Bulletin No. 155 - The Beet Leafhopper and the Curly-Leaf Disease That It Transmits

E. D. Ball
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and the
Curly-Leaf Disease That It Transmits

By E. D. BALL

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THE BEET LEAFHOPPER AND THE CURLY-LEAF DISEASE THAT IT TRANSMITS.

By E. D. BALL

INTRODUCTION

The beet leafhopper (Eutettix tenella Baker), is the most serious pest of the western sugar beet. It has through the disease it transmits caused periodic losses to the western sugar-beet industry, amounting in the aggregate to many millions of dollars. Curly-leaf, the disease which this insect transmits, has in some of its worst outbreaks caused the abandonment of thousands of acres of beets in certain districts and a serious reduction in tonnage of the remainder, so that the total loss in a single area has several times passed the million-dollar mark. Besides these striking and widespread outbreaks which fortunately have not been numerous, it has continued from year to year to reduce tonnage in certain districts until at least seven factories have temporarily or permanently suspended operation on account of losses from this source.

The subject is also of striking interest and importance at this time because curly-leaf is the first plant disease definitely determined to be entirely dependent upon a specific insect for transmission.

The discoveries of the last few decades with reference to the insect transmission of animal and human diseases have in many cases revolutionized the methods employed for their control. There are a large number of plant diseases for which no casual organism has as yet been found, curly-leaf among the number. The establishment of the method of transmission of even one of these has opened the way to further research with reference to the nature of the causative agent. This in turn may throw new light on the cause of other diseases and each new fact added forges another link in the chain of evidence necessary to formulate methods of control.

*Curly-leaf was the name applied to the specific disease caused by the puncture of Eutettix tenella Bak. at the time the discovery was made. It has always been used in that restricted sense. Curly-top and blight have been used as general terms to designate all forms of leaf distortion occurring in an area without reference to the causes. It is now known that a number of leaf curls caused by different insects, as well as a group of "physiological diseases" and conditions not yet understood, have been included under these terms.
The problem presents many peculiar conditions and on account of the probable long flights of the insect and the uncertainty of origin of the swarms cannot be treated by state boundaries, but rather the entire area affected must be studied as a whole. Even after the broad facts are known, each region will have its own problems to be worked out. But, until these problems are solved, beet growing will continue to be a hazardous undertaking in many regions and the per cent of failures from this cause will no doubt continue.

The following pages briefly summarize the development and present status of the entomological and economic phases of the subject and are of value, not so much as a record of work done, as a historic and scientific foundation upon which much future work is needed.

ACKNOWLEDGMENTS

The Spreckles Sugar Company has contributed liberally to research work on this problem. Not only should it be commended for its financial contributions, but it has always furnished prompt and accurate information of conditions. The writer is under special obligations to Manager F. E. Sullivan and Professor G. T. Scott for assistance and information, and to Professor R. L. Adams for the same favors and a copy of his manuscript thesis from which a number of extracts have been made. Doctor E. G. Titus has furnished information from his notes and has assisted in many ways. Mr. W. K. Winterhalter has been very helpful, in general, and furnished notes on several regions. Mr. P. J. Prein loaned his notes on the Yakima experiments, Dr. Hedgecock furnished information of Nebraska outbreaks, and Mr. Fred Goold has answered numerous questions, while the officials of many factories have extended courtesies on the occasions of visits and furnished information. To all of these the writer is under obligation. Professor L. R. Jones has been very helpful with reference to pathological problems involved and generous with literature.

HISTORICAL

The sugar-beet industry in the west was started in Alvarado, California, in 1870. Several factories were built and changes made in the next few years, but owing to defective machinery,
lack of knowledge of beet raising and probably partly to pests and diseases, little headway was made until about 1890. Alvarado, with a few early interruptions, continued to run in a small way, and in 1888 a factory was built at Watsonville; in 1890 one at Grand Island, Nebraska; in 1891 one each at Norfolk, Nebraska; Lehi, Utah, and Chino, California. For several years following this no new factories were built, but the western Experiment Stations and the United States Department of Agriculture were sending out seed and beets were grown in trial plots in nearly every district of the west, many of these tests continuing until about 1900. By this time factories had become established in Los Alamitos ('97), Crockett ('98), Betteravia ('98), Oxnard ('99), and Salinas, California, ('99); Le Grande, Oregon ('98); Ogden ('98) and Logan, Utah ('01); Waverly, Washington ('99); Grand Junction ('99) and Loveland, Colorado ('01); Ames, Nebraska ('99), and a factory ran at Eddy, New Mexico, during '96 and '97. Sugar-beet growing was by this time pretty well distributed over the west and it is unfortunate that there are practically no records of pests or diseases during these early years. Curly-leaf, no doubt, contributed its share to the troubles and losses of the period, but there was no one trained to recognize or record it.

In the early days especially, when much propaganda and promotion were going on, officials connected with the industry studiously avoided giving out information and always minimized all troubles for fear it would hurt development. This lack of cooperation and information often seriously handicapped the scientific workers and retarded the solution of many of the problems of the industry. Factories have been dismantled and the districts abandoned largely through troubles which could have been overcome had the scientists been given an opportunity to study them. It is a pleasure to record that this policy of secrecy is now the exception, and that today cooperation and support are the rule.

In June, 1899, a serious disease appeared in the California fields which threatened to annihilate the new industry. During this year or the next it was found in every western beet region. Samples were sent to American and European scientists and a number of investigators began work on the problem. The dis-
case, which was called Western Blight, or California Blight, at first, was more severe in 1900 but much less so in 1901. It did not appear in the California section again in any amount for several years.

In the meantime much work was done and many attempts made to ascertain the cause of the trouble. Professor E. J. Wickson, F. T. Bioletti and Doctor Ralph E. Smith of the University of California, E. E. Smith of Stanford, E. M. Erhorn, H. Mendelssohn, N. W. Pierce, Doctor Albert Koebele, Doctor H. H. Behr and Doctor Gustave Eisen all reported their findings verbally or in writing* to the sugar companies. A number of European scientists reported on the samples sent; among them were Professor A. Herzfeld of Berlin, Professor Linhart of Hungary, Professor-Doctor Hallrung of Halle, and Doctor Bruns Steglich of Dresden. Their reports as abstracted by Linhart (1901)** and Adams (1909) furnish much of interest and information, but offer no solution of the problem.

The sugar companies of California, in co-operation with the State Experiment Station, started experimental work on the problem in 1905. Professors R. E. Smith and G. W. Shaw supervised the work which was carried on the first year by H. T. Ramsey and the second by T. F. Hunt.

In the spring of 1906 the Spreckles Sugar Company established an experiment station of its own and employed Doctor A. Wilhelmj and Doctor Schneider. A year later R. L. Adams took charge of this work and in 1910 Mr. George Scott succeeded him.

The United States Bureau of Plant Industry began investigations of this disease in 1900 and has continued to date.

The writer took up the problem for the Utah Experiment Station in 1905 and continued the work in co-operation with the United States Bureau of Entomology until 1908. Since that time the work has been continued on the larger aspects of the problem as opportunity offered. In this work nearly all of the western beet growing regions have been visited and many of them have been under observation through a series of years.

**REVIEW OF THE LITERATURE**

Considering the large number of scientists interested in this

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*See Adams, 1909.

**A complete bibliography arranged by author and date will be found in the back.
problem at one time or another, the amount of literature on the subject is remarkably small. This is no doubt due, in a large measure at least, to the fact that all of the results of the first five years and many of those of later date have been either indecisive or negative in character.

Linhart (1901) summarized and discussed the findings of the European and American scientists with reference to this disease. Different ones held that fungi, bacteria, insects, excessive hot winds, lack of potash, soil conditions and lack of moisture were contributing causes. The insect referred to was a coccid and the inference was from the large number of lady-beetles present.

Townsend (1902) gave a description of the disease and a figure of the dark rings of the beet. He agreed with Pierce that lack of moisture around the tap root was responsible.

Smith (1906) discussed the California outbreak of 1905 with description and figures and stated that this was a definite disease with characteristic symptoms and not simply an injurious effect of unfavorable conditions. Attention was called to its relation to the so-called physiological diseases of aster and tobacco.

Ball (1906) announced the occurrence of large numbers of Eutettix tenella Bak. which seriously damaged the fields of Utah in 1905, and stated that its punctures 'seem to cause a sort of thickening of the veins of the leaf and an unhealthy condition called 'curly-leaf' or 'blight.''' Attention was called to the fact that hot weather and other insect attacks might have weakened the beets so that they yielded more readily than they otherwise would have. It was noted that a related species caused the leaves of pigweed to become 'curly' and red and that the injury in both cases was entirely out of proportion to the number of insects.

Wilhelmj (1907) held that the beets absorbed injurious amounts of alkali salts while seeking moisture, if planted in a dry soil. If a heavy rain occurred a great number of side roots appeared to the detriment of the beet, which now blighted.

Ball (1907) in a monographic review of the genus Eutettix included a discussion of the curling effects of the attack of different members of the genus on beets. The life history of the
beet leafhopper was given for the first time and the stages figured. Different types and degrees of injury were figured, including the thickened or "warty" veins so characteristic of curly-leaf. Cage experiments were carried on with E. strobi Fh. demonstrating the production of leaf curls and red discoloration varying in seriousness of injury with the age of the beet.

Townsend (1908) described the symptoms of curly-top, discussed its occurrence, but included the disease described by Arthur and Golden from Indiana, although he noted that it did not fit the description in leaf characters. His statement that there is no record of a serious outbreak until 1900 must have been an oversight as the historic California outbreak was in 1899 and the first serious Utah trouble even earlier. He concluded that curly-top seldom appears two years in succession, again ignoring the 1899 outbreak.

He then discussed possible causes, taking up twenty or more theories and by negative evidence disproved each one. Realizing the limitations of this sort of evidence, however, he concludes, "Therefore, it can be stated with certainty only that the factors discussed are not responsible for curly-top under the circumstances and conditions under which the observations and experiments were made."

Ball (1909) brought together the results of the observations of 1905 and the details of the cage experiments of 1906. Cages were used to determine the life history and in an attempt to determine the number of leafhoppers necessary to cause the disease. He records that in a cage experiment, in July and August, sixteen leafhoppers stopped the growth of an eight-inch beet in a week, caused it to stand still for another week, and that it commenced to curl up and wither and finally died in a little over a month from the beginning; while the check beet more than doubled in size in the same time.

Adams (1909) gave a history of curly-leaf in California from 1899 on, reviewed all the work of the Spreckles Experiment Station from its beginning in 1905 to date, and abstracted the findings and conclusions of the European investigators employer at the time of the 1899 outbreak and later. He recorded the visit of the writer to the Spreckles laboratory, the caging of four Eutettix on a beet and the production of curly-leaf in the new
leaves, the first curly-leaf that had ever been produced in that laboratory. This paper contains many valuable records of early outbreaks and a long series of observations on the effect of different times of planting on the amount of blight.

Spisar (1910) reported the result of the examination of some beets sent from Idaho in 1909 and reviewed the writer’s paper (Ball, 1909). He concluded that the disease cannot be caused by the puncture of the insect (Eutettix tenella) alone, nor through the deposition of eggs, but agreed with the writer that there must be something injected analogous to that of gall-forming species in general.

H. B. Shaw (1910) presented the results of cage experiments in producing curly-top carried on in 1908, and discussed the relation of this disease to the mosaic disease and stigmanose. He also discussed the life history and habits of the insect, drawing largely (as credited in the introduction and elsewhere) from the writer’s publications.

Bunzel (1913) reported on the oxidase content of the leaves of curly-top beets and found it two to three times as great as in the normal beet, thus paralleling the conditions found in the mosaic disease of tobacco and the leaf curl of potato.

Adams (1913) summarized the present knowledge and recommended methods of preventing losses.

Smith and Bonequet (1915-a) confirmed the work of the writer as to the puncture of E. tenella being the cause of curly-leaf. By continuing the experiments they found that about two weeks were required after the puncture before the disease appeared under greenhouse conditions, and that a five-minute application was sufficient to cause the disease. Specific interior lesions were found in the phloem. A specific organism appeared to be a constant inhabitant of the tissues of curly-leaf beets, but only on the surface of healthy ones. Innoculations failed to produce the disease and the suggestion was made that it might be a co-agent with some other factor. They were able to transmit the disease by grafting wedge-shaped pieces of root carrying buds into the shoulders of healthy beets.

Bonequet and Hartung (1915) tested leafhoppers taken from wild plants on beet seedlings and could produce no curly-leaf. A part of these leafhoppers were placed on curly-leaf beets and
PLATE I

Fig. 1. A mangel seriously injured by curly-leaf. Fig. 2. A curled leaf showing warty veins and papillae. Fig. 3. Underside of leaf to show warty veins and veinlets (light spots are cast skins of beet leafhoppers).
after from three to seven days they were placed on other seedlings which then developed curly-leaf, while none of those which were not transferred produced the disease.

Smith and Bonequet (1915-b) confirmed their discovery of a specific organism in the sieve-tubes of curly-leaf beets. They were able to find this organism in the youngest and most minute vascular bundles of affected leaves. The same organism was found in lesions in a large number of curly-top conditions not caused by Eutettix tenella. They confirmed the experiments of Bonequet and Hartung and found that after feeding on a curly-leaf beet a leafhopper could not transmit the disease until after an incubation period of not less than twenty-four hours nor more than two days.

Bonequet (1916) reported the organism found in the sieve tubes "to be a most vigorous nitrate reducer." Tests of curly-leaf tissue disclosed the presence of nitrites and even of ammonia while tests of normal beets were negative for both substances. He determined the organism to be Bacillus morulas, n. sp.

**SYMPTOMS OF CURLY-LEAF**

The appearance of a beet affected with curly-leaf will vary greatly, depending upon the age at the time of attack, the number of leafhoppers and the weather conditions.

The one absolutely definite symptom in all cases and the first to appear is the thickening and distortion of the veins of the young growing leaves, giving a rough, warty appearance to the under side. (Pl. 1, fig. 2.) The enlargement of the veins causes these leaves to curl up at the edges, bringing the roughened under-side into view. (Pl. 1, fig. 2. Pl. 2, fig. 3, 5 and 6.) Knot-like swellings and nipple-like papillae arise at intervals on the veins and even on the most minute veinlets, especially at the junctions. (Pl. 1, fig. 2. Pl. 3, fig. 10.)

If the beet is well established or the attack mild, the leaves will roll up separately and remain that way. If the beets are attacked before or at thinning time and the weather conditions are favorable, the whole top of the beet may become dwarfed and thickened, the stems curve upward and inward with more or less folding of the leaves, forming a fairly compact lettuce-like head (Pl. 2, figs. 4a, 6, 7 and 8), which usually turns a
sickly yellow, shrivels and dies. Where these extreme conditions are common the stems may turn dark, crack open on the curves and a sweet, dark liquid exude from them and even from the midribs of the leaves. This liquid becomes sticky and attracts flies and in many cases sugar crystallizes out and forms scales along the margins.†

In most cases there is an increase in the number of fine rootlets, often to such an extent that the entire root becomes "woolly" (Pl. 4, fig. 3), and when pulled a mass of dirt is held by these roots. Cross-sections of the beet root often show concentric dark circles from the darkening of the fibro-vascular bundles.

DISTRIBUTION OF CURLY-LEAF

This disease has appeared in every western state* in which sugar-beets have been grown, from Nebraska and Kansas west to the coast, as shown by Fig. 1. Townsend (1908) and Shaw (1910) quote Smith as concluding that the disease described by Arthur and Golden** from Indiana was the same as the west-

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†This sticky juice often attracts adult lady-beetles in large numbers, possibly because it resembles honey dew. These swarms of lady-beetles have misled different investigators into the belief that there had been some honey dew-secreting insect on the beets previously and that the lady-beetles had completely cleaned them up. This no doubt accounts for the suggestions that plant lice or coccids were responsible for the condition.

*The writer, in previous publications (Ball, '09), was in doubt as to whether the serious California outbreaks had been due to curly-leaf or to some other form of curly-top. Visits to the state previous to that time had all been made in years in which there was little blight of any kind in the regions visited, and the major portion of that found was due to other causes than the beet leafhopper. The conditions found at Corcoran in 1909 and over the entire northern section in 1914 left no doubt of the cause of the earlier outbreaks.


ern curly-top. This seems to have been an error in interpretation of Smith's conclusions, as curly-top was not known at that time. The thickening of the veins, the one definite character of curly-leaf, did not occur and the outbreak is so far beyond the probable distribution of the leafhopper or even of its pos-

![Fig. 1. Map of the western states, showing regions in which curly-leaf has appeared.](image)
sible flights as to make the connection very doubtful. Until curly-leaf has been recognized east of the Mississippi by someone familiar with it, this locality ought not to be included.

The map (Fig. 1) shows the distribution of this disease as far as it has been possible to obtain it with accuracy. Sugar-beets were tested in small plots in practically all parts of these states for a period of years, ending about 1900. There were, no doubt, many cases of curly-leaf in these localities, but in sending in samples only the best beets would be sent and few would have been able to recognize it even if present. Curly-leaf is one of the limiting factors in successful sugar-beet production, and it is unfortunate that one of the most valuable parts of these extensive tests was entirely lost.

The occurrence in the larger areas will be discussed under
separate heads. Cases of curly-leaf outside of commercial sugar-beet areas have been observed by the writer on a test plot of the experimental arid farm at Nephi, Utah, and on mangel lands at St. George, Utah. Prein reports seriously blighted sugar-beets at North Yakima, Washington. Cort and Packard* report blight in test plots in the Imperial Valley, California, and it has been recorded from the experiment station at Amarillo, Texas.

SEASONAL OCCURRENCE OF CURLY-LEAF

Great difficulty has been experienced in obtaining definite records of the prevalence of curly-leaf in the different areas. Early records are in most cases doubtful at best, as the specific nature of the disease had not been recognized and everything was indiscriminately called blight or blamed on drought.

On Figs. 4 and 5 the proportional seriousness of curly-leaf injury in the different years is shown in a series of curves. These curves are not intended to represent the proportional total injury from year to year, but only that occurring in the most seriously-damaged locations. Owing to the widespread distribution in the worst years, the proportional injury would be much greater than that shown.

CALIFORNIA

Curly-leaf rarely appears in the regions along the coast, where fogs are prevalent, but as one passes to the interior points it becomes more frequent and seems to be somewhat proportional to the temperature encountered. There used to be more trouble from this disease in the southern district until they began planting in November and December, thus bringing the beets up to good size before the hot season.

The district around Lake Tulare had trouble nearly all the time, from the opening in 1906 until the factories closed down. The actual record there is fragmentary, but every time an examination has been made blight has been found, the amount of damage being inversely proportional to the distance from the lake. The crops close to the lake have always been badly affected, but beet production in this district has never been successful and curly-leaf seems to be one of the limiting factors.

*Bull 184, Cal. Exp. Sta. 1911.
The King City district has suffered more from this disease than any other district in the state. Curly-leaf was more continuous at Corcoran (Tulare) while the factories were running, but the King City district has raised beets much longer and has had a greater acreage. It is safe to say that when there was any curly-leaf in the coast region of California, King City had its share. In the three serious and widespread outbreaks that have occurred in California this district would have about three years of trouble while the outlying regions had only the one. The years of widespread trouble were 1900, 1905, and 1914, and in each case the King City district had an attack the previous year and often a slight one the year before that. Small outbreaks on certain planting have occurred in other years, the most definitely-recorded one being in 1909.

The outbreak of 1899 spread to practically all the regions then growing beets except along the fog belt of the coast and did serious damage in all the hotter, drier districts. The southern region had even more damage in local areas and special plantings in 1900 and the Spreckles district also suffered worse. From that time on little curly-leaf occurred except as above mentioned, until in 1905 when all of the northern districts were very seriously affected, many thousands of acres being abandoned and most of those harvested giving low yields. The southern districts had by this time generally adopted November-December planting and were not so seriously injured. No serious general injury occurred from then until in 1914 when the entire northern region, now including the Hamilton district, was again seriously attacked. This outbreak came very early in the season and, even before thinning, thousands of acres were abandoned. Late plantings in the northern district escaped with only minor losses and the fall plantings in the southern region were not seriously affected. All plantings in the San Bernardino district were seriously injured.

UTAH AND SOUTHERN IDAHO

Curly-leaf appeared in 1898 and 1899 and did considerable damage to the beet crops of the Lehi and Ogden factories, the only ones in the state at that time. There is little definite information about this outbreak, as it was given no publicity and
apparently no scientist visited the region during that time. Some accounts trace the beginning as far back as 1897.

Curly-leaf appeared in the Sevier Valley again in 1903 and caused a loss of less than one-third of the crop. The next year the area was greater and the loss nearly two-thirds of the crop, while in 1905 the crop in this valley was almost a total loss, the disease spreading northward into all sections of the state, and on up the Snake River district into Idaho. The loss in the central part of the state was nearly half the crop, while in the northern portion it ran down to about one-third and even less than that in the southern Idaho district. The next year was quite different climatically and practically free of the disease. A very slight attack appeared in Sevier in 1908 and quite a serious one locally in a few sections in 1911 with less in 1912. The 1911 outbreak appeared in certain areas as far north as Ogden. In 1914 a small amount of curly-leaf appeared again in Sevier, followed in 1915 by a remarkably early and severe outbreak that threatened the destruction of the entire crop and rapidly spread throughout the state and up into southern Idaho. A cold wet spring and an early summer prevented the injury and saved the crop except in certain districts in the Sevier Valley in which it had already gone too far. A hot wave late in the season allowed considerable late injury to develop throughout the state but especially serious in the Sevier Valley.

WESTERN COLORADO

The record of curly-leaf for this district is only fragmentary and would not be comparable in any case as the beet-growing district has been shifted from one region to another several times. The Grand Junction factory started in 1899 with the beets grown on adobe soil adjacent. There was some disease in that year, but no definite record of how much. The next year when the writer visited there late in the season there was said to be less than in the previous year. No beets were grown for the next two years and only fragmentary records of disease conditions are at hand for the following years. There was a serious outbreak in 1905, and quite a little in 1911. The year 1915 started out as in Utah and as the temperature was higher the disease did more damage.
THE COLUMBIA AND LOWER SNAKE RIVER DISTRICT

A large number of test plots were grown in the Yakima Valley in 1905 under the supervision of P. J. Prein. The test plots in all parts of the valley developed serious curly-leaf conditions in June and by July were mostly abandoned. Some tests at Ellensburg were not so badly affected. Mr. Prein visited the valley in the fall of 1904 and found a small field of beets that had been seriously injured by the disease. The writer found the leafhopper swarming on Atriplex and Russian thistle at Pasco and North Yakima in 1909 and common as far up as Wenatchee.

Beets were grown in the Nampa region some time before the factory was built and suffered with curly-leaf in 1905. This factory started in 1906 and this year the crop was exceptionally free from disease here as well as in all the adjacent western region. The next year there was some injury and it grew steadily worse until crop failures closed the factory at the end of 1910.

The LeGrand Valley factory started in 1897, but no record is at hand of conditions, except that there was "more or less blight every year" up to 1904 when Professor Titus reports serious injury in fields at Echo. The 1905 epidemic was reported from here, although the information is not definite as to amount. There apparently was little or no injury in 1906 and only a little in 1907. In 1908 the injury was widespread and serious in the worst regions, and in 1909 a little less serious, but sufficient so that for this and other reasons the factory closed at the end of another year.

THE ARIZONA DISTRICT

Beets were grown in this district for a number of years before the factory started, but there is no satisfactory record of their condition. The factory at Glendale was started in 1903, but was not operated until in 1906, then only in short runs for two years, and it was closed again for two years more. In 1910 it started again and there was a serious outbreak of curly-leaf that year and the next, while in 1912 very little appeared.

THE FALLON, NEVADA, DISTRICT

This factory has had a serious time with crop failures,
which blight has been reported as one of the causes, but no definite statements are at hand to indicate just how severe or how often the disease has appeared.

THE COLORADO-NEBRASKA-KANSAS DISTRICT

The Grand Island, Nebraska, factory started in 1890 and shipped beets from the northern Colorado districts until the Loveland factory was built in 1901. Hedgeeock reports (in correspondence) that blight appeared in the Grand Island region in 1900 and again in 1901, in the latter year occurring over a wider area, but not so serious as at Grand Island the year previous.

The factory at Rocky Ford was built in 1900 and the next year a small amount of curly-leaf appeared in the Arkansas Valley region. In 1903 the disease was quite serious in the whole southern Colorado section, extending down into Kansas.

In 1908 curly-leaf started very early in the Arkansas Valley region and finally spread to include the entire Colorado-Nebraska-Kansas district, being very severe in the Arkansas Valley and lighter in the northern part of the state. The average production of the state was the lowest yet recorded.

THE BEET LEAFHOPPER

This insect (Eutettix tenella) was first recorded on sugar-beets by Gillette and Baker (1895), who found it at Grand Junction. In August, 1900, Professor G. W. Shaw called the writer's attention to curly-leaf in fields at the same place. An examination showed the presence of this leafhopper along with a few others, and it was so recorded, but no significance was attached to the coincidence at the time. On July 8, 1905, the writer in company with Superintendent George Austin visited the beet fields around Lehi, Utah, and found the leafhoppers occurring on the beets everywhere, but especially abundant on the fields where the curly-leaf or blight (as it was then called) was the worst. As a result of these observations, and of others made throughout the state that year, the announcement was made (Ball, 1906) that its punctures caused curly-leaf and the insect was named the beet leafhopper.
DESCRIPTION OF THE DIFFERENT STAGES

The adult of this leafhopper is a tiny, creamy or greenish-white insect, changing as it grows older to a straw color or even has a reddish tinge. It is about one-eighth of an inch long and only about one-fourth as wide. As it flies readily and can leap long distances, it is rarely seen unless occurring in numbers or unless the observer is trained to the task.

The egg is pale, greenish-white, long and slender, slightly curved and so minute that it can scarcely be seen without a glass. The eggs are placed in the stems or large veins of the leaf and are shoved obliquely backward and downward through the epidermal layer where they often adhere to it when it is stripped from the stems. A few are pushed in so deeply that they are partly or wholly imbedded in the deeper tissue. More of them will be found in the outer angles of the stem than in any other location, and they will usually remain there when the epidermis is stripped off.

The larvae are at first white and hairy and so tiny that they are scarcely visible, but as they grow they look like the adult except that they do not have wings. They may remain white or develop an irregular pattern or "saddle" of brown or red on the back of the thorax and abdomen. They can leap with surprising agility and are rarely seen unless approached with caution.

THE LIFE HISTORY

As has been pointed out (Ball, 1907), this is a single-brooded species, and egg laying extends through a long period of time, so that the earliest larvae often mature before the last eggs are laid. This long egg-laying period makes it hard to give limits to the different stages and has often led observers to conclude that there was a rapid succession of broods when instead there was only the one.

PLATE III

Fig. 1. Adult beet leafhopper, 1a, male genitalia, 1b, female genitalia.
Fig. 2. Typical larvae. Figs. 3, 4 and 5. Variation in color and pattern of larvae. Fig. 6. Stem of beet leaf with epidermis partly rolled back to show position of eggs. Fig. 7. Eggs magnified. Fig. 8. Eggs ready to hatch, protruding from a shrunken stem. Fig. 9. Egg scars on a shrunken stem. Fig. 10. Under-surface of a typical curly-leaf attacked leaf, showing swollen and irregular veins and nipple-like papillae.
Fig. 2. Life history chart of Eutettix tenella and E. strobi on beets.
Another mistake often made is in calculating the number of broods from the length of the season. In this way it would be easy to conclude that there were two or even three broods at Glendale, Arizona, for it will be observed (Fig. 2) that the larvae appear there in March while they do not appear in Utah until in June. There is, however, no longer time elapsing between the appearance of the larvae and the harvesting of the beets than there is in Utah. The temperature would probably be higher in Arizona and the development of the insect slightly more rapid, but this would also influence the maturity of the beet.

In general, the adults appear suddenly in a region at a time when most of the beets are up and in a few days will be found distributed over the field in fairly uniform numbers. If there are no later flights, beet fields that were not up at this time will have very few leafhoppers until late in the season. The adults commence to feed on the beets at once and, if the season is sufficiently advanced and the weather warm will begin to lay eggs within a few days and continue to do so for a long time. If the weather is cold, egg laying may be postponed for some time. The eggs hatch in about 15 days at that time in the season and the larvae mature in about 20 to 25 days more, so that the first fresh adults of the season’s brood may appear, under Utah conditions, in from 40 to 50 days after the adults appear in the spring, while the last ones of the brood may be nearly two months later.

On the average, the adults appear after the earliest beets are thinned and the larvae do not become numerous until the beets are touching in the row but not across rows.

Figure 2 shows graphically the average time of appearance of the different stages in the different regions, the heavy line representing adults and the light line above, the larvae. At the bottom of the chart is shown the same data for E. strobi, a two-brooded species also occurring on beets to show the contrast between the long, indefinite and overlapping periods of a single-brooded species as compared with the short, definite broods of a two-brooded one.

DISTRIBUTION OF THE LEAFHOPPER

The leafhopper has been found over a very wide area in the
west, and southwest, extending into Mexico* for some distance at least. The single ruled area in Figure 3 shows the extreme limits of the known distribution in the United States. Over a very large part of this area, however, the insect is never found except in times of great abundance and damage on beets. In other seasons careful search over its favorite haunts will fail to reveal a single example, indicating that it does not normally occur over this entire area.

Very little is known as to the actual boundaries of the normal breeding area, and on account of its periodic flights it will require repeated explorations in years of abundance and periods of scarcity before they can be definitely mapped. Enough has been done, however, to eliminate certain areas as definitely out of the continued breeding range and to indicate in a general way that others are to be included.

*T. H. Jones in U. S. D. A. Bull. 192, p. 2, gives Eutettix tenella Bak. as feeding on beans and other small crops in Porto Rico on the authority of Barrett. This is apparently an error. Barrett referred to the insect in question as Agallia tenella Ball; he probably meant Agallia nevella Say.
THE BEET LEAFHOPPER

EAST OF THE ROCKIES

It is certain that it is not normally found in this region as far north as Denver and probably not as far even as the Arkansas Valley, although the serious outbreaks there indicate that it breeds within a reasonable distance. In the same way it is not found breeding in any of the beet-growing areas of Utah, but the serious outbreaks at Grand Junction, Colorado, and in the Sevier Valley, indicate that these areas are close to the border of the permanent abode.

From collections made and other information obtained it is probable that it breeds in the more arid regions of Texas, New Mexico, and Arizona, and extends considerably north of the line of these states in favorable locations, with one isolated area in the Columbia river region. In Fig. 3 an attempt has been made to show this by cross ruling. The estimate of the northern limits can at the best be only a rough guess, depending on the length of their range of flight, which is at present unknown. This line may be a variable one, extending further north for a few years after a flight and being gradually pushed back by unfavorable seasons. No attempt has been made to eliminate the mountain areas in this ruling, but the insect will not be found breeding at any great elevations.

While the leafhopper no doubt breeds in suitable places on large areas of the arid regions, as indicated by the cross ruling on Fig. 3, the information at hand is only sufficient to fix in a fairly definite way three areas from which it has been known to spread to the beets. These areas are double crossed in the plate and roughly represent the Pascoe-Yakima area in Washington, the Escalante Desert in Utah, and the Lake Tulare region in California. There must, of course, be others and no doubt are many worse centers than these, but their comparative distance from present sugar-beet areas may be greater.

THE INTERMOUNTAIN REGION

The occurrence of curly-leaf in the Sevier Valley, where there is a low pass over the mountains, and again in Salt Lake Valley and Bear River Valley—close to low passes, suggests strongly that Utah infections come from the Escalante desert region, and the finding of the beet leafhopper fairly thick in several places
in the desert appears to confirm this. The only difficulty with this conclusion is that these hoppers in the desert may have been from swarms that flew in there from still more distant regions. The greater severity of the curly-leaf in the Sevier Valley, although on account of its elevation it is no warmer than other beet regions farther north, also points to this desert as the source, as this valley is much closer to the desert than the other regions and the hoppers always appear here in advance of those in the northern regions. Cache Valley, the most distant from this desert, is always the latest to be infested.

The most striking evidence of the source of infestation, however, is the boundary of the blight area in the Sevier Valley region. The worst blight always appears in a long, narrow strip extending from a point between Elsinore and Monroe, on through Austin and Sigurd to Salina, which is almost in the direct line of the air drainage over the pass from the desert. The beets in this path have several times been severely injured or destroyed when very little injury was done to those on the side, especially those more or less sheltered by projecting mountain masses.

**THE CALIFORNIA REGION**

Except in periods of abundance the beet leafhopper is not found in the region along the coast from San Francisco south to the Mexican border. The same condition prevails in the inland regions north of Sacramento. On the other hand, the leafhoppers have been found breeding in abundance on the native Atriplex in the Lake Tulare region each time a visit has been made. Curly-leaf has been seriously destructive in this region ever since beets were introduced. This district extends down as far as Bakersfield and the same conditions are probably repeated in suitable areas in the Mojave Desert and Death Valley sections. The leafhoppers were found commonly in the Imperial Valley, and it is probable that this whole region is within the permanent breeding grounds and is the source of the California troubles.

If the above is true it would easily explain why King City had more blight trouble and worse infections than any other place on the coast region. King City is the nearest beet-growing point to this region, and is in direct line of air drainage between Monterey Bay and the low pass over into the interior,
This would explain why the leafhopper always appears earliest at King City and later at Salinas and further north.

Chino has had more blight than any other place in southern California until recently beets were planted at San Bernardino with the result that they blighted still worse. A glance at the map (Fig. 3) will show that this is just what the relative locations of these two places, with reference to the interior deserts and the probable breeding grounds, would lead anyone to expect.

**THE COLUMBIA-SNAKE RIVER REGION**

One of the most difficult problems in attempting to explain the blight outbreaks in the past has always been the serious and prolonged outbreaks at Nampa and LeGrande when there was no trouble in the southern Idaho or Utah regions. If the leafhoppers flew north, as we had argued, then this region should have been the last to be affected.

What appeared to be a solution of the problem was discovered when it was found that the leafhoppers were swarming on the native Atriplex in Pendleton, Oregon, and even worse at Pasco and North Yakima, Washington, extending up the Columbia at least to Wenatchee. This gave a new center of dispersal and established the fact that the blight attacks of this region were not necessarily coincident with those of the Utah region, where the hoppers came from an entirely different source. The climatic conditions of the two regions are so different that there is little wonder that severe outbreaks occurred at different times.

The whole subject of distribution needs much more investigation. The permanent breeding grounds can only be definitely located by following up the investigation from season to season, including ones where flights are being made and others during times when there is no damage occurring except in permanent places or closely adjacent regions.

**THE FOOD PLANTS OF THE BEET LEAFHOPPER**

Little more is known in regard to food plants than was previously reported (Ball, '09). The insect has been found feeding upon greasewood (Sarcobatus), Russian thistle, sea-blite (Don-dia), shad scale (Atriplex confertifolia) and several species of
annual Atriplex. In the Coast and Columbia regions especially. It has been found most abundantly on a small, reddish, heavily-seeded, small-leaved species of annual Atriplex (A. tularesensis), which grows abundantly in the interior valleys of California. Next to the Russian thistle, this plant harbored more leafhoppers than anything else. The greasewood has been carefully watched in all regions where it occurs, and very few hoppers have been found on it at any time; it, therefore, is probably not the original host plant, as suggested. The tall rank-growing annual Atriplex with halberd-shaped leaves, so common in the intermountain regions, has never been found to harbor the insect.

Shaw (1910) cites this leafhopper as feeding on dock (Rumex), growing in a badly-infected beet field and causing circular wine-colored spots. This is probably an error as these spots are often found when there are no beet leafhoppers in the region. Shaw (1910) also cites a case where they fed on cabbage growing near an infested field and produced the thickened veins. This is also doubtful as there are varieties of lettuce and cabbage that show this vein symptom normally, and the cabbage leaf on the outside where the leafhoppers could feed on it, would not be the one to blight, if the results in the sugar-beet are any guide. It has also been reported as feeding on and producing the swollen veins on horseradish, but the condition referred to is common where no leafhoppers occur. Shaw (1910) also infers that they are found in "sage brush country." In all the writer's observations they have, however, never been found on sage brush or in a sage brush area.

The beet leafhoppers prefer sugar-beets to other cultivated varieties, but will seriously injure mangels (Pl I, fig. 1) and even table beets.

THE FLIGHTS OF THE LEAFHOPPER

No one has ever seen a flight of these leafhoppers, as far as the writer is aware. Yet, the fact that they do fly in immense swarms for long distances and over mountain ranges of great height, is fairly well established by other facts. The writer has found them in abundance on the snow on Pikes Peak above 14,000 feet and has captured examples on the Beaver mountains at 12,000 feet. They were seen swarming near Panguitch, Utah,
at an elevation of 7,000 feet, just at the time the immense swarms swept over the beet regions of Utah in 1915. They were first observed in the evening just as the sun was setting and at this time were flying around and hovering over a little patch of young pigweed. The next morning they were there in numbers, but quite sluggish with the cold. When this patch was visited a little later they were gone and none could be found in the valley. This was the first and only time they were ever seen in flight, except as individuals fly when approached; in this case they paid little attention to the observers. This has been interpreted as an evening rest while migrating as the mountain valley is above the limit of beet raising and no doubt above the limit of their breeding range, but is located in the approach to a mountain pass leading over to the southern desert and these swarms were no doubt passing over the mountains.

The fact that leafhoppers appear suddenly in great numbers, fairly evenly distributed over wide areas, wherever there are beet fields and are not found in any numbers on other fields, indicates a different means of dispersal from that of ordinary hibernating insects. Their appearance and uniform distribution over new areas where beets had never been grown before at the same time they appear in the old fields could not be accounted for in any other way. Shaw (1910) suggests that crop areas where beets are not grown would act as a barrier to invasion. The spread of swarms of this insect over an area from three hundred to four hundred miles within a period of two to three weeks makes the feasibility of any ordinary barriers very doubtful. Such cases of wide distribution of the insect over areas where it had been extremely rare or absent the previous year have occurred in the Colorado-Nebraska region, the Utah-Idaho region and the California region. In these flights no difference has been observed between new beet areas and old in the number of hoppers present. If these hoppers went into hibernation from local beet areas, their spring distribution should either coincide with the beet areas of the previous year or else with the favorable hibernating region.

Fields not more than a week or ten days apart in time of appearance may be very differently affected. The older beets may have a large number of leafhoppers uniformly distributed,
while the younger beets have only a comparatively small number also uniformly distributed. These facts indicate that there is little redistribution after a satisfactory location is found. It also indicates that the members of a swarm passing over a beet district either find the beet field at once and settle down to stay or else pass on out of the region.

Several instances have been observed where beets at the base of a mountain slope have been more seriously affected than those in the surrounding regions. This may be due to the lighter soil and more sheltered situation which are favorable to its development, but in several cases it has appeared probable that swarms passing over a region before the beets were up, had been prevented by fogs or storms from passing on over the bordering mountains and that a few had turned back and later settled down on the first beets they found at the base. This condition has been found in a field back of Salinas several times, and here the coast range mountains are often covered with fog when the valley is free. A similar condition was found west of Tremonton in 1905 and the local trouble at Garland in 1908 (Shaw, 1910) may have been of this type. Taken all in all, the theory of periodic flights accounts for the distribution, as far as known, much better than any other explanation offered.

We need, however, to know where the centers of dispersal are located, whether flights from these regions take place each season or only in seasons of abundance, whether there is only one flight or a succession of flights from a region, and whether these flights are in all directions or in whatever direction the wind happens to be at the time. It may be that these flights are in the nature of migrations northward in the spring and southward in the fall. Again the flights may go with the wind, but the wind from these areas may have a fairly definite path at that season of the year. The fact that they are found on the snows of mountain tops may indicate that their flights are so high as to be governed by upper air currents rather than lower, and may also explain why flights have never been observed.

**TIME OF APPEARANCE OF SWARMS**

Flights have occurred in the Salinas Valley in California and the Sevier Valley in Utah at different times in different seasons and apparently in some cases at different times in the same
season. The history of the flights of the Rocky Mountain locust is very similar in this respect. Sometimes swarms would appear early, sometimes late, and often several different swarms would appear in a season.

Adams (1909) records a number of observations and a long series of experiments on time of planting in different places in the Salinas Valley. The early results are somewhat obscured by the fact that they did not at first have a clear idea of the curly-leaf as a specific disease and included other factors, but wherever "blight" is mentioned as occurring in any amounts it can be depended upon as an indication of the presence of the leafhopper at some earlier period.

In 1900 plantings made before April 20 at King City all blighted while those planted later did not, indicating that flights were over before May 1 that year.

In 1905 all plantings blighted while very young at King City, including those coming up late in May, indicating that there were early flights and either redistribution on to the late plantings or else that flights occurred as late as June 1. As we have other records of single flights in this district occurring later than that, the latter inference is probably correct. A planting made late in May at Spreckles did not blight while others did, indicating that this late flight did not extend that far north.

In 1906 at King City plantings made in December (1905) and January showed little blight, while plantings made near the middle of March, April and May blighted severely. The April one began blighting soon after thinning and the May planting before thinning—both were failures. These figures indicate that known flights came in that year as early as April 10 and as late as the last of May. That they did not fly much later is indicated by the fact that plantings made May 22 and 31 at Soledad and June 3 at Spreckles did not show much blight while all earlier ones in these localities did.

In Utah in 1905 several swarms must have appeared in the southern part of the beet district, as the earliest beets were blighted soon after thinning, while the latest planted ones were affected before they were old enough to thin, indicating that there were two or more flights; otherwise, some beets would have escaped. Curly-leaf did not appear in Cache Valley until six
weeks later than it did in the south, and by this time the earlier beets were large enough to shade the ground and were only slightly affected while the later ones suffered severely.

In 1906 the leafhoppers came into Sevier county early in June and late plantings that were not up sufficiently at that time to attract them were not infested so there was probably only one flight that year. They came into the Lehi fields soon after June 1st, but again late fields were not infested, indicating that there was but the one flight, and that it reached both places within a few days of the same time.

In 1915 the Sevier Valley fields that were up before May 1st were badly blighted by the middle of June while fields that were up two weeks later were comparatively free. The swarms reached Salt Lake Valley before May 20, as beets not up until after that date were not infested. In Cache Valley they were first noticed about June 1st, and in a few days could be found in abundance in every field then up. Later fields were never infested. From these records it will be noted that the leafhoppers appeared in the Sevier Valley a month before they did in Cache Valley, 220 miles to the north.

PERIODICITY OF OUTBREAKS

The determination of the periodicity of insect outbreaks in general is one of the most important problems before the entomologists today. In an insect like the beet leafhopper, where the use of remedial measures after it has once punctured the beet may be of little value, the determination of the factors that control its periodical appearance become doubly important and warrant extended study.

In Figs. 4 and 5 all the information at hand, with reference to the periods of abundance and scarcity of this insect in the different areas, has been brought together and plotted as curves. All localities that appear to have been affected by the same factors have been grouped together and the curve represents the comparative seriousness of the outbreak of curly-leaf in different years in the worst affected locality in the area. Usually the extent of the infection is roughly proportional to the height of the curve so that the greater portion of the area would only be affected in the years in which the curve was at or near its maximum.
Outbreaks no doubt occurred before 1898, but unfortunately there is no record of them. About 1890 sugar-beet growing began to spread in the western area and within a few years sugar-beets were either being grown commercially or were experimentally tested in nearly every available region between Nebraska and the coast. It seems, therefore, almost certain that no serious widespread outbreaks like the 1899 one or the two that have occurred since appeared between 1891 and 1898. There may have been and probably were flights of leafhoppers during this period or even since 1900 that were not observed, for even a large flight of leafhoppers followed by cold, wet weather in which little blight developed would not have been recorded.

It must be remembered then in interpreting these curves that they may not represent all the flights of the leafhoppers, but only those that occurred in comparatively hot and dry periods. The records of the King City, California, region, however, may be considered to be complete because their summer season was always sufficiently hot to develop blight if the leafhoppers were present. In the same way the Utah record is probably complete, as the writer began work in the spring of 1903 and any abnormal occurrence of leafhoppers after that date would have been observed.

In studying these curves a very definite agreement in the serious outbreaks is observed between the California coast and the Utah areas. The three periods of serious trouble coincide almost exactly while the fragmentary records from Grand Junction indicate that the same periods were repeated there.

This agreement indicates a widespread influence of some sort—just what that influence may be is problematical. It cannot be strictly climatic, for while the 1899 and 1905 blight periods were hot seasons, other seasons were equally hot in which no blight occurred. The problem is complicated by the fact that we do not know for certain where the swarms came from that infested any of these regions and, therefore, cannot say what the climatic conditions were in their breeding grounds.

On studying the curves for the Nampa and LeGrande areas, the 1905 outbreak followed by the entire disappearance in 1906 is very similar to the Utah and California curves. From that time on the blight grew rapidly worse until the factories closed
Figs. 4 and 5. Showing the periodic occurrence of outbreaks of curly-leaf in the different regions. (Note—The curve shows the comparative amount and severity of the blight in the worst section of each area only.) The total damage in the worst years would be
proportionally much greater than that represented by the curve. The names of the older factories in each area are inserted in the year in which they were built. These names have no reference to the curves, nor to the occurrence of the disease.
at the end of the 1910 run. The Glendale curve was interrupted by the absence of beets, but probably belongs in a similar class. The fragmentary curve from Corcoran, together with the known record of the factories there, suggest that in these four regions blight is the rule and that a year when it would be absent, the exception. As has been suggested, these regions are probably within the breeding range and do not depend upon flights for their infections.

The record for the region east of the Rocky Mountains is not as complete as could be wished, but there have been only two serious outbreaks, and these have not coincided with any curves from west of the mountains. This suggests that the source of the flights of leafhoppers to this area is from a different region under different influences from the source of the western flights.

We have then, apparently, two different types of areas—one in which the blight is the rule and in which sugar-beet growing has not succeeded, and another in which outbreaks of blight are the exception and appear only periodically. To this class belong the very best producing beet regions of America and in these areas the industry will continue to develop.

Any information by which the probable occurrence of these periodic outbreaks could be foretold would, therefore, be worth millions of dollars to this industry. This information can only be obtained by long and careful study of the habits and reproductive power of the insect on its native food plants and in its natural breeding range. As both the extent of its food plants and the limit of its breeding range are still in doubt, the problem is a complex one.

**PECULIAR NATURE OF THE CURLY-LEAF DISEASE**

A puncture of the beet leafhopper is absolutely necessary to cause the disease to develop in the beet. Under favorable conditions Titus found that a very short application of a single insect would produce the disease on a young beet. Smith and Boncquet (1915) found that a single hopper applied for five minutes on an eight-leafed beet produced the disease.

The disease never appears on any but growing leaves and usually on the younger ones first. Thus it is rare that the leaf which is punctured is the one to show curly-leaf first. As long
as conditions are favorable blighted leaves continue to appear unless the disease becomes so severe as to entirely stop the growth of the beet. If all the leaves are cut off the new ones will appear with the characteristic symptoms. If the beet is planted the following year to raise seed the disease will again appear.

On the other hand, if conditions are not favorable the curly-leaf may not appear at all, almost regardless of the number of leafhoppers and length of time they feed upon it (Pl. IV, fig. 2). When conditions change widely during a season, the development of curly-leaf will often change accordingly. A beet starting to blight early in the season may, under cold and wet conditions, develop a number of healthy looking leaves and still later, when hot weather has returned, put out others badly curly (Pl. 2, figs. 4 and 4a). Often a beet that showed no curly-leaf symptoms the first year will blight as a mother beet planted for seed raising. In one case a strain of beets whose vitality had been lowered blighted much worse than normal beets along side of them. The disease never spreads from beet to beet except as it is transmitted by the leafhopper. All attempts to transfer the disease by inoculation have failed. Smith and Boncquet (1915) were able to transfer the disease by grafting in a section of the shoulder of a beet containing a bud.

DOES THE PUNCTURE OF THE BEET LEAFHOPPER CAUSE CURLY-LEAF?

The writer had at hand in 1906 so much evidence pointing unquestionably to the conclusion that the curly-leaf condition was due to the puncture of Eutettix tenella that this was announced as a fact without extended discussion in the brief space allowed in an annual report (Ball, 1906). The two succeeding papers (Ball, 1908 and 1909) were both prepared in 1907 before any controversy had arisen, and so while most of the facts were brought out in the discussion that feature was not emphasized.

This conclusion was accepted by most of those then engaged in the work, with the exception of Townsend (1908), who expressed doubt. The writer immediately took the matter up with Dr. Townsend’s assistant, Mr. Shaw, in charge of sugar-beet in-
vestigations in Utah. The whole matter was gone over and the cage experiments and other evidence explained with the result that Mr. Shaw became convinced that the statements were true and assistance was given him in planning cages and in determining material, so that he might duplicate the experiments and convince his chief. This he succeeded in doing.

Acting under suggestions no doubt, this work was later published (Shaw, 1910), and the writer's work reviewed in such a way as to omit all reference to the cage experiments. Shaw by limiting the writer's work to "wide field observations" and suggesting that Dr. Titus' results were accidental, laid the foundation for the claim that he had been the first to prove the connection. As this ignores the workers of the Utah station, including Dr. Titus' and the writer's careful experiments, as well as a mass of supporting evidence practically conclusive in itself, it seems worth while to discuss separately the published evidence available before this claim was made.

**PROOFS AVAILABLE UP TO JANUARY, 1908**

The writer as the result of long experience in the study of leafhoppers* and their relation to plant injuries was able within a short time after his attention was called to the outbreak in July, 1905, to determine that the injury resulted from the puncture of the leafhopper. Attention was called at the time to the fact that it was not due to the sap extracted, but to the condition produced (Ball, 1906), which was likened to the process of gall formation in plants (Ball, 1908). This conclusion was based on the following facts which were then known, or were determined during the season:

1. Eutettix tenella belongs to a group of leafhoppers that produce distortions of the leaves of their native food plants. (Osborn, 1897), (Ball, 1907).

2. Three of these species had already been observed to pro-

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**PLATE IV**

Fig. 1. Beet field allowed to grow up to weeds; the only field in the region not badly blighted. Fig. 2. Cages in which leafhoppers were kept for four weeks during exceptionally cold, wet weather. (Note that plants did not blight.) Fig. 3. A typical "woolly" beet. The mass of fine roots holds the dirt.

*Thirty papers had been published up to that time. This paper will probably be number 45.
duce curling and distortion of beet leaves. (Ball, 1907 and 1909).

3. This leafhopper has been found feeding and breeding only on members of the beet family.

4. Curly-leaf occurs only in fields in which the leafhopper is found and the amount of injury, other conditions being equal, is proportional to the number of leafhoppers and the age of the beets.

5. The curly-leaf conditions occurs only in the area inhabited by this leafhopper.

6. The individuals of these curl-producing leafhoppers are known to remain on a single plant throughout the season unless disturbed.

7. Where only an occasional beet in a field is blighted, it is usually possible to find the leafhopper on this particular beet, and if larvae have been produced the egg scars and cast skins will be found, while on healthy beets no trace of the insect is observable.

8. The next season (1906), (Ball, 1909), definite cage experiments were undertaken in which sixteen leafhoppers stopped the growth* of a quarter grown beet in less than two weeks, and caused it to curl up and die in two weeks more, while the check continued to grow vigorously. The sixteen leafhoppers would not have been able to suck enough sap to seriously injure a single leaf of this beet.

9. Dr. Titus in cage experiments to determine the time required to produce curly-leaf in a young beet, produced the characteristic symptoms with the application of a single hopper for a short time.

This briefly was the sum of the available knowledge of the cause of curly-leaf when Shaw, through suggestions and assistance of the writer, took up the task of confirmation.

*The statement was made (Ball, 1909) that "no curly-leaf was produced" in this beet. At that time it was expected that the curly-leaf symptoms (warted veins) would appear around the punctures on the large leaves as they do following a puncture of *Eutettix strobi*. It is now known that curly-leaf develops first in the younger leaves and it is not doubtful that it developed in this case but the beet stopped growing so quickly and curled up so rapidly that the younger leaves were not visible from the outside of the cage.
THE BEET LEAFHOPPER

CONFIRMATION SINCE JANUARY, 1908

10. In 1908 Shaw (1910) carried on a series of cage experiments on very small beets and on those two months or over in age, and succeeded in producing curly-leaf where leafhoppers were introduced and none whatever in the checks. Leafhoppers were sent to Dr. Townsend at Washington and they produced curly-leaf on young beets under test conditions.

11. In 1909 the writer found a serious outbreak of curly-leaf in the Lake Tulare region of California, and sufficient evidence in other sections to prove that the California blight was the same thing that had been studied in Utah, and which was caused by the leafhopper.

12. In 1909 Adams put four leafhoppers on a small beet in the greenhouse. Twenty-five days later the beet was stunted and affected with curly-leaf while the check had doubled in size and was still vigorous.

13. Smith and Bonequet (1915) carried on an elaborate series of experiments in which curly-leaf was produced freely by various methods of using the leafhopper, but never without. This series of careful confirmations from widely different sources leaves little room to question the accuracy of the original conclusion. The fact that with all the innumerable tests that have been made, involving many thousands of dollars in money, twenty to thirty investigators, and running through sixteen years of work, curly-leaf has not once been produced except through the use of the leafhopper, and that no experiment has failed to produce it where the leafhopper has been used under normal conditions is a tribute to scientific accuracy as well as abundant proof of the case.

DO ALL LEAFHOPPERS CARRY THE DISEASE?

The discovery of Bonequet and Hartung that leafhoppers from certain wild plants did not transmit the disease until after they were allowed to feed on curly-leaf beets, still further complicates the problem. If leafhoppers from the desert region could not transmit the disease until they had fed on a diseased beet, it might be possible to entirely stamp the disease out of a region by making use of favorable seasons when very few hoppers were present and few beets attacked.

It is hard, however, to reconcile these facts with the other
facts at hand—that immense swarms of leafhoppers have arrived from unknown regions at various times and settled down in areas where there was not a single diseased beet and immediately produced the disease. If the above discovery is true, and it has been confirmed by Smith and Boncquet, then it must be assumed either that these leafhoppers came from some diseased field of the preceding year, or else that there is some wild plant that carries the disease. If the latter assumption is held, then that plant either did not occur in the Tulare region from which the non-infectious hoppers came, or else it did not carry the

PLATE V

Fig. 1. A field of healthy beets. Fig. 2. A field that at one time almost covered the ground, now curling up and beginning to "go back." (This field was plowed up later.)
disease in that region. The latter assumption is hardly tenable because this region has been badly affected whenever beets have been grown there.

If, on the other hand, it is held that these hoppers come from diseased fields of the previous year, some rather startling numbers must be accounted for. There appeared on the beet fields of Utah in the spring of 1915 swarms that ran from one hopper to every two beets up to five and six hoppers to a beet. This would mean between one and ten billion hoppers in the beet fields in the state; let us say five billion. These were very largely females and only the survivors of a last year's brood. Twenty per cent survival is probably a very high figure, which would mean a production of 25,000,000,000 leafhoppers the pre-

PLATE V

Fig. 3. A field that was half grown before it showed blight; now every beet badly affected. Fig. 4. A field that was attacked early.
vious year on beets to account for this infestation. But these hoppers were very uniformly and evenly distributed over the entire area, a large part of which had none the previous year, so they must have flown long distances over mountain ranges and large areas where there were no beets. It is inconceivable that any large per cent of them ever succeeded in reaching beet fields, so the previous year’s production must have been much greater than that. The production of that number of leafhoppers on beets would have certainly meant much more serious losses than were recorded for this region and could only be accounted for by flights from the serious California outbreaks of 1914. This would involve the crossing of chain after chain of mountains and traveling from 600 to 800 miles in an air line.

This discovery and attendant speculation opens up a number of phases of the problem, any one of which might lead to information that would assist in controlling these outbreaks.

**CONDITIONS FAVORABLE TO CURLY-LEAF DEVELOPMENT**

Curly-leaf cannot develop in a beet until it has been punctured by a leafhopper. Just how soon it will develop after that time or how severe the attack will be, depends upon the exact combination of a number of factors.

The most important single factor seems to be temperature, but temperature and moisture are so closely associated in arid regions that it is hard to separate their influences. Curly-leaf did not develop in the early summer in Cache Valley in 1915 when the weather was exceptionally cold and wet,* while the serious outbreaks in 1899 and 1905 were during hot, dry seasons. It has also developed rapidly and has been exceptionally severe in seasons that were not extremely hot, indicating that while it may be held in check by extremely cold and wet weather or accelerated by equally hot and dry periods, it will develop injury in seasons that are otherwise highly favorable for the development of the beet crop. In Sevier Valley in 1911, fields in which the leafhoppers were abundant were practically destroyed, while others, within a few miles but out of the range of flight of this swarm, gave exceptionally heavy tonnage.

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*The writer started a number of field cage experiments just as the weather turned cold, using 1 to 5 leafhoppers to a 6-leaved beet. No curly-leaf had developed at the end of a month.
That the heat was more of a factor than moisture is also indicated by the fact that fields which were allowed to grow up to weeds that shaded the ground (Pl. 9, fig. 1) were not blighted as badly as clean, cultivated fields adjoining. The heavy weed crop would, however, tend to reduce the moisture content of the soil faster than clean cultivation. Wherever affected beets have been shaded during the heat of the day, whether by weeds on the ditch, by trees or by buildings, the favorable effect has been noticeable. Prein records the same results in the Yakima outbreak, especially where shaded by hops.

Whether the temperature that affects the beet is that of the air on the leaves or the temperature of the soil on the feeding roots or even the reaction of the soil temperature on the adjacent air is not known. Much work along these lines is needed.

The most serious and persistent outbreaks of curly-leaf have been in the warmer districts of the respective sugar beet regions, but this cannot be separated from the fact that most of these warmer districts are also adjacent to the probable haunts of the leafhopper.

The disease is almost always worse on light, sandy land, but here again temperature and moisture both enter, as such land is both hotter and drier than a loamy soil.

That moisture in itself is detrimental to the development of the disease has not been demonstrated, because warm and moist conditions are rare in arid regions. Curly-leaf does not develop to any extent in the fog regions of the coast, but that may be due to the absence of the leafhopper. Beets that were watered earlier than usual have often withstood the curly-leaf better than their neighbors. This may be due to any one of three causes—the direct influence of the water on the roots, the change in temperature of the soil, or the change in humidity of the atmosphere near the surface.

Retarding the growth of the beet by lack of moisture at any time in the season is one of the surest ways of increasing the development of curly-leaf. This is especially true in the early season before the beets have grown large enough to shade the ground. Where the growth of the beets has been retarded by cold, wet weather, no such results have followed. Here again
it is not possible to separate the effect of the different factors and careful experimental work is needed.

The smaller the beet at the time of attack the more serious the disease. Fields in which blight develops before thinning time, or even soon after, rarely produce anything worth harvesting, if there were leafhoppers enough at that time to puncture every beet (Pl. 5, fig. 4).

Fields in which this occurred in Sevier Valley in 1915 promised for a time to recover as the cold, wet weather continued, but later in the season as the weather came back to normal the curly-leaf gained on the beets and stopped their growth. On the other hand, where the leafhoppers have been present in numbers, but no early blight developed on account of the weather conditions, the beet may suffer with the disease later, but only the younger leaves will be affected and the beet will ordinarily continue to grow (Pl. 2).

The larger the number of leafhoppers on a given beet the more rapid will be the development of the disease from its appearance up to the time when the beet stops growing. In the writer’s cage in 1906 sixteen leafhoppers stopped the growth of an eight-inch beet so soon after the disease appeared that the new leaves did not develop sufficiently to be observed to be curly and soon after their progeny appeared it withered and died. Most of the worst outbreaks have only had from one to four or five hoppers to a beet before the progeny appeared.

In general, hot dry weather, young beets, sandy soil, clean cultivation, lack of moisture (beets wilting in heat of day), and a large number of leafhoppers or their larvae are the conditions that tend to be favorable to the development of the disease.

**THE EFFECT ON BEET SEED PRODUCTION**

The presence of curly-leaf in a region makes the production of sugar-beet seed more than doubly hazardous. As the seed beet requires two years for its development and is equally susceptible during the second year, this fact alone doubles the danger, but the risk is even greater than that. The siloing of the beet reduces its vitality, and if the following spring happens to be dry and windy the seed beet will often suffer for moisture before a new root system is established. Beets that were punctured the
previous year but were able to withstand the disease, will often develop serious curly-leaf symptoms under these conditions. Seed beets from fields that show only slight damage the previous year often develop a large per cent of curly-leaf cases and the greater number of these fail to send up a seed stalk at all.

Seed production to be profitable should, therefore, be confined to those areas in which curly-leaf appears only in the exceptional year.

AMOUNT OF DAMAGE

Ten million dollars is a conservative estimate of the direct loss that the growers and factory operators suffered in the sixteen years (between 1899 and 1915) through crop reductions or failures due to this disease. If the losses through failures and removal of factories and other losses incident to these were counted it would bring the total up to approximately one million per year for the period.

This estimate seems excessive at first glance, but when one considers that there have been three serious and widespread outbreaks west of the Rocky Mountains and two in the plains region, and that in single areas of these regions losses of $1,000,000 or over have been suffered in single years, the total does not seem so large. Saylor records* that one factory in California planted 3,500 acres in 1905 and harvested only 500 tons. Other districts with areas of beets many times as large were affected even more severely so the total loss must have been nearly two million dollars in the central California district that year. The Utah region lost fully a million that season, ranging from a practically total loss in the Sevier Valley (average of two tons from those harvested) down to a 60 per cent loss in the central region and a 30 per cent loss in the north. The Salinas Valley abandoned several thousand acres in 1914 and suffered severe loss on that much more, making a total loss of over $1,000,000 in that area alone, while the blight extended throughout the entire central region and was severe in isolated areas in the south. The Nampa region lost an average of $250,000 per year for four years before the factory closed, while the Corcoran, Glendale, Fallon, and Grand Junction records have been somewhat similar.

These areas, in which the disease is so frequently destructive, have most of them abandoned beet growing or moved their main fields to less affected districts, so that the large losses of the future will no doubt come from the periodic outbreaks in regions where the majority of the seasons are comparatively free. The average losses in these outbreaks have been between two and three million dollars each, and as the acreage increases the losses will no doubt increase unless warning can be given or remedial measures developed. Under the stimulus of present high prices factories are being reopened and others built in districts that have doubtful futures.

**POSSIBILITY OF PREVENTING INJURY**

By Destruction of Leafhoppers.—Ordinary methods of combatting leafhoppers have not proven satisfactory in controlling this condition. The destruction of an active, sucking insect that cannot be poisoned and, therefore, must be killed by a contact insecticide is a difficult problem at best. When there is added to this the fact that even if the insect is destroyed, the disease which has been introduced by its first puncture may go on and destroy the beet, the problem becomes still more complicated.

Successful work has been done in killing leafhoppers on grapes, apples and potatoes by the use of kerosene emulsion or nicotine solutions. The adult of the beet leafhopper is larger and more resistant to sprays than its relatives and strong solutions are required to kill it. Experiments have shown that a 15 per cent kerosene emulsion must be used. By using a drag to pull the leaves of the beets over and directing the spray at the beet at the instant the leafhoppers were jumping to avoid it, a large proportion of them may be killed. Catching devices using sticky shields that are pushed along over the beets have proven successful in eliminating a large number of the hoppers.

None of these methods have, however, proven successful in controlling the disease because the continued presence of the leafhoppers is not essential to the development of the disease when conditions are otherwise favorable.

The place to destroy the leafhoppers so as to prevent curly-leaf would be on the breeding grounds from which they fly to the beet fields, but that is probably impracticable. At present, at least, it is impossible because these areas are not known, and
even if accurately known they must be too extended to even contemplate handling anything more than exceptionally infested areas.

**By Time of Planting.**—If the situation cannot be controlled by eliminating the leafhoppers, it may be largely avoided by outwitting them. Sections of California, where it is possible, have largely overcome the trouble by planting their beets in November and December, thus developing their beets to a considerable size and a high degree of vigor before the leafhoppers appear. In areas where the beets do well under this treatment and are large enough to be touching in the row when the leafhoppers appear this will solve the problem. In other areas where the leafhoppers appear earlier, this may not be successful. Where a region lies close to a breeding ground it may occasionally be infested by a larger number of leafhoppers early in the season and suffer severe loss. This early planting means early maturing; thus the beets have made most of their growth before the extreme hot weather and before the large brood of larvae has appeared. No beet, however large, appears to be able to withstand the attack of any considerable number of leafhoppers in normal growing weather.

Even in most of the regions where fall planting cannot be practised, the early planted beets have a marked advantage over the later planted ones. The early beets get more moisture, are larger at the time the hoppers appear, and can be brought to a point where they will shade the ground before the disease has time to develop. In ordinary seasons and light infestations, if the early beets are kept growing vigorously from thinning time on, they will shade the ground in a very short time and after that with proper care can be counted on to make a crop. In exceptionally hot seasons, heavy or very early infestations the beets will not reach this stage.

As the result of ten years' experiments at the Utah station it has been shown that beets which were irrigated early enough and often enough so that they never wilted during the day for lack of moisture, but continued a vigorous growth at all times, not only made larger beets, but they were better shaped and higher in sugar content than beets that were allowed to suffer
for water to the extent of wilting during hot afternoons, as was formerly thought to be the proper method of handling.

This is especially important in handling attacks of curly-leaf, as beets which stop growing for any cause are always the worst affected, and if hoppers appear on these early in the season they rarely recover. Beets planted late in the season are usually thinned in hot dry weather and thus receive a severe setback, just at the time of the leafhopper attack, often with disastrous results.

In a few localities, such as the Spreckles region, where temperature and moisture conditions allow planting through an exceptionally long period of time, planting may be delayed with profit, in years of bad infestation, until just before flights are over when these beets will come up free from leafhoppers, and if pushed from then on will be half grown before the adults appear again to infest them.

In all cases, it is important in bad years to give frequent irrigation and cultivation, keeping moisture close to the surface and the temperature of the soil as low as possible and at the same time developing a vigorous and continuous growth of the beets.

By Predicting Outbreaks in Advance.—The most important method of preventing injury from this disease in the future will probably be in accurately locating the breeding areas from which it spreads and studying conditions thereon so that possible or probable flights of the leafhoppers can be predicted. It is probably more important to be able to say that there will be no flights to a given region during a season than to predict the probability of such occurrence. When the breeding range and region of distribution by flights are fully known, it will be possible to give assurance of freedom or comparative freedom when the numbers on these areas are limited. The "warrior" grasshopper (Camnula pellucida) was a serious menace to crop production in some of the western mountain valleys until its breeding grounds were located and mapped and the periodic swarms destroyed before emerging from the ground. Since that time no one living in an up-to-date community need fear that pest. It is possible that when this same knowledge is available for the beet leafhopper equally successful means of checking its disease breeding swarms will be found.
PARASITES AND PREDACEOUS INSECTS

Much publicity has been given to the control of insect pests by means of imported parasites and in one or two exceptional cases this method has been successful. Funds amounting in the aggregate to millions of dollars have, however, been spent on this phase of the destruction of a number of our worst pests, such as the Gipsy Moth, San Jose Scale, Cotton Boll Weevil, Grasshoppers and Alfalfa Weevils, without reaching a point where dependence can be placed upon them as a substitute for active control measures; not that this money has in any sense been wasted. All insects are kept in check by some agency of this kind or usually a combination of parasites and predaceous enemies and fungous diseases. The leafhopper may increase forty times in a season, but in the long run they remain about the same in numbers, showing that the great majority are normally cared for in some such way.

Hartung and Severin (1915) report from 6 per cent to 47 per cent of the leafhoppers parasitized in different localities and dates in central California in 1914. The larger percentages were found late in the season, after the disease had been transmitted and most of the damage done. Even if they had found practically all the leafhoppers in the valley parasitized at this time, it would have been no assurance that the next crop would be free from attack.

The writer searched for several days one season in the beet fields of the coast region of California without finding a single example of the leafhopper, and yet within a few years immense swarms of these insects were present throughout the region.

In Cache Valley, Utah, in 1914, there were very few leafhoppers, and it was hard to find an example; yet, in the spring of 1915 there was a leafhopper present for every beet in the area.

The place, therefore, to study parasitism or to introduce parasites is not in the cultivated fields, but on the desert wastes from which the invading hordes are recruited. If this supply could be cut off, the problem would be solved for the larger part of the area subject to attack.
Any attempt to forecast the probable appearance of a periodic insect is surrounded with difficulties. It becomes especially hazardous in the case of an insect with such complex relations and such a variety of unknown factors as the beet leafhopper.

Figs. 4 and 5, showing three fairly uniformly spaced curves of outbreaks for the coast and intermountain region, would indicate a strong probability that it would be some years before these regions would normally expect a repetition of the troubles of 1914 and 1915. On the other hand, the eastern Colorado district has not had serious trouble for eight years and appears already to have run longer without an outbreak than the normal cycle.

The other district records are so incomplete that little can be judged except that curly-leaf seems to be the rule and good harvests, the exception. Several factories in these doubtful areas will run again this year after several years of idleness. If they will furnish accurate information of conditions, it will be very helpful in judging the future as well as in guarding the present.

What the future has in store is problematical. There may have been much more than a normal number of outbreaks in the past twenty years; it is equally possible that there has been much less than the normal number. The damage in the future will no doubt decrease as knowledge increases.

SUMMARY

The punctures of the beet leafhopper (Eutettis tenella Bak.) cause a specific disease in sugar beets called "curly-leaf."

Attention was first called to the trouble in 1899 and 1900, when it appeared throughout the entire western region from California to Nebraska.

Many European and American scientists worked on the problem and many theories were advanced and disproved as to the cause of the condition.

Another widespread outbreak in 1905 renewed activity. R. E. Smith announced the specific nature of the disease. Ball discovered that it was caused by the punctures of E. tennela, worked out the insect's life history, and confirmed the transmission of the disease by cage experiments. Titus found that
one leafhopper would cause the disease on a young beet. Shaw, Townsend and Adams repeated the cage experiments with like results.

Townsend described the disease, summarized the evidence for and against different theories and reported failure of all efforts to transmit it artificially.

Smith and Boncquet found that the disease appeared in about two weeks under laboratory conditions, and that there were lesions in the fibro-vascular bundles inhabited by an organism.

Boncquet and Hartung found that leafhoppers from wild plants would not transmit the disease until they had fed on curly-leaf beets.

Smith and Boncquet confirmed this and found that three hours on a diseased beet was sufficient, and that there was an incubation period of one or two days before the leafhopper could transmit the disease. They found similar lesions and the same specific organism present in several cultivated plants of this family with types of distorted leaves not caused by curly-leaf—but never in healthy plants.

Boncquet found that the organism present in the lesions was a vigorous nitrate reducer and decided that it was a new species.

The rough "warty" condition of the underside of an affected leaf, caused by the enlarged and distorted veins and resulting in the leaf margin rolling inward, is the most characteristic symptom.

Over the larger part of this area it has only appeared two or three times in twenty years. In smaller areas it has usually appeared in three-year attacks, cumulative in nature, after which it has almost totally disappeared for a time. In still other areas it has appeared the greater part of the time and in these areas beet raising has not been successful.

Eutettix tenella is the smallest member of a group of leafhoppers that cause leaf curls on different plants; all of the others produce color as well as distortion.

This insect is single brooded, hibernates as an adult, flies to the beet field in late spring and lays eggs in beet stems—a few at a time until mid-summer. The larvae mature in summer and the adults disappear in early fall.

E. tenella is a native insect inhabiting the southwestern
United States and northern Mexico, with an extension of area in the Columbia River region. From this region it is found distributed for hundreds of miles in the bad years.

It is found on shadscale, greasewood, Russian thistle and fine-leaved annual salt bushes. Which one, if any of these, is its original food plant is not known.

Swarms of these insects appear suddenly in beet fields previously uninfested. Much evidence points to the conclusion that these swarms fly from their breeding grounds on wild plants for long distances over mountain chains and other barriers.

Sometimes there will be only one flight into a particular region; if so, beets coming up later will not be infested.

West of the Rocky Mountains the three widespread blight periods were 1899-1900, 1905, and either 1914 or 1915. East of the Rockies 1903 and 1908 have been the years of serious outbreaks.

These periods have all been hot and dry for a part of the season, at least, but in other seasons equally hot and dry the beets have not been affected at all because no leafhoppers appeared.

Curly-leaf has never been produced except through the punctures of a beet leafhopper. If a single leafhopper is applied to a beet for five minutes, the curly-leaf disease will appear after about two weeks, if conditions are favorable.

Cold, wet weather will stop the development of further symptoms of curly-leaf on a slightly diseased plant, or prevent their development on a previously healthy one, even if a number of leafhoppers are kept thereon.

Sufficient evidence was at hand to warrant the conclusion that curly-leaf was transmitted by the leafhopper when the announcement was made. Since then it has been confirmed and amplified by seven investigators.

Leafhoppers taken from wild plants did not transmit the disease until they fed on diseased beets. Three hours on a beet rendered them pathogenic, but they could not transmit until after an incubation period of one or two days.

It is probable that some wild plant carries the disease and leafhoppers coming from this plant are able to transmit it to the beets.
A large number of leafhoppers, early attack, hot weather, and clean cultivation are favorable to curly-leaf development. The converse of these factors, together with frequent cultivation, early irrigation and shade or weeds are unfavorable. Seed growing is doubly hazardous in curly-leaf areas.

Loss from curly-leaf may be largely prevented by avoiding dangerous areas, by planting small acreages in a "blight cycle," by time of planting, by not thinning just as the leafhoppers appear and by knowledge of conditions on breeding grounds.

Parasites doubtless assist somewhat in controlling the leafhopper, but to be at all effective, should be introduced into the permanent breeding grounds.

The outlook for the immediate future in the intermountain and coast regions is favorable; for the plains region, doubtful; and for the Glendale, Tulare, and Columbia-Snake River region, serious.
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