general boundary to include all these areas was drawn in. The location of areas of each host at some time during the period is shown in more detail in figure 6, where they are mapped separately.

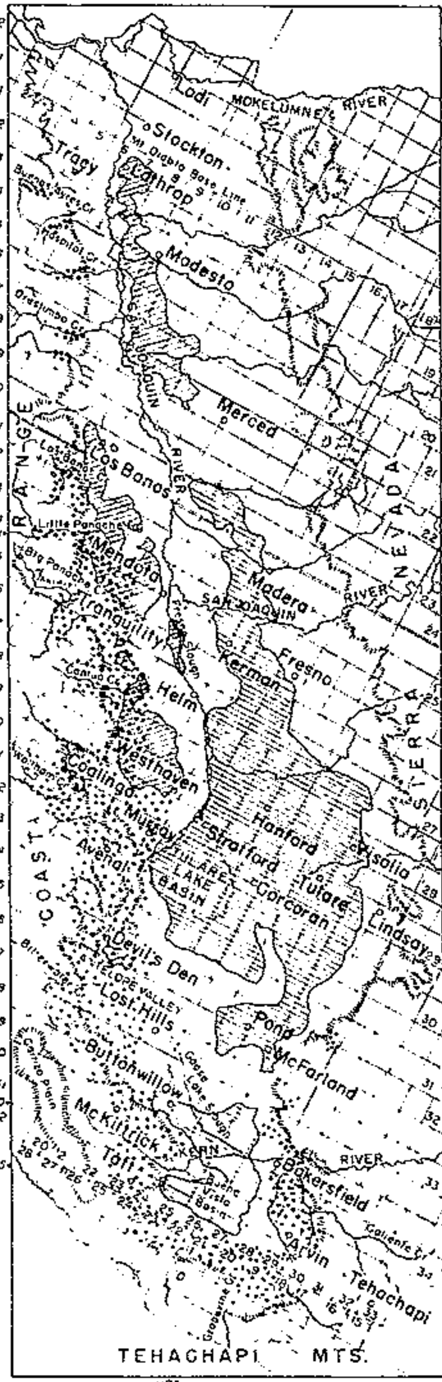

Figure 5.—The spring and summer breeding grounds of the beet leafhopper in the San Joaquin Valley. The summer breeding grounds (lined) are a composite of the areas occupied by the three important weed hosts at some time during the period from 1931 to 1937. Slanting lines indicate the important western group of breeding grounds, horizontal lines the less important eastern group. The spring breeding grounds (dotted) are shown as to their general location without any definite boundaries.

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The spring breeding grounds extend as far north as Tracy, occupying relatively small acreages in that locality. Going southeastward along the edge of the foothills of the Coast Range, the spring breeding grounds become more extensive in the areas of lesser rainfall. The centers of high leafhopper populations in the valley, however, shift

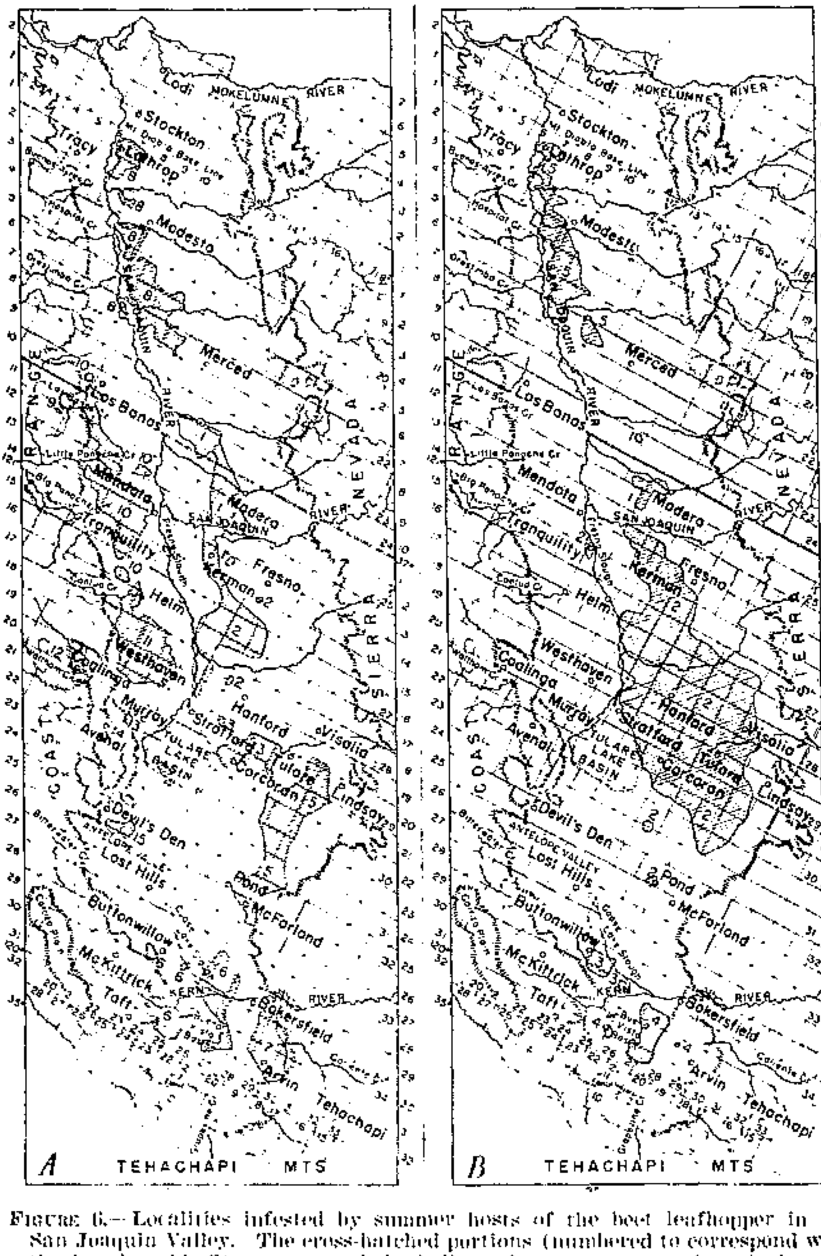


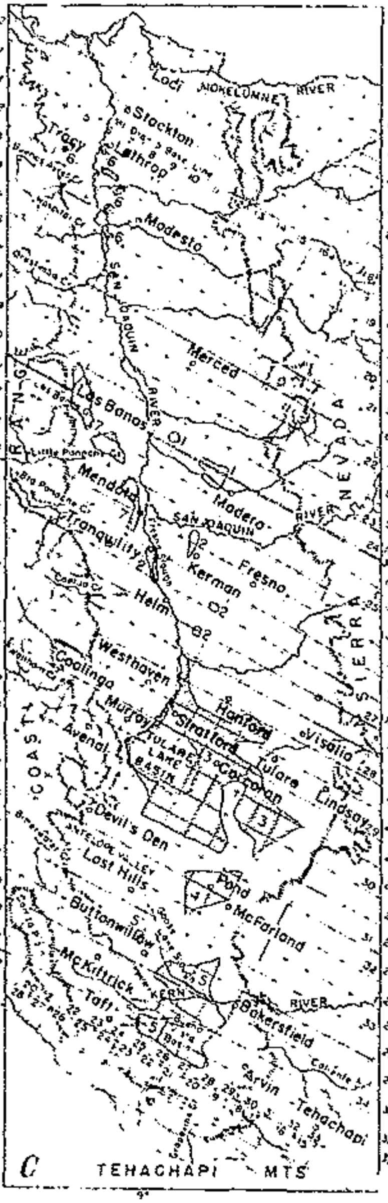
FIGURE 6.—Localities infested by summer hosts of the beet leafhopper in the San Joaquin Valley. The cross-hatched portions (numbered to correspond with the key in table 3) were occupied wholly or in part at some time during the

from year to year. For example, in some seasons prolonged drought may practically eliminate the more southern portions as breeding grounds.

In California, most of the sugar beets are grown in the Sacramento Valley, north of Stockton. Prior to 1925 attempts were made to grow beets in the central part of the San Joaquin Valley, but these attempts were abandoned because of excessive damage from curly top. Beginning in 1935, a considerable acreage of curly top resistant beets has been grown along the west side of the San Joaquin Valley from Los Baños to Buttonwillow. Even these have been damaged to some extent, particularly the late plantings.

Tomatoes are grown commercially from Merced north in both the San Joaquin and the Sacramento Valleys, but in some years heavy damage occurs as far north as Stockton. South of Merced County very few tomatoes are grown commercially, probably as a direct result of the curly top hazard.

The localities in which summer weed hosts are abundant fall into two important groups depending upon their relationship to the spring breeding grounds. The eastern group (fig. 5, horizontal lines) lies mostly within the cultivated district, contains scattered areas of the three important summer hosts in mixed or pure stands, and includes nearly all the acreage of bractscale, most of the fogweed, and a large part of the Russian-thistle. The western group contains relatively heavy infestations of summer hosts, mostly Russian-thistle. This group is considered to be much more important than the eastern group because of its proximity to the spring breeding grounds so that the losses during migration are much lower.[5]



period 1931–37 by a stand of 10 percent or more: A, Russian-thistle; B, bractscale; C, fogweed.

[5] LAWSON, F. R., CHAMBERLIN, J. C., and YORK, G. T. THE DISSEMINATION OF THE BEET LEAFHOPPER. Manuscript in preparation for publication.

The extreme southern portion of the valley is included in the e group because it is far from the principal sugar beet and tomat tricts. However, this locality may produce populations of leafhoppers that infest nearby small acreages of sugar beets and tomatoes and in some years may contribute to the infestation of more distant sections.

SUMMER WEED-HOST AREAS IN RELATION TO TOPOGRAPHY AND SOIL

The summer hosts of the beet leafhopper are practically limited to the flat lands of the valley, that is, the valley floor and gently sloping plains. The only exceptions worth mentioning are relatively small areas of Russian-thistle in the hills southwest of Los Baños and near Coalinga.

All three weed hosts occur on widely different soil types, including practically all those found in the valley (*7, 8*). In 1931, the year in which there was the greatest acreage of weed hosts, about half the Russian-thistle found on the transect survey was on sandy loam, approximately a third on sand, and a sixth on loam. A small remainder was on fine sandy loam and clay loam. If the large areas of Russian-thistle on Panoche loam in the vicinity of Coalinga and Mendota were included in these figures, the proportion on loam would have been greatly increased. Most of the bractscale was found on loam, fine sandy loam, and sandy loam, in approximately equal proportions, but small acreages were found on clay loam and sand. Slightly over a third of the fogweed was on sandy loam, with somewhat less than a third on fine sandy loam, and a little over a fifth on loam. Small portions were found on clay loam, sand, and clay.

The summer host weeds show varying degrees of tolerance to soils with a high salt content. Fogweed often grows with alkali heath (*Frankenia grandifolia* Cham. & Schlecht.), saltgrass (*Distichlis spicata* (L.) Greene), and seepweed (*Suaeda fruticosa* Forsk.), all of which are excellent indicators of a high salt content. Bractscale has not been observed to grow on land with a high salt content but does grow in moderately saline soils and is apparently tolerant of certain chemicals that ordinarily prevent plant growth. Ditchbanks in Stanislaus County that had been poisoned with sodium arsenite to prevent the growth of weeds produced a heavy stand of bractscale when no other plants were present. Russian-thistle has been observed growing in soils known to be somewhat saline, but is never abundant on such land.

The wide variation of soil types on which these plants can flourish indicates that, except for extreme types, the character of soil is a relatively minor factor in their distribution. Other factors, such as the use to which the land is put, have a more important effect.

RELATION OF WEED-HOST AREAS TO THE PRESENT PLANT COVER AND TO THE TYPES OF ORIGINAL VEGETATION

In any area the native vegetation previous to intensive disturbance by the white man was the result of the interaction of a complex series of physical and biological factors. The distribution of any given original type is a measure of the range or extent over which approximately the same set of factors operate. If the distribution of a weed can be determined in terms of the type or types of native vegetation, its possible future distribution is indicated. This is true if the disturbance by man has merely removed the original vegetation without seriously changing the factors determining its distribution. Some of the disturbances, however, are so profound as to result in physical or chemical changes in the soil, such as changing the level of the water table and the salinity of the soil. Such changes must be taken into consideration in determining the distribution of weed hosts.

Most of the land at present infested with Russian-thistle was originally covered by bunchgrass of the Pacific grassland type (*11*) which has been destroyed by cultivation or excessive grazing. Russian-thistle also occurs to some extent on land formerly occupied by other types where the original vegetation was destroyed by cultivation or excessive grazing or where drainage and irrigation have lowered the salt content.

Bractscale occurs almost entirely on land that has been plowed, and usually recently plowed. The portion of the valley infested by this weed covers what was originally lowland types, but also Pacific grassland and, to a much less extent, tree savannah. Bractscale is almost entirely absent from land formerly covered with desert saltbush (*Atriplex polycarpa* (Torr.) S. Wats.).

Fogweed is found mostly on lands formerly occupied by the spiny saltbush (*Atriplex spinifera* Macbr.) and lowland types. It occurs to some extent on lands formerly occupied by bunch grass, at present farmed and so altered by seepage as to have a high water table and a fairly high salt content. No large acreages of fogweed are found on land formerly covered with desert saltbush.

SUMMER WEED-HOST AREAS IN RELATION TO THE PRESENT USE OF LAND

The land on which Russian-thistle, bractscale, and fogweed occur can be divided into three major types on the basis of the present use of the land; namely, idle, abandoned, and cropped land. All land on which the three weed hosts were found on the transect surveys have been grouped into these categories, and the proportions are given in table 1.

TABLE 1.—*Percentages of the 3 important weed hosts of the beet leafhopper as found on idle, abandoned, and cropped lands in the transect surveys, 1931 to 1936, inclusive*

Weed host	Linear extent of stand [1]	Condition of land			
		Idle	Abandoned	Cropped land	
				Grain	Other crops
	Miles	*Percent*	*Percent*	*Percent*	*Percent*
Russian-thistle	184.65	38.4	33.4	22.9	5.3
Bractscale	130.25	49.7	22.0	25.9	2.4
Fogweed	258.45	35.3	36.6	27.3	.8

[1] Total length of weed-host areas as measured along the road by the automobile speedometer.

The classification "idle" includes those lands on which no crop was growing at the time of the survey but which had been plowed or cropped 1 or 2 years previously. "Abandoned lands" include those that were considered not to have been plowed or cropped for 3 years or more. Such lands usually had a cover of winter annuals and were sometimes disturbed by grazing to such an extent that the winter-annual cover had been almost destroyed. In such cases the classifications "idle" and "abandoned" were not always distinct.

Lands that were covered with a mixed stand of weed hosts in 1931 are not included in the table, since in that year the relative proportions of the weeds in the mixture were not recorded. Mixed stands found in other years are included and are listed under each of the constituents.

Table 1 shows that, with the exception of fogweed, weed hosts were more abundant on idle land than on either of the other types. Fogweed and Russian-thistle occurred more often on abandoned land than on land with crops, but bractscale was found slightly more often with grain than on abandoned land. Grain is the only crop of any importance in which summer weed hosts were abundant. All three weed hosts, and Russian-thistle in particular, are pests to some extent in other crops but are usually thinned by tillage to stands too sparse to have been recorded.

As compared with the other two weed hosts a higher percentage of the bractscale occurred on idle land. It also occurs on abandoned land where the winter-annual cover has been destroyed. Wherever a cover of other plants is present, bractscale is found only as patches of dwarfed plants. Under certain conditions Russian-thistle may grow abundantly on abandoned land now used for grazing, where there is a fairly complete cover of other plants, but it usually grows where the cover has been damaged by excessive grazing, by feeding of rodents, or by some similar cause. On such land in certain years, Russian-thistle covered large tracts in the Los Baños-Mendota, Coalinga, Westhaven, Devil's Den, and Arvin localities (fig. 6, *A*, and table 3). Although in these localities Russian-thistle grows mostly on abandoned land, it sometimes spreads to range land that has never been plowed but where the plant cover is very similar, because of heavy grazing.

Fogweed occurs abundantly on abandoned land, now excessively grazed, near Tulare and Buena Vista Lakes and in the Kern River lowlands. Usually on these tracts there is a sparse cover of winter annuals and, in some cases, a scattered stand of perennials, chiefly saltgrass, seepweed, and alkali heath.

Further evidence of the close connection between the abundance of summer weed hosts and intermittent farming is brought out by the record of the succeeding 5 years in what were weed-host areas in 1931 (table 2).

A high percentage of 1931 weed-host areas was cropped at some time during the 6 years of record. Since a majority of weed-host areas were on idle or abandoned land (table 1) much of which was cultivated at least once during the 6-year period under observation, it is quite clear that weed hosts tend to occur on land that is intermittently farmed.

In the well-farmed districts land is cultivated every year and seldom permitted to lie unused, consequently weed hosts cannot form stands worthy of consideration over any sizeable area. Even along fence rows and ditchbanks they are usually kept down. But in those districts where economic conditions, inadequate irrigation water, or excessive alkali cause farmers to permit land to lie unused, weed hosts become abundant.

TABLE 2.—*Percentages of the weed-host areas of 1931 on land cropped at least 1 year during the period 1931–36, inclusive, and on land not cropped during this period*

Weed host	Linear extent of stand [1]	Type of land	
		Cropped at least 1 year 1931–36, inclusive	Not cropped at any time 1931–36, inclusive
	Miles	*Percent*	*Percent*
Russian-thistle	52.9	71.3	28.7
Bractscale	43.45	86.1	13.9
Fogweed	67.5	59.6	40.4

[1] Total length of weed-host areas as measured along the road by the automobile speedometer.

ABUNDANCE OF SUMMER WEED HOSTS

The acreages of the three important summer hosts in the San Joaquin Valley for the years 1931 to 1937, inclusive, are given by localities in table 3. The western group includes those localities near the spring breeding grounds, which, as explained in the previous section, are considered of primary importance.

The acreages given in table 3 are subject to the sources of error which were discussed under Methods and, therefore, only large variations should be considered. Variations of one-half or twice are considered significant except that figures of less than 1,000 acres, when obtained by the transect method, are unreliable.

Table 3 shows that there was a pronounced downward trend in the total acreage of Russian-thistle in the eastern group from 1931 to 1935 with 1936 remaining about the same as 1935. This general trend was characteristic of all localities except Arvin and the small one at Tulare Lake. In contrast to the fairly regular trends of the eastern group, the acreages of Russian-thistle in the western group fluctuated markedly from year to year. The greatest total acreage for this group was reached in 1935, when there was a very heavy increase in the Westhaven locality.

Bractscale acreage, which is practically restricted to the eastern group, followed the same general trend as Russian-thistle; i. e., it decreased from 1931 to 1935 and remained about the same in 1936.

Fogweed acreage showed greater fluctuation. The Buena Vista-Buttonwillow locality, which was next to Tulare Lake in the acreage of fogweed, had high points in alternate years, in 1931, 1933, and 1935, but the tendency toward cyclic recurrence indicated by these figures is considered of no significance in as short a period as 6 years.

On the whole, bractscale and Russian-thistle acreages in the eastern group, where they were largely in cultivated districts, underwent sharp reductions to a point where the acreages in 1936 were small and relatively unimportant. Russian-thistle in the western group maintained a large but unstable acreage, largely on grazing land. Except for the small Los Baños-Mendota locality. fogweed acreage was reduced, although that which still remained in the Tulare Lake locality in 1936 was considerable.

TABLE 3.—*Acreages of the 3 most important summer weed hosts of the beet leafhopper in the San Joaquin Valley*[1]

Locality	Key to map[2]	Year 1931	1932	1933	1934	1935	1936	1937
RUSSIAN-THISTLE (FIG. 6, *A*)								
Eastern group:		*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*
Lindsay-McFarland	5	39,689	20,410	6,681	7,231	1,588	629	
Arvin	7	13,072	15,330	24,638	8,075	2,190	4,928	
Bakersfield-Buttonwillow	6	6,813	3,300	1,165	2,006	122	489	
Madera-Kerman	1	13,915	8,634	8,047	4,317	1,048	0	
Fresno-Stratford	2	18,285	7,424	5,431	3,505	550	412	
Corcoran	3	5,200	507	350	1,395	0	0	
Tulare Lake	4	0	0	1,268	3,803	169	0	
Total		96,974	55,605	47,610	30,332	5,965	6,458	
Western group:								
Los Baños hills	9	[3] 1,000	[3] 2,000					
Los Baños-Mendota	10		6,322	3,245	26,968	12,589	17,044	7,605
Westhaven	11	[4] 19,460	[4] 3,000		10,961	39,335	11,501	14,979
Coalinga	12	[4] 7,400	[3] 2,000		7,498	0	378	234
Murray	13	640			450	32	0	0
Avenal	14				0	677	0	0
Devil's Den	15				308	0	1,126+	9,590
Lathrop-Merced	8			7,757	6,958	2,246		
Total[5]		27,500	11,322	3,245	46,185	52,633	30,049	32,408
Total for both groups[5]		124,474	66,927	50,855	76,517	58,598	36,507	
BRACTSCALE (FIG. 6, *B*)								
Eastern group.								
Madera	1	2,280	130	489	586	0	130	
Hanford	2	100,946	39,709	33,627	15,649	3,761	6,494	
Buttonwillow	3	5,229	2,144	715	0	987	748	
Bakersfield-Buena Vista	4	5,574	2,305	1,845	0	980	115	
Total, eastern group		114,029	44,288	36,676	16,235	5,728	7,487	
Western group:								
Lathrop-Merced	5			4,682	2,158	1,261		
Total for both groups				41,358	18,393	6,989		
FOGWEED (FIG. 6, *C*)								
Eastern group:								
Madera	1	3,319	794	216	72	0	72	
Kerman-Tranquillity-Helm	2	2,011	1,384	371	593	0	297	
Tulare Lake	3	118,582	61,025	33,199	60,595	13,276	38,059	
Pond	4	1,621	0	0	270	0	180	
Buena Vista-Buttonwillow	5	38,212	10,778	16,240	1,557	10,481	1,121	
Total, eastern group		163,745	73,981	50,026	63,087	23,757	39,729	
Western group:								
Los Baños-Mendota	7		1,528	440	4,729	2,304	1,835	939
Lathrop-Merced	6			1,112	485	224		
Total, western group				1,552	5,214	2,528		
Total for both groups[5]			75,509	50,466	67,816	26,061	41,564	

[1] Includes only stands of 10 percent or greater density. Areas containing mixed stands of more than 1 weed host are included under both species. The eastern group was surveyed by the transect method and the western group by detailed mapping except as noted.
[2] The numbers correspond to those given in the maps in figure 6.
[3] Rough estimates.
[4] Based on transect surveys.
[5] Does not include Los Baños hills or Lathrop-Merced.

The reason for these fluctuations will be discussed later when the data bearing on the causes have been presented.

The total acreage of summer hosts in the San Joaquin Valley may appear to be hopelessly large insofar as any possible control measures are concerned, but it should be borne in mind that the extent of the land affected by leafhoppers bred on these summer hosts is also very large. The San Joaquin Valley alone covers somewhat more than 7 million acres. In 1931, when summer weed hosts reached their maximum abundance, Russian-thistle occupied approximately 1.8 percent of this acreage, bractscale 1.6, and fogweed 2.3 percent. A better idea of the relative magnitude of weed-host acreages can be obtained by a comparison with the acreages of the crops affected. Table 4 gives the acreages of sugar beets and tomatoes in the Salinas, Sacramento, and San Joaquin Valleys, the districts most affected by leafhoppers produced in the San Joaquin Valley. In 1931 the combined acreage of beets and tomatoes was less than that of Russian-thistle alone, but by 1935 these crops occupied a greater acreage than the weed hosts.

TABLE 4.—*Acreages of sugar beets and tomatoes in districts affected by leafhoppers from the San Joaquin Valley*[1]

SUGAR BEETS

District	Year						
	1931	1932	1933	1934	1935	1936	1937
Sacramento Valley	54,908	54,603	49,971	50,077	55,478	80,456	80,457
Salinas Valley	1,392	8,329	18,269	17,128	17,360	17,399	14,755
San Joaquin Valley	2,802	2,442	3,288	640	1,321	4,979	13,591

TOMATOES

District	1931	1932	1933	1934	1935	1936	1937
Sacramento Valley	4,798	5,471	5,523	8,162	12,603	18,908	21,188
Salinas Valley	11,844	12,010	11,823	13,649	15,491	15,089	14,331
San Joaquin Valley	4,711	4,818	4,643	13,474	19,715	26,837	17,984
Total beets and tomatoes	80,545	87,673	93,517	103,330	122,058	169,758	162,306

[1] Figures obtained from the California Cooperative Crop Reporting Service.

WHAT BECOMES OF WEED-HOST AREAS?

The question "What becomes of weed-host areas?" can be dealt with more readily if the various areas of the three summer weed hosts are considered in two classes, one comprising those areas within the cultivated district on land that is intermittently farmed, and the other those on grazing lands either permanently abandoned or never plowed.

ON INTERMITTENTLY FARMED LANDS

The purpose in studying the history of weed-host areas on lands intermittently farmed was to determine what proportion of these areas reappears, what proportion is replaced by other plants, and what proportion is replaced by crops. The answer to the first question, the proportion that reappears, is given in table 5.

The weed-host areas used as a basis in table 5 include all areas occupied by weed hosts in any year for the first time since 1931. Previous

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to 1931 these areas may or may not have been occupied by weed hosts, as no records for earlier years were kept. The first recorded appearance of weed hosts on these areas may have been in 1931 or any following year except 1936. The proportions that did and that did not again appear in weeds in subsequent years are given regardless of what happened to individual areas in the interim.

TABLE 5.—*History of weed-host areas for 6 successive years, based on total linear miles of weed-host areas recorded on the transect surveys 1931–36, inclusive*

Year of record	Tracts on which Russian-thistle reappeared	Tracts on which Russian-thistle was replaced or destroyed	Total linear measurement	Tracts on which bractscale reappeared	Tracts on which bractscale was replaced or destroyed	Total linear measurement	Tracts on which fogweed reappeared	Tracts on which fogweed was replaced or destroyed	Total linear measurement
	Percent	*Percent*	*Miles*	*Percent*	*Percent*	*Miles*	*Percent*	*Percent*	*Miles*
1	100.0	0	113.8	100.0	0	125.75	100.0	0	189.25
2	33.9	66.1	113.8	16.2	83.8	125.75	16.3	83.7	189.25
3	19.4	80.6	99.5	12.6	87.4	117.00	23.0	77.0	171.85
4	8.2	91.8	83.15	5.5	94.5	112.95	6.8	93.2	155.00
5	4.6	95.4	71.9	1.4	98.6	101.85	7.0	93.0	141.65
6	3.0	97.0	50.25	2.7	97.3	85.45	8.3	91.7	108.55

For instance, an area may have been occupied by Russian-thistle in 1932 for the first time in the records and was included in the first percent column and in the first year of record. If the same area was again occupied by Russian-thistle in 1934, it was again listed in the same column in the third year of record. The intervening year, 1933, was included in the next column, second year of record. The cause of the lack of the appearance of Russian-thistle on this area in 1933 is not considered here but in a later section. The table is concerned with showing that weed-host areas tend to disappear regardless of apparent causes, and that they do not reappear consistently year after year in any large proportion.

Only about one-third of the Russian-thistle areas reappeared the second year, about one-fifth the third year, and less than one-tenth after the third year. There is a similar but greater drop in the number of bractscale and fogweed areas that reappeared the second year. In general, the sharp drop in the second year followed by a continued decline at a decelerating rate is characteristic of all three weed hosts. The summer weed-host areas that did not reappear were replaced by other plants or by crops. The relative proportions of these are shown in table 6.

TABLE 6.—*Relative proportions of weed-host areas that were replaced by other plants and by crops 1931–32*

Weed-host area	Replaced by other plants	Replaced by crops	Total linear measurement
	Percent	*Percent*	*Miles*
Russian-thistle	53	47	62.4
Bractscale	55	45	99.1
Fogweed	64	36	148.2

To show the rate of replacement of weed hosts by other plants it is necessary to select areas not destroyed by plowing, so that the process can be followed through a number of years. The observed replacements on areas so chosen are given in table 7.

TABLE 7.—*Rate of replacement of weed hosts of the beet leafhopper by other plants on sites not disturbed after the first year*

SOIL DISTURBED DURING FIRST YEAR

Year of record	Tracts on which Russian-thistle reappeared	Sites on which Russian-thistle was replaced by other plants	Total linear measurement	Tracts on which bractscale reappeared	Sites on which bractscale was replaced by other plants	Total linear measurement	Tracts on which fogweed reappeared	Sites on which fogweed was replaced by other plants	Total linear measurement
	Percent	*Percent*	*Miles*	*Percent*	*Percent*	*Miles*	*Percent*	*Percent*	*Miles*
2	36.2	63.8	20.05	21.3	78.7	12.45	7.1	92.9	16.25
3	16.3	83.7	6.45	15.7	84.3	5.1	19.1	80.9	7.05
4	3.5	96.5	2.85	1.5	98.5	3.25	4.3	95.7	5.8
5	0	100.0	2.1	0	100.0	.6	0	100.0	1.3
6	0	100.0	.85	0	100.0	.25			
SOIL NOT DISTURBED									
2	40.1	59.9	18.2	15.4	84.6	11.4	14.1	85.9	34.3
3	16.6	83.4	10.55	6.6	93.4	6.8	49.2	50.8	17.8
4	14.0	86.0	5.7	8.2	91.8	3.65	11.7	88.3	7.7
5	0	100.0	2.35	0	100.0	1.2	4.3	95.7	3.5

The weed-host areas in table 7 are limited to those on sites where the natural course of succession was not interrupted by plowing or cultivation after the first year. No attempt has been made to eliminate sites that were disturbed by grazing or burning, since such disturbance was not always evident in the annual surveys. General observation indicated that nearly all abandoned or idle lands are grazed or burned or both, consequently lands that were not plowed were not entirely undisturbed.

The upper half of table 7 lists only areas containing a mixture of weed hosts and annual crops the first year, that is, those whose history began with a definite record of disturbance. The table shows that a large proportion of such areas was replaced by other plants in the second year. Although by the fifth year no weed-host stands remained, by this time the quantity of data, as represented by the mileage surveyed, had decreased to the point where it was not very extensive.

The lower section of table 7 shows the rate of replacement beginning with weed-host areas on idle or abandoned land. Here it is known that the replacement did not begin previous to the first year of record, since sites were chosen that had not been occupied by weed hosts the previous year. The sites listed were not plowed but may have been burned or grazed, as were those in the first section of the table.

The rate of replacement of weed-host areas on these idle or abandoned lands by other plants shows the same trend as that beginning with a mixture of weed hosts and annual crops.

The data show that in the years when the studies were made, summer weed-host areas did not reappear but were rapidly replaced by other plants if they were not destroyed by cultivation. The conclusions are supported by general observation.

Of the plants that replace summer weed hosts, winter annuals are the most abundant. This was discussed at some length in a previous publication (*11*). The most important of the winter annuals are grasses (species of *Bromus* and *Festuca*) and alfilaria (*Erodium* spp.).

Summer annuals in some cases are important constituents of the plant covers that replace the three summer weed hosts, particularly in the early stages of succession. The most common of these summer annuals are spikeweed (*Hemizonia pungens* (H. and A.) T. and G.), tarweeds (*Hemizonia* spp.), bluecurls (*Trichostema lanceolatum* Benth.), turkey mullein (*Eremocarpus setigerus* (Hook.) Benth.), and, in the northern part of the valley, telegraph plant (*Heterotheca grandiflora* Nutt.). Other summer annuals that have been recorded on weed-host sites are jimsonweed (*Datura stramonium* L.), horseweed (*Erigeron canadensis* L.), sunflower (*Helianthus annuus* L.), and burweed (*Franseria acanthicarpa* (Hook.) Cov.). On the more saline soils alkali heath, saltgrass, seepweed, goldenweed (*Aplopappus venetus* var. *vernonioides* (H. B. K.) Munz), licorice (*Glycyrrhiza lepidota* (Nutt.) Pursh), jackass clover (*Wislizenia refracta* Engelm.), and Australian saltbush were found.

All these plants occur in various mixtures and vary in abundance from year to year. Only those are listed that were found frequently in sufficient density to be important constituents of the cover. In other words, no attempt has been made to list rare or infrequently occurring species. Spikeweed in some years is the most important of the summer annuals that replace weed hosts. In years of abundance, tract after tract is covered with a dense stand of this plant. In other years it is common but not abundant.

Further information as to what becomes of weed-host areas is presented in table 8, which shows the kinds of crops grown on weed-host sites; i. e., tracts formerly occupied by weed hosts.

TABLE 8.—*Crops grown on sites formerly occupied by weed hosts of the beet leafhopper*

The weed host that formerly occupied the site	Grain	Plowed, fallow	Cotton	Alfalfa	Sorghum[1]	Vineyard	Miscellaneous	Total crops
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Miles*
Russian-thistle	29.6	23.2	21.7	6.9	4.7	4.3	9.6	69.0
Bractscale	29.4	13.0	17.9	12.0	15.6	.9	11.2	89.8
Fogweed	37.8	34.4	10.5	2.4	10.1	0	4.8	124.15

[1] Includes only the grain sorghums and not the molasses sorghums or sudan grass, which are listed with the miscellaneous crops.

The heading "Plowed, fallow" includes the lands that had been plowed but on which no crop was growing at the time of the survey. Some of these were grain fields where the crop had been harvested and the ground plowed, some were probably idle land that had been prepared for fall planting, and others were summer fallow. The miscellaneous column includes crops that occurred rarely on land formerly occupied by weed hosts and also includes a few fields that had crops of doubtful identity because of inadequate records. Grain, cotton, and sorghum are the principal crops that follow stands of weed hosts. Since these crops do fairly well on somewhat saline soils, and since grain, which is the most important, can be grown with a minimum of irrigation water and tillage, these are the crops that are raised most extensively on the outlying farms at the fringes of the well-cultivated districts. In the better farming districts, where the soil is free from alkali and plenty of irrigation water is available, alfalfa, vines, and orchards occupy most of the land. These crops represent a more or less permanent investment. The land is valuable and usually tended by resident farmers cultivating small acreages. On the other hand, the grains and cotton are often grown in large acreages by nonresident farmers who abandon the land if prices are low and the outlook unfavorable.

On Grazing Land

The Russian-thistle areas found on grazing land have a different history from those on land intermittently farmed. The history of a typical Russian-thistle area on grazing land is shown in the maps in figure 7. In these maps the entire portion marked "plains" is old abandoned land which at one time or another had been plowed, with the exception of small parts near the hills that have not actually been plowed but through heavy grazing have been reduced to practically the same kind of plant cover.[6] The broken line dividing the cultivated district from the plains is drawn approximately to represent the conditions in 1934, but in later years there were some changes in this boundary. Any Russian-thistle areas affected by the extension of cultivation have been eliminated from consideration in these maps.

In the years 1931, 1932, and 1933 no formal surveys were made, since extensive cruising, mostly during leafhopper surveys, had revealed only small, scattered patches of Russian-thistle. In 1934 there appeared the large area shown on the map in figure 7, *A*. Actually, the extent of the Russian-thistle growth was much larger than shown, since only stands with a density of 10 percent or more are included.

In 1935 the acreage of Russian-thistle was much smaller than in 1934. The same general tract was infested, with a few extensions at the northwestern end and in the middle. Those parts which were covered with Russian-thistle in 1934 but free of it in 1935 had only the usual cover of winter annuals. In 1936 (fig. 7, *B*) there was a large increase in Russian-thistle acreage. In this year, however, the bulk of the acreage was in new territory not previously infested either in 1934 or 1935 and lay mostly to the south of the old infestation. Only about half of the 1935 Russian-thistle area persisted in 1936. In 1937 (fig. 7, *C*) there was a large decrease. Very little of the 1935 and 1936 Russian-thistle areas persisted in 1937, and the only new area of any consequence lay 5 miles to the southeast.

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[6] The parts that have never been plowed usually contain remnants of a former perennial grass cover which are lacking on abandoned land. The dominants of the present vegetation (winter annuals), however, are very similar to those on abandoned land.

Russian-thistle areas on these plains are characterized by marked and sudden shifts in location and size from year to year, although there is a tendency for each year's infestation to lie partly within the boundaries of or to the south of the previous year's. This holds true for other Russian-thistle areas as well as the one mapped. The cause will be discussed in more detail in later sections on seed distribution and the effects of rainfall.

Fogweed, like Russian-thistle, grows extensively on grazing land. Whereas Russian-thistle is largely restricted to land that was formerly occupied by bunchgrass or, to a less extent, by desert saltbush and is now covered by winter annuals, fogweed grows on land that was formerly occupied by lowland types and at present has a mixed cover of winter annuals and perennials. Fogweed areas on grazing land have not been studied in detail, but there are large fluctuations in acreage and location. Bractscale, as previously noted, does not occur to any extent on grazing land.

COMPETITIVE EQUIPMENT OF THE THREE PRINCIPAL SUMMER WEED HOSTS

Those characteristics of the weed hosts that are of importance in their distribution and competition with other species will next be considered. The characteristics of Russian-thistle (*10*) are much better known than those of bractscale and fogweed. Russian-thistle is distributed over much of the Western States. Its early history in this country is given by Dewey (*4*) and Goff (*5*). Robbins (*12*)

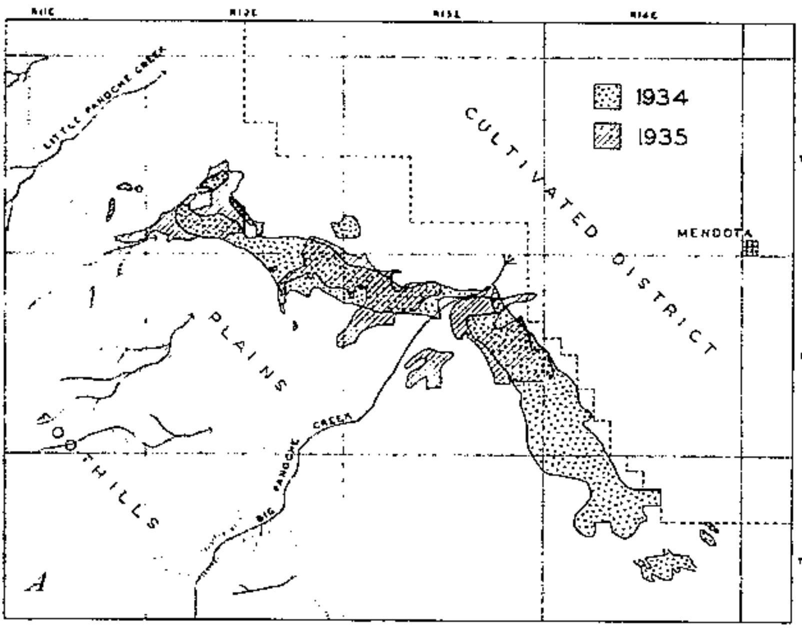
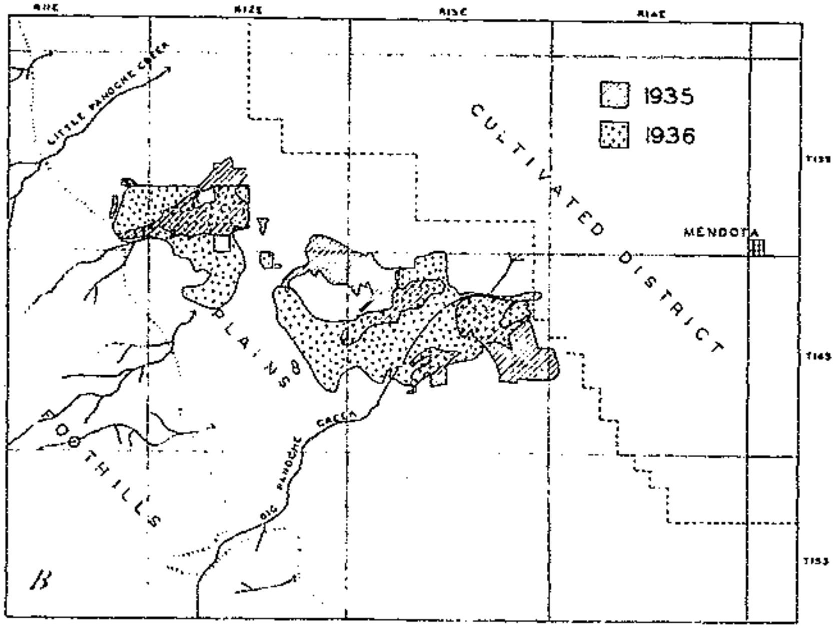
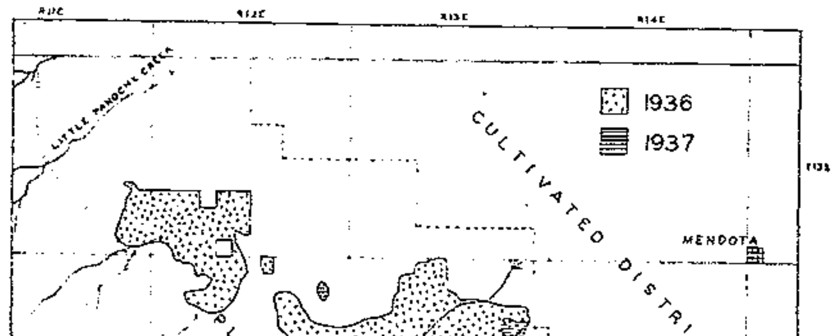


FIGURE 7.—Areas of grazing land in the Panoche section of the San Joaquin Valley infested by the Russian-thistle. The entire portion marked "Plains," between the foothills and the stepped broken line, consists of old abandoned land now grazed. *A*, The parts in the enclosed areas marked by dots were





infested to the extent of 10 percent or more in 1934, that similarly infested in 1935 being shown superimposed as lined areas; *B*, in like manner the 1936 infestations (dotted) are superimposed over the 1935 infestations; *C*, this map carries the same idea through the conditions in 1937.

gives its history in California. The Range Plant Handbook (*3*) describes the plant in some detail. Fogweed and bractscale are native species, but being much more limited in distribution are not so well known. Hall and Clements (*6*) give something of the general ecology and occurrence of these two plants.[7] In the present studies Russian-thistle has received the most attention because of its greater importance as a leafhopper host.

Time of Germination and Growth

Russian-thistle, bractscale, and fogweed are all summer annuals. In the San Joaquin Valley they germinate in early spring but grow very slowly before the coming of warm weather. Rapid growth begins in May, somewhat earlier for fogweed and bractscale than for Russian-thistle, and is most rapid in June. Seed is produced in the latter half of the summer. Russian-thistle has not been observed to produce seed before the first of July. The end of the growing season varies greatly from year to year and from place to place in the same year, depending on plant density and soil moisture.

In general, Russian-thistle will mature and dry later than bractscale and fogweed. During the period 1931–37 the last two for the most part matured and dried late in August or in September, although vigorous stands sometimes remained green and succulent until killed by frost in October or November. Most Russian-thistle stands remain green until October, and over large acreages often do not die until killed by frost, but may dry any time after germination if competition is severe.

To bring out the effects of competition on summer annuals more clearly it is necessary to discuss the competitive equipment of the winter annuals, the chief competitors. These germinate in the fall or early winter as soon as enough rain falls. The amount of rain necessary for germination varies with the temperature and the period over which the rainfall extends, but is usually one-half to three-fourths inch. The winter annuals then grow throughout the winter and mature and die in the spring. The amount of growth and the length of the growing season are conditioned by the available moisture and the density of the stand. In some years, when rainfall is light, drying occurs as early as March. In other years the winter annuals may live until the middle of May. Normally, drying occurs in the latter half of April or the first half of May. At this time Russian-thistle, bractscale, and fogweed are just beginning to make rapid growth.

Other summer annuals which may compete with the three summer weed hosts have little or no priority in germination, although they also germinate in the spring and make their growth in late spring and summer.

Seed Distribution

Although the general manner in which Russian-thistle seed is distributed is fairly well known, some of the details are brought out and

[7] These authors list fogweed (*Atriplex expansa*) as a subspecies of *Atriplex argentea*.

emphasized here since they enter into the discussion later. The plant is a tumbleweed, and the usual agent of seed distribution is the wind. The bushy, well-rounded individuals, such as are usually found in sparse stands, are best adapted to being carried in this way. Plants in dense stands are spindly, are not easily rolled, and are usually entangled with others and so held in place.

After their death the well-rounded plants break loose at the soil level, although some moisture is apparently necessary before the stem will break, and extensive rolling does not occur until sometime after the first rains have fallen. This is an important consideration in control measures, for if plants can be destroyed before the rains come, extensive seed dissemination is prevented. In the cultivated districts plants become lodged in ditches or against other obstructions and will sometimes pile up against a fence in such great numbers as to break it down. On the grazing lands, where the only obstructions are occasional gullies and dry washes, plants moving before the wind sometimes cover considerable distances before coming to rest. The bulk of the seed is dropped, however, within a comparatively short distance.

As pointed out in the previous section, on the plains Russian-thistle tends to occur near and to the south of the previous year's stand, apparently because strong winds in this region generally come from the north or northwest and move old plants to the south or southeast, seeding heavily the lands immediately adjacent in these directions. The distance the seed is carried with the plant by wind is limited, but it may be carried any distance with hay or grain. For instance, the original introduction into the United States was in flaxseed from Russia. Seed may also be carried to some extent by water.

Fogweed, like Russian-thistle, is a tumbleweed. When the plants are rounded in shape they are blown by the wind in great numbers. Other than this, little is known by the writers about the seed distribution of this species.

Bractscale is not a tumbleweed, since plants of this species usually remain in place after maturity and do not have the typical rounded shape of tumbleweeds. They have not been observed rolling before the wind like Russian-thistle and fogweed, and the conspicuous piles of dead plants along fences do not occur. Although the fruits are winged, the wing is small in proportion to the weight and size of the fruit, and observations indicate that very little bractscale seed is carried by wind.

This species often grows along ditchbanks, and some seed is probably carried by water. The plant also grows abundantly around barnyards, and manure from such areas is another possible source of infestations. Seed is also carried by livestock. Viable seed was recovered from sheep manure gathered in a grain field infested with a heavy growth of bractscale. Other animals probably carry the seed, although sheep are more likely to eat this plant than are other animals. Seed has been found in grain, but it may not have been viable, since bractscale is usually green at the time grain is cut.

The available information indicates that bractscale is widely distributed and that the sudden appearance of new stands is a result of favorable conditions that permit it to make a good growth from seed produced in the preceding season by small scattered plants.

THE MAJOR FACTORS THAT INFLUENCE THE ABUNDANCE OF SUMMER WEED HOSTS

Three factors exercise a major influence over the abundance of summer weed hosts. These are seed supply, rainfall, and competition with other species. The first of these, seed supply, is determined by the abundance and distribution of the seed produced the previous year. This has already been discussed at some length.

The effect of rainfall on the abundance of the three summer weed hosts is shown in table 9 by partial correlations.

TABLE 9.—*Partial correlation coefficients of seasonal rainfall and acreage of the 3 summer weed hosts of the beet leafhopper*

Independent factor, rainfall in—	Factors held constant, rainfall in—	Coefficients of partial correlation for—			
		Russian-thistle		Bractscale [3]	Fogweed [1]
		Western group [1]	Eastern group [2]		
January and February	March and April, May and June	0.008	−0.102	0.023	0.005
March and April	January and February, May and June	−.092	.128	.092	.002
May and June	January and February, March and April.	−.080	.720**	.763**	.581*
May	June	−.240	.203	.432*	.098
June	May	−.245	.783**	.706**	.634**

*Significant at the 5 percent level.
**Significant at the 1 percent level.

[1] Includes only Los Baños-Mendota, Westhaven, and Coalinga localities, 1934–37, inclusive.
[2] Tulare Lake omitted. All other localities are included and are for the years 1931–36, inclusive.
[3] Only eastern group figures 1931–36 were used.

The results summarized in table 9 were obtained by reducing the acreages of weeds in the several localities given in table 3 to a comparable basis and by reducing the acreage of each weed host found in any one locality in any given year to a percentage of the total acreage of the same weed host that was found in all years in the particular locality under consideration. Rainfall records at Weather Bureau stations within or near each locality were averaged by 2-month intervals for the period from January to June and separately by monthly intervals for May and June. Partial correlations were calculated from these data. The figures for each year in each locality were treated as separate variates. For instance, in tabulating the acreage of bractscale, the figure for Madera in 1931 was treated as a single variate, Madera in 1932 as another variate, and Hanford in 1932 as another, and so on. Since the several localities have been reduced to a comparable basis, variation between any two in the same year can be given equal weight with variation in the same one from year to year.

The correlation coefficients for Russian-thistle have been computed separately for the eastern and western groups, since the former consists chiefly of cultivated land, the latter of grazing lands. In calculating means of rainfall, the same Weather Bureau station was used in some cases for two different but adjacent localities. For instance, the data from the Coalinga station were used for correlations with Russian-thistle acreage in the Coalinga locality, and the same weather data were averaged with those from the Helm station for correlation with the acreages of the same weed host in the Westhaven locality.

In table 9 the correlation coefficients by 2-month intervals indicate that rainfall in the first two periods in the year (January-February and March-April) has no significant effect on acreages of any of the three weed hosts. Rain in the third period (May-June) significantly affects acreages of bractscale, fogweed, and Russian-thistle. When the effects of May and June rainfall are separated, it is found that May rain has a significant effect on bractscale acreage only. June rain significantly affects acreages of bractscale and fogweed, and of Russian-thistle of the eastern but not of the western group.

The size of the correlation coefficients indicates that in those localities significantly affected, June rainfall was one of the important factors that controlled annual fluctuations in acreages. Table 9 indicates differences in the reaction of the three weed hosts to rainfall, and for this reason they will be discussed separately.

Russian-thistle

To understand why rainfall in June, and only in June, affects Russian-thistle acreage in the eastern group, but from the correlations appears to have no effect in the western group, it is necessary to consider the third factor, that is, effects of competition with other plants. It has been shown (pp. 14, 19) that in the eastern group a large portion of the acreage of Russian-thistle is found on idle land where the stands are quickly replaced by competing species, chiefly winter annuals, if the land is not plowed. In the western group the bulk of the Russian-thistle grows on grazing land where a variable cover of winter annuals is present. These plants exercise their most important influence on Russian-thistle through their effect on the soil moisture, and soil moisture in an arid region such as the San Joaquin Valley is a critical factor, usually determining whether plants can grow and produce seed.

In this region the summers are practically rainless, so these weed hosts, which make their greatest growth in summer, must depend on the moisture that has been stored in the soil from the preceding wet season. The winter annuals, however, which are the principal competitors of the summer annuals, start growth with the first rains in the fall. In consequence, winter annuals have first chance at the available soil moisture, and where they are sufficiently abundant they so exhaust the supply that none is left for the later growing summer annuals. Thus the latter can thrive only where the winter-annual cover has been destroyed unless some supplementary source of soil moisture is available. This is the reason why so large a portion of the Russian-thistle in the cultivated area is found on idle land and why it tends to disappear when the winter-annual cover has established itself.

However, in the interval between the first year of abandonment, when winter annuals are very scarce, and the time when a complete cover of these plants becomes established, there is a critical period of 1 or 2 years when small amounts of rainfall may be very important to the growth of Russian-thistle. If rain falls early in the spring, it serves to increase greatly the growth of the winter annuals, since they are at the height of their growth period and in a position to use the additional moisture very quickly and effectively. Russian-thistle is growing slowly at this time of year and can make less effective use of the additional moisture. Thus, in the end the rainfall early in the spring further increases the severity of the competition which the winter annuals afford Russian-thistle. But if the rain falls later, after the winter annuals are dead or nearly so, this moisture is available for the further growth of summer annuals.

In the cultivated district a considerable acreage of Russian-thistle is always found on idle land where competitive plants are few and where the soil moisture available from the winter rains has not been depleted and so is available for the growth of Russian-thistle. In addition there are lands where varying amounts of Russian-thistle and winter annuals are mixed and where the former can grow if sufficient rain falls after the winter annuals are dry. The amount of rain necessary will depend directly upon the cover of winter annuals and the severity of competition. It is in such situations that even a light rainfall late in the season may mean the survival of Russian-thistle and a great increase in its acreage. Winter annuals may mature and dry in some years as early as the first of May or as late as the first of June. June rains always come after maturity of these plants and always tend to increase the acreage of Russian-thistle. When the winter annuals dry early, May rainfall tends to increase the acreage of Russian-thistle, but when the winter annuals do not dry until late in May, rain in this month decreases the acreage of the Russian-thistle. These effects tend to cancel one another over a period of years, and this is why the correlation coefficients in table 9 show no significant relation between Russian-thistle acreage and May rainfall.

In the western group, Russian-thistle grows on grazing land where a cover of winter annuals of some kind is present. Although this cover may be sparse, nevertheless it affords severe competition as compared with that in the lands in the cultivated district which have been recently plowed. In consequence, rainfall which is sufficient to produce a large increase in Russian-thistle under the relatively mild competitive conditions in the eastern group is not sufficient to have any effect in the western group.

It is only when June rainfall is unusually heavy, as it was in 1931, or when intense local storms in the hills cause flash floods, that there is sufficient moisture for the Russian-thistle to continue growth and mature seed. In some cases the silt and debris of floods cover a square mile or more, burying the cover of winter annuals and leaving bare soil. Part of the acreage covered by Russian-thistle in the Panoche section in 1934 was of this type, and many of the sudden changes in the location and acreage shown in figure 7 are due in part to such erratic local storms.

The abundance of Russian-thistle in the San Joaquin Valley, then, is determined by several factors acting in conjunction. The diagram in figure 8 illustrates the interaction of these factors. The large outer circle (*A*) represents any locality in the San Joaquin Valley, all of which is covered by the general rains of winter and all of which has a good cover of winter annuals except the small portion within circle *C*, where this cover is absent or sparse. The part where Russian-thistle seed is present is shown by circle *B*, and the part covered by additional rains in late spring by circle *D*. In the triangular portion *F*, formed by the intersection of the three small circles—that is, where seed is present, where winter annuals are sparse or absent, and where late spring rains fall—it is almost certain that Russian-thistle will grow and mature. In *E*, where seed is present, where competition is lacking or at least not severe, and where spring rains do not fall, Russian-thistle will grow, but if its stand is dense it will die prematurely. In *G*, where seed is present and late spring rains occur, but competition is very severe from winter annuals, Russian-thistle will not survive except when spring rainfall is unusually heavy, and even then will form only an open stand of small or medium-sized plants.

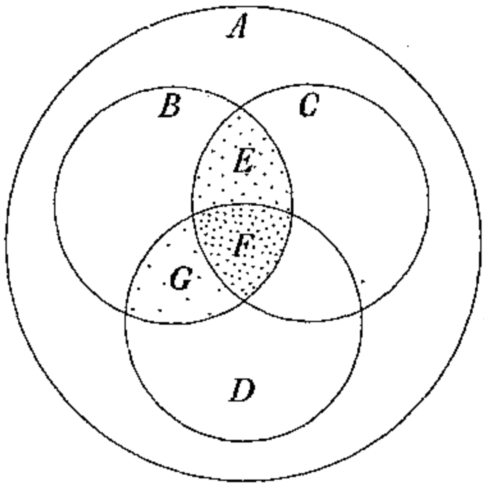


FIGURE 8.—Diagram of the effects of rainfall, seed supply, competition, and the interaction of these factors on the growth of Russian-thistle: *A*, Covered by winter rains and with a uniformly dense cover of winter annuals, except within circle *C*; *B*, Russian-thistle seed present; *C*, winter annuals sparse or absent; *D*, covered by late spring rains; *E*, where Russian-thistle will grow but will die prematurely if its stand is dense; *F*, where Russian-thistle will almost certainly grow and mature; *G*, where Russian-thistle will not survive except in years when late spring rains are unusually heavy.

Where the cover of competitors is heavy, Russian-thistle dies when young, and large numbers of small, dead plants can be found in such situations. Figure 9 illustrates the dwarfing effect of a dense

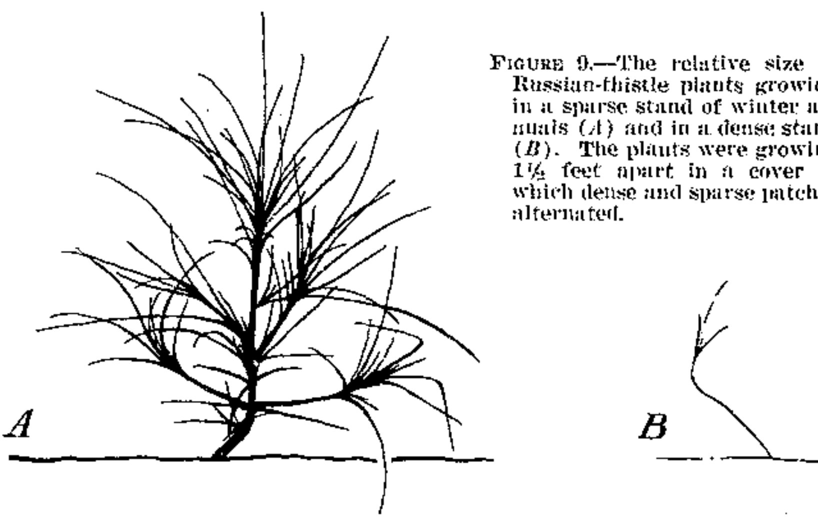


FIGURE 9.—The relative size of Russian-thistle plants growing in a sparse stand of winter annuals (*A*) and in a dense stand (*B*). The plants were growing 1½ feet apart in a cover in which dense and sparse patches alternated.

stand of winter annuals on Russian-thistle and also the larger growth in a sparse stand of winter annuals. The plant *A* was 4½ inches high and 4 inches wide, and *B* was 2¼ inches high. The essential point, however, is the difference in the form of growth and in its total volume, since it is obvious that in heights the plants would vary greatly with local conditions. Thus a spindly Russian-thistle plant in a dense growth of winter annuals might have the same height as an individual growing in a sparse cover, and yet the difference in total volume might be greater than that illustrated. The drawings are made from photographs taken south of Mendota, Calif., April 15, 1941. The difference becomes even greater on idle lands where the soil as well as the plant cover has been disturbed (fig. 10).

FIGURE 10. Effects of competition on Russian-thistle. On the left the soil has been disturbed and the cover of winter annuals destroyed. Russian-thistle forms a good stand. On the right it has been almost entirely excluded by a sparse cover of winter annuals. In such situations small dead plants can usually be found. Carrizo Plains, Calif., 1934.

Less is known about the effects of competition between Russian-thistle and other summer annuals. In some cases such competition must be severe. For instance, spikeweed occurs in dense stands on idle lands that were covered by Russian-thistle the preceding year. On grazing lands or old abandoned land the tarweeds and bluecurls sometimes grow in considerable abundance mixed with Russian-thistle and compete for soil moisture.

Russian-thistle growing as a weed in grain does not do well except where the stand of grain is thin. Severe competition is indicated since even in irrigated fields the plants of Russian-thistle are much smaller where the grain is thick than where it is thin.

BRACTSCALE AND FOGWEED

The effects of rainfall and competition on bractscale and fogweed appear to be in most respects very similar to the effects on Russian-thistle. Both these tend to occur on denuded land where they are rapidly replaced by other plants, chiefly winter annuals. Acreages of bractscale and fogweed are affected by June rainfall and acreages of the former are also affected by May rainfall.

Bractscale is much more closely confined to newly plowed or idle lands than is Russian-thistle. Dense stands of bractscale do not occur on lands in the cultivated district where a cover of winter annuals has developed; that is, this plant cannot grow where the cover of winter annuals is sufficient to exhaust the soil moisture that comes from the winter rains and is less able to withstand competition than Russian-thistle. The dwarfing due to competition is shown in figure 11 in drawings made from photographs taken near Lemoore, Calif., April 16, 1941.

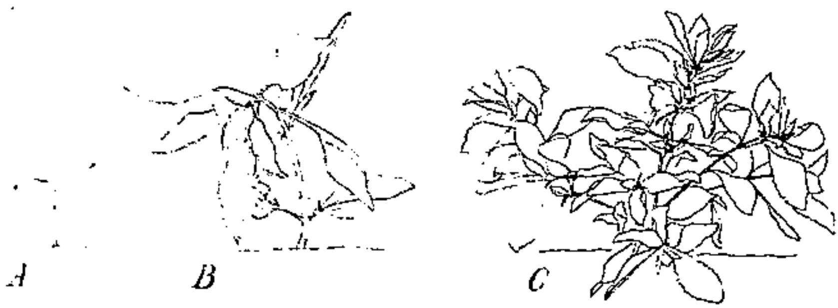


FIGURE 11.—Effect of competition on bractscale: *A*, in a dense stand of grass; *B*, in a dense stand of bractscale; *C*, young plants growing in a nearly bare spot. The plants were growing within a few feet of each other.

Fogweed grows abundantly on old abandoned land where the cover of winter annuals is sparse, either because of grazing, or usually because of the soil being somewhat saline. In some cases perennials such as seepweed and saltgrass are also present and competing with the fogweed, but if there is a good stand of the perennials fogweed cannot grow and mature.

THE EFFECTS OF OTHER FACTORS ON THE ABUNDANCE OF SUMMER WEED HOSTS

Besides the factors already mentioned, there are other influences that affect the abundance of summer weed hosts. In intermittently-farmed districts the relative amount of land abandoned or idle in any particular year obviously would affect the acreage of weed hosts. The prices of cotton and grain, and the supply of irrigation water in those districts where water is sometimes deficient, would in turn affect the amount of land abandoned. In some localities mineral salts in the irrigation water from wells force the abandonment of land at frequent intervals. An abundance of fall rains increases the amount of old abandoned land plowed in the hope of producing a crop of grain for which irrigation water is not available.

Taking the valley as a whole, abandonment in any one portion may be offset by increased plowing in another. In years of an economic crisis, when a very marked and sudden drop in farm prices occurs, the acreage of abandoned land increases abruptly. With a return to better prices the abandoned land is returned to cultivation gradually.

THE RELATIONS OF ECOLOGICAL FACTORS TO METHODS OF REDUCING SUMMER WEED-HOST ACREAGES

In the present bulletin the ecological factors underlying the methods of reducing host-plant acreages will be discussed, but no attempt will be made to discuss particular methods in detail, except to cite a few as illustrations. Practical measures are discussed in more detail in another publication.[8]

Russian-thistle in Cultivated Districts

The method most commonly used for reducing the acreage of weeds in general is to destroy the growing plants. This not only eliminates the crop of the current year but also reduces the future supply of seed if the plants are killed before the seed begins to mature. Considering the large acreages of Russian-thistle in the San Joaquin Valley, the method of destroying growing plants is an expensive process if complete eradication is attempted. If instead of elimination a reduction in acreage is attempted, then it is not so important to destroy growing plants as it is to prevent dissemination of seed, since the acreage in any succeeding year is dependent on dissemination to nearby uninfested tracts. It has already been shown that old stands tend to disappear, being either destroyed by plowing or replaced by winter annuals.

The possible sources of seed in the newly bared lands are (1) seed held over in the soil for several years from previous infestations, (2) seed from scattered and more or less continuous infestations in crops, or (3) seed from nearby stands which has been carried by wind, water, livestock, or in infested hay, grain, manure, etc.

Attempts to reduce the acreage of Russian-thistle in Stanislaus County indicate that seed from the previous year's growth is the principal source of each year's infestation and not seed held over in the soil. In the fall of 1933 all the Russian-thistle that could be found in about 41 square miles was piled and burned. An adjacent and heavily infested tract of 73 square miles was used as a check on the effectiveness of the program. Where Russian-thistle was burned there was a reduction of 68 percent, from 1,736 acres in 1933 to 556 acres in 1934. In the check there was an increase of 53 percent, from 2,222 acres in 1933 to 3,410 acres in 1934. These figures are based upon results of the detailed survey and include only stands of 10 percent or greater density. Taking the increase in the check into consideration, there was a calculated reduction of 79 percent in the cleared portion. This work was repeated in the fall of 1934 with the inclusion of some addi-

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[8] Lawson, F. R., Cook, W. C., York, G. T., and Piemeisel, R. L. Russian-thistle as a summer host plant of the beet leafhopper in the San Joaquin Valley, California, and methods of reducing its acreage. U. S. Bur. Ent. and Plant Quar. Cir. E-573, [13] pp., illus. 1942. [Processed.]

tional land. In the burned tract there was a reduction of 74.9 percent, from 931 acres in 1934 to 234 acres in 1935. In the check there was a reduction of 62.8 percent, from 3,035 acres to 1,129 acres. Again considering the check, there was a calculated reduction of 32.4 percent.

These data indicate that a considerable reduction in Russian-thistle acreage resulted from the destruction of the seed supply. As a fact, the reduction was due to destruction of that portion of the seed supply that normally would have been carried to adjacent fields not previously infested, and was not due to the destruction of that portion of the seed supply which would have reseeded the fields cleared by burning. The work was done so late in the season that in handling dry plants with ripened seed enough seed was dropped locally to reseed the burned fields.

In addition to preventing Russian-thistle seed from being carried to adjacent tracts there is the possibility of reducing the number of tracts of newly bared soil that are suitable for establishment of new stands. This could be done either by continuous cultivation or permanent abandonment of lands that lie idle part of the time. Thus, any factor, such as improved water supply, drainage, etc., which would stabilize farming in these districts and prevent intermittent abandonment would decrease the acreage of Russian-thistle.

Russian-thistle on Grazing Land

The usual methods of Russian-thistle control that can be used in the cultivated districts are not applicable to grazing lands. As previously stated, the existence of Russian-thistle on these lands is at best a precarious one and is dependent on a poor condition of the winter-annual cover. Any measures designed to reduce Russian-thistle acreage should be of such nature that the degree of competition is increased by improvement of the rival plant cover rather than decreased by its destruction.

On the grazing lands, at the present time, there are many agencies that cause destruction of vegetation, but in general the most severe and extensive of these is overgrazing, although locally others, such as the work of rodents, may be very destructive.

Russian-thistle could not maintain itself on these plains if the original perennial cover had not been destroyed, since perennials offer even more competition than a good cover of winter annuals. The native perennial grasses and shrubs not only begin growth early in the season but also continue to use moisture after the winter-annual cover is mature. In an established stand of perennials the soil space is fully occupied by the roots of the perennials, and an annual such as Russian-thistle, which grows new from seed each year, cannot successfully compete. No large infestations have ever been observed on lands where a reasonably good stand of perennials occurred.

Although the reestablishment of a perennial cover is desirable, it is not essential for the reduction of Russian-thistle acreage, since this could be accomplished by improvement of the present winter-annual cover long before perennials could be well established. The first effect of an increase in the present cover would be a decrease of Russian-thistle in those years when late spring rainfall is barely sufficient under present conditions. A further effect of improvement would be the elimination of spots where the winter-annual cover is sparse. It is in such spots that Russian-thistle maintains itself in years when the rainfall is not sufficient for it to grow in the prevailing cover of winter annuals. If it were not for such spots, the winter rains which sprout Russian-thistle seed every year would deplete the seed supply in one or two unfavorable years, such as occurred in the Panoche locality (fig. 7) from 1931 to 1933 and again in 1937. With such a depletion of the Russian-thistle seed supply, heavy infestations would be impossible, even in years of exceptionally heavy spring rainfall.

The most effective method of improving the winter-annual cover would be through a reduction in the present rate of its destruction. Near Tracy on two 10-acre plots, which were protected against grazing, there was a marked change in the vegetation of winter annuals both in kind and in greatly increased density. Excessive grazing, however, is only one of the agencies destructive to vegetation, and if other sources of destruction are important locally they also must be controlled.

In addition to the improvement of the winter-annual cover as a means of reducing Russian-thistle acreage, supplementary measures can be used for artificial destruction of the seed supply or the prevention of dissemination by wind. Small isolated patches in otherwise uninfested localities can be removed by hoeing. Temporary fences placed in strategic locations on the leeward side of heavily infested tracts would prevent large quantities of seed from being carried to adjacent tracts.

Complete eradication of a weed as widespread as Russian-thistle is highly improbable. As long as there are large tracts of deteriorated grazing land suitable for its growth, continuous reinfestation will occur, and a small quantity of seed will result in more serious reinfestation than would a larger quantity if suitable situations were eliminated. If improvement of the existing winter-annual cover is not undertaken, at least no measures should be put into effect which would cause further deterioration, and attempts to destroy Russian-thistle stands by such measures as wholesale burning and plowing will in the end cause more harm than good. The present cover of winter annuals is already in poor condition as compared with what it might be as demonstrated in the two fenced plots at Tracy, but even at that, it is all that prevents a great increase in Russian-thistle acreage.

Bractscale and Fogweed

The available information on methods of reducing bractscale and fogweed acreage is scanty. What is known suggests that, with the exception of seed distribution of bractscale, these two plants are very similar to Russian-thistle in their ecological characteristics and somewhat similar measures are applicable for reduction of their acreages.

Since bractscale is found abundantly on idle land and not on old abandoned land, cessation of the practice of intermittent farming would automatically eliminate a large portion of the bractscale acreage. In the northern part of the valley at least, the bulk of the acreage of bractscale occurs on land where grain and beans are grown without irrigation. Such bractscale areas are usually located in the midst of the more intensively cultivated districts on nonirrigated lands that have never been leveled. These centers of infestation will no doubt be gradually eliminated, but the process might be accelerated by economic measures that would help the owners to level and irrigate such lands.

Measures designed to reduce the seed supply of bractscale offer little promise of success considering its wide distribution and the evidence that new stands come largely from seed already in the ground or produced by small, inconspicuous, scattered plants. Some improvement might be expected from control of bractscale stands along ditchbanks. Further research on the seed supply might suggest other measures, but the present knowledge indicates that the land-improvement measures mentioned above are the most practical method of reducing the acreage of this plant.

Fogweed is a tumbleweed like Russian-thistle and, as such, probably would respond in a comparable way to measures designed to control the seed supply. Likewise, the control of intermittent farming and overgrazing would probably have the same effect on fogweed as on Russian-thistle acreage. On grazing land a permanent reduction of the acreage of fogweed might be effected more quickly than a similar reduction of Russian-thistle. Most of the fogweed on grazing land occurs within the boundaries of what were formerly lowland types of vegetation on more or less saline soils. Although such soils do not support so heavy a cover of winter annuals as do the less saline types, the succession to perennial takes a much shorter time. Alkali heath, seepweed, and some saltgrass are usually present already, and if grazing is reduced, the succession to a complete cover of perennials is relatively rapid.

GENERAL DISCUSSION

In 1931 weed hosts covered large tracts of land that were lying idle as a result of the severe economic depression. As agricultural conditions improved in subsequent years such lands were again plowed, but if another economic crisis occurs land will again be left idle and the same cycle will be repeated, with large acreages of weed hosts as a result. On grazing lands a series of wet years or a temporary reduction in number of stock would effect an improvement in the winter-annual cover with a consequent reduction in weed-host acreages.

As stated in a previous publication (*11*) if either the winter or summer hosts of the beet leafhopper were greatly reduced, populations of this insect and crop losses from curly top would also be reduced since both sets of hosts are esential in the annual cycle of the leafhopper. It is also true, however, that if the number of stock on the western ranges is again increased, or if a series of dry years sets in, excessive damage to the winter-annual cover will take place, and this will result in large acreages of weed hosts. If the rate of deterioration of the winter-annual cover on the plains and foothills of the San Joaquin Valley is not permanently checked, Russian-thistle, which is the most important summer host plant of the leafhopper, will in the future increase to such vast acreages that the destructive abundance of this insect will be greatly increased.

SUMMARY

The ecology of three summer hosts of the beet leafhopper was studied as these plants occurred in the San Joaquin Valley, Calif., by means of detailed surveys and by transects.

Of the many summer host plants of the beet leafhopper, the most important are Russian-thistle, bractscale, and fogweed, weeds that are found on many different types of soil, but practically limited to the valley floor and adjacent sloping plains.

Russian-thistle is the most important of the three, both because of its occurrence near the spring breeding grounds of the leafhopper and its suitability as a host. All three are abundant on land that is intermittently farmed or has been recently abandoned. Russian-thistle, and to a less extent fogweed, also occur abundantly on old abandoned land now used for grazing. Grain is the only crop in which the summer weed hosts were abundant.

The summer weed hosts were rapidly replaced by other plants on individual areas, winter annuals usually taking their place.

In the grazing lands the areas occupied by Russian-thistle are marked by sudden shifts in location and size from year to year, with the boundaries overlapping but with the spread more often on the leeward side.

Russian-thistle, bractscale, and fogweed germinate early in the spring but grow very slowly before the coming of warm weather. They cannot compete successfully with the winter annuals that germinate in the fall and are well established by early spring. Russian-thistle and fogweed are tumbleweeds and scatter their seed as they are blown along by the wind, the bulk of the seed being dropped before the plants have gone very far.

Rainfall early in the season favors the growth of the winter annuals and is a disadvantage to the Russian-thistle. But rains coming late, after the winter annuals have matured, will favor the Russian-thistle.

These weed hosts compete with both the winter annuals and other summer annuals for the available soil moisture. The effects of rainfall and competition on bractscale and fogweed are about the same as on Russian-thistle.

The summer weed hosts can be reduced in abundance by direct measures, such as the destruction of the growing plants or the seed supply, and in the cultivated sections these may be the most practical methods of control. But on grazing land the most practical method of reducing the abundance of these weeds would be the control of overgrazing. Excessive grazing, by greatly thinning the winter-annual cover, makes suitable places for the weed hosts to grow. Any measure that will improve the cover of winter annuals will eliminate these suitable places and make conditions unfavorable for the growth of these weeds.

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