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FIELD STUDIES ON THE BACTERIAL WILT OF ALFALFA

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Field Studies on the Bacterial Wilt of Alfalfa
JAMES S. WIANT AND G. H. STARR

INTRODUCTION

The maintenance of profitable stands of hay has been a serious problem for the alfalfa growers of this state during recent years. Conspicuous thinning out of stand has occurred in old fields and new seedings have been much shorter lived than in former years. The explanation commonly given has been that of winter killing, although considerable speculation has been aroused concerning the effect of different farm practices upon the occurrence of this type of loss. It was apparent, however, that very little definite information was available regarding the exact nature and cause of the alfalfa troubles in the state and that such information might have considerable economic importance. Field-survey studies of alfalfa were, therefore, begun by the senior author in the late summer of 1929 and continued through 1930 and to mid-summer of 1931 in the important irrigated alfalfa regions of Wyoming. They were continued by the junior author during the summers of 1933 and 1934, but over a less general area. During the early part of the survey it was found that bacterial wilt was widespread in the state and that this disease played an important role in the thinning out of alfalfa stands. The scope of the survey was, therefore, broadened so that detailed studies could be made of the distribution of bacterial wilt, its relation to alfalfa failures, and the effect of certain factors upon the losses from this disease.

DESCRIPTION OF THE FIELD STUDIES

Two methods were employed during the course of the field studies: (1) that of making observations of a general nature in some fields and (2) that of making extensive observations of a detailed nature in other fields. The first method was used during a

1. Formerly Assistant Agronomist and Plant Pathologist of the Agricultural Experiment Station, University of Wyoming, Laramie.

2. Caused by Phymomonas insidiosa McCulloch.

3. Prior to the completion of the field studies, a preliminary report (Wyoming Agricultural Experiment Station Bulletin Number 177, entitled "Bacterial Wilt of Alfalfa," was issued for the purpose of calling the attention of the alfalfa growers of the state to the importance of bacterial wilt. In that publication will be found a description of the disease, a summary of the literature published upon it up to that time, and a general discussion of the disease in its relation to alfalfa production.
brief tour through several important alfalfa-producing localities in 1929 and, following that, chiefly as a means for determining the prevalence of bacterial wilt in areas where the more detailed studies were not made. The second method was the one used primarily throughout these investigations. It consisted of making a study of a number of typical fields selected in different localities, including those that appeared to be in good condition as well as those that were apparently in poor condition.

When possible the following information was obtained from the grower: Variety and source of seed, date of seeding, previous crop history, method of rotation usually employed, number of cuttings per year, number of irrigations per year, extent of pasturing, estimated yields in past years, and types of alfalfa troubles encountered. General observations were then made throughout the field during the course of which the size of plants and the uniformity of stand were particularly noted. Plants were examined at various points in the field for evidence of bacterial wilt or winter injury.

On the basis of these general observations from one to three areas, one square yard in size, were then selected as typical of the field. All of the plants within these areas were counted and the percentage affected with bacterial wilt or winter injury, respectively, was determined. Where any evidence of bacterial wilt occurred in the field, specimens of the plants were taken and later examined by laboratory methods. A sample of the soil was collected from each field and later tested in the laboratory for available phosphorus and soluble salts.

The total number of plants examined within a field varied from a few in those fields which, during the course of the general observations, appeared to be in good condition, to several hundred in fields that showed thinning out of stands or other evidence of trouble. The figures representing stand per square yard, percentage of winter injury and bacterial wilt, respectively, are regarded in terms of the entire field, only as approximate estimates. This fact is given consideration in the interpretation of the results. Whenever practicable the method of correlation was used in analyzing the data obtained.
Thirty-seven fields located in Hot Springs, Washakie, and Park counties were studied in this detailed manner in 1930. Sixty-six fields located in Johnson, Sheridan, Park, and Big Horn counties, together with 13 fields of the previous year comprised the group studied in 1931. One hundred and seventeen fields located in Converse, Fremont, and Washakie counties were studied in 1933. Eight fields located in Albany County were likewise studied in 1934. In most instances the fields were visited prior to the time of the first cutting.

Two types of farming were represented in the field studies. The first was that of cattle or sheep ranching where alfalfa was the most important crop grown and where it was highly desirable to maintain good stands for long periods. These ranches were located chiefly in foot-hill regions where local mountain streams were the source of irrigation waters. The second type was that of more diversified farming, where, along with alfalfa, such crops as sugar beets, potatoes, beans, and small grains were of major importance while livestock was of secondary importance. These were representative of the farming conditions existing on the large irrigation projects of the state. In no part of the area included in these investigations was either natural rainfall or sub-irrigation of much importance as a source of water supply.  

RESULTS OF THE FIELD STUDIES

NATURE OF THE ALFALFA TROUBLES ENCOUNTERED

*Failure to establish good stands on new seedings.* Comments are frequently made by alfalfa growers upon the difficulty of establishing satisfactory stands of hay on new seedings when in reality they refer to the thinning out of well-established stands early in the life of the field. The field observations did not indicate that this type of trouble, the failure to obtain good initial stands, was a problem of general importance.

*Reduced yields in fields of good stand.* A few fields were observed in which the hay was very short, although the stand was uniformly good. The yields were, therefore, low because of the

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4. Alfalfa grown in the non-irrigated (dry farming) regions of the state yields a light crop and is raised chiefly for seed purposes. Bacterial wilt has never been observed in these areas.
stunted condition of the plants. For the most part this condition was found in fields where the soil was markedly deficient in available phosphorus. The results of the soil tests suggest further that a number of fields apparently making normal yields would respond somewhat to the addition of phosphates. Without minimizing the importance of adding phosphates where needed, it should be stated that losses from phosphorus deficiency have unquestionably been of secondary importance to the type of loss that is described below.

Reduced yields occasioned by a thinning out of stand. A reduction in yield caused by a thinning out of the stand was the type of alfalfa trouble most frequently encountered during the course of these investigations. Fields in which this occurred presented a "ragged" appearance due to the "patchiness" of the stand. This was usually accompanied by an unevenness in the height of the plants. It is this type of trouble that has been commonly referred to by growers as winter-killing. In some instances it undoubtedly did result from the killing of plants during periods of alternate freezing and thawing. The field studies have demonstrated, however, that in most cases this type of loss is the result of a gradual thinning out of the stand by bacterial wilt.

DISTRIBUTION OF BACTERIAL WILT IN WYOMING

The information obtained on the distribution of bacterial wilt in the state is presented by counties:

Platte. Twelve fields were examined near Wheatland in 1930. In four of these approximately 50 per cent of the plants were infected with bacterial wilt, two fields contained a small percentage of the disease, and six fields appeared to be free of the disease.

Goshen. Of 27 fields examined in 1930 near Torrington, Lingle, Veteran, Yoder, and Hawk Springs, 10 contained 30 to 40 per cent of bacterial wilt. One field contained a trace of wilt. The disease was not found in 16 of the fields.

Converse. Six fields were examined near Douglas in 1930. Bacterial wilt was found in all but one field. The average for the five was 35 per cent of the plants infected. One hundred and seven fields near Douglas were examined in 1933. They showed an average of nearly 33 per cent of the plants infected.
Johnson. Of 23 fields examined in 1931 near Kaycee and in the regions along Crazy Woman Creek, French Creek, and Clear Creek near Buffalo, 20 contained bacterial wilt with an average of approximately 37 per cent of the plants infected.

Sheridan. Twelve fields were examined near Sheridan in 1931 in the regions along Big Goose Creek, Soldier Creek, Upper Prairie Dog Creek, and Lower Prairie Dog Creek. Bacterial wilt was found in 11 of the fields with an average of approximately 38 per cent of the plants infected.

Park. Twenty-one fields were examined in 1930 and 1931 near Powell and in the regions of Upper and Lower Sage Creeks and that of the Irma Flats near Cody. Fourteen fields contained bacterial wilt with an average of 40 per cent of the plants infected.

Big Horn. Eight fields were examined in 1931 near Emblem, Basin, and the Shell Creek region. Bacterial wilt was present in all of these fields with an average of approximately 38 per cent of the plants infected.

Washakie. Twenty fields were examined in 1930 and 1931 near Worland. Seventeen contained bacterial wilt with an average of approximately 44 per cent of the plants infected. In 1933, five two-year-old fields examined in this county had an average of 10 per cent of slightly infected plants.

Hot Springs. Fifteen fields out of eighteen, examined in 1930 and 1931 near Thermopolis, Lucerne, and the regions along Cottonwood Creek and Owl Creek, contained bacterial wilt with an average of approximately 37 per cent of the plants infected.

Fremont. Comparatively few fields were visited in this county in 1930 and 1931. The disease was observed, however, in several fields near Lander and Riverton at that time. In 1933, five fields near Riverton showed an average of approximately 47 per cent of the plants infected.

Natrona. Specimens of alfalfa plants infected with bacterial wilt were received by mail on several occasions from growers near Casper. No field observations were made in the county.

Albany. Bacterial wilt was not observed in a few fields examined near Laramie in 1930. In eight fields examined in the county during 1934, over 21 per cent of the plants were infected.
The field survey was sufficiently inclusive to reveal clearly that bacterial wilt is widely distributed throughout the more important alfalfa-producing counties of the state. The figures presented above show that an average of over 35 per cent of the plants were diseased in approximately 80 per cent of the fields examined.

THE RELATION OF BACTERIAL WILT TO STAND

During the course of the field studies it became apparent that bacterial wilt was closely associated with poor stands. An analysis of the data on bacterial wilt and stand was, therefore, made by the method of correlation. The correlation coefficient for 36 fields examined in 1930 was found to be \(-0.449\); for 78 fields of 1931 it was \(-0.428\); and for 125 fields of 1933 and 1934 it was \(-0.395\) (all three coefficients significant.). This shows that a fair degree of correlation in the negative direction exists between the total number of plants remaining in a unit area and the percentage of those plants that are affected with the disease. This relationship is illustrated in Figure 1. The solid line AC represents the line of regression of stand against wilt. Thus, at point A with no wilt present the stand is 53 plants per square yard, at B with 50 per cent of the plants affected the stand is 34 plants, while at C with all of the plants infected with bacterial wilt the stand is 14 plants per square yard.

The method here employed for estimating the percentage of disease does not provide for the consideration of the death of diseased plants prior to the time of making the survey. The correlation between bacterial wilt and stand would, therefore, undoubtedly have been much greater had the total number of diseased plants been determined (including those that had died following infection

\[ \text{Probable error of correlation coefficient} = \pm \frac{0.6745 \times (1-r^2)}{\sqrt{n-1}} \]

where \( r \) = the correlation coefficient, and \( n \) = the number of the pairs of values used in the correlation study. It is significant that no correlation coefficients be considered significant unless they are greater than four times their probable error.
as well as those still remaining) and had this total number of diseased plants been expressed as the percentage of the original stand as it existed before the disease appeared in the field. The fact that a fair degree of correlation is shown to exist without making this correction suggests that the effect of bacterial wilt on stand is much more pronounced than here indicated.

AGE OF FIELD IN RELATION TO BACTERIAL WILT

In view of the relation of bacterial wilt to the thinning out of alfalfa stands, it is likewise important to know the relationship between age and bacterial wilt. The correlation between the percentage of plants infected with bacterial wilt and the age of the field was therefore determined. The correlation coefficient for 31
fields of 1930 was found to be .330 and for 78 fields of 1931 it was .188. The coefficient is small in both cases and in neither case is it significant. The fact that fields ranging in age from 2 to 25 years were included here suggests that relationships which might exist between bacterial wilt and age in those fields of the lower age classes might not have been brought to light. Accordingly, the correlation coefficient for the 69 fields of 1931 of ages from two to eight years inclusive was determined and found to be .251, a figure greater than that obtained with all 78 fields but not indicating a significant correlation. Similarly, the correlation coefficient for the 58 fields of ages two to six years inclusive was found to be .395 and for the 51 fields of ages two to five years, inclusive, it was .442 (both coefficients significant). There is thus a progressive increase in the size of the correlation coefficient as fields older than eight, six, and five years, respectively, are eliminated from the correlation study.

The relationship between age and bacterial wilt was more pronounced in the studies of 1933. Thus, the correlation coefficient for 117 fields of that year was .424 (highly significant).

A summary of the results obtained during the three years will be found in Figure 2, in which the scatter diagram shows the percentage of bacterial wilt plotted against age of fields up to and including those eight years old.

It will be noted that bacterial wilt increased fairly regularly from none in one-year-old fields to 45 per cent in five-year-old fields after which, with the exception of seven-year-old fields, it remained fairly constant through eight years.

The failure of bacterial wilt to increase between the ages of five and eight years may be partially accounted for by the assumption that after a field has reached an age of five years with 45 per cent of the plants diseased, the death rate among diseased plants becomes approximately the same as the rate of spread of the disease to healthy plants, with the result that the percentage of the survivors that are diseased remains fairly constant.

Fields older than eight years are not included in the chart because of the small number of these available for this study. They are too few to permit of generalizations. The wilt in these fields
Fig. 2. Scatter diagram showing the relation of bacterial wilt of alfalfa to age of field as determined by a study of 191 fields, eight years old and younger, made in 1930, 1931, and 1933. The solid line connects the average per cent of wilt at various ages.

The relationship between age and stand is of particular interest in connection with this observed correlation between age and bacterial wilt. Correlation studies of age and stand on the records from 78 fields of 1931\(^6\) yielded a coefficient of \(-.483\) and on those

\(^6\) The correlation coefficient for 32 fields of 1930 was \(-.368\). The number of fields on which the data were obtained during the year was too small for a coefficient of this size to be significant.
from 117 fields of 1933 a coefficient of \(-0.585\). Both are highly significant and show, therefore, a pronounced negative correlation between stand and age. This relationship is illustrated in Figure 3 for all fields of 1933 of ages one to eight years, inclusive. The line AC represents the line of regression of stand against age. Thus, at point A with fields one year of age, there are 82 plants per square yard; at B with fields five years of age the stand is 44 plants, while at C with fields eight years of age the average stand is only 16 plants per square yard. In fields older than eight years the average stand remains fairly constant varying from 7 to 18 plants per square yard. These stands may be seen in the following summary: One nine-year-old field had an average stand of 18 plants per square yard; one ten-year-old field, 11 plants; one 11-year-old field, 11 plants; five 12-year-old fields, ten plants; two 12-
year-old fields, eight plants; three 15-year-old fields, ten plants; one 16-year-old field, eight plants; two 18-year-old fields, eight plants; one 19-year-old field, seven plants; and three 20-year-old fields had an average stand of 11 plants per square yard. Three fields older than 20 years had an average stand of eight plants per square yard.

RELATIONSHIP BETWEEN WINTER INJURY AND BACTERIAL WILT

Histological studies by Jones\(^7\) have shown that the bacterial wilt organism enters the plant chiefly through the winter injury lesions (frost cankers) that are so commonly found on the shoots and tap roots of alfalfa plants. In the present studies the correlation method was used for the purpose of determining this relation of winter injury lesions to bacterial wilt.

The correlation coefficient for 37 fields of 1930 was .512; for 79 fields of 1931 it was .414; and for 112 fields of 1933 it was .627. All three coefficients are highly significant. This decided correlation between winter injury and bacterial wilt is interpreted as furnishing additional evidence of the importance of winter injury lesions as points of entry for the wilt bacteria.

The relationship between bacterial wilt and winter injury for the combined fields of 1931 and 1933 is shown in Figure 4. The regression of bacterial wilt against winter injury appears to be non-linear so that the data are shown in relation to a definite curve.\(^8\) It is interesting to note that at practically any point on the curve of regression the percentage of winter injury is considerably greater than that of bacterial wilt. Thus, at point A with four percent wilt there is no winter injury, at point B with 25 percent bacterial wilt there is 60 percent winter injury, and at C with 60 percent bacterial wilt there is 100 percent winter injury. This is regarded as showing the lag between the time of formation of winter injury lesions and that of infection by the wilt bacteria.

\(^7\) Jones, F. R. Development of the bacteria causing wilt in the alfalfa plant as influenced by growth and winter injury. Journal Agricultural Research 37: 545-569. 1928.

\(^8\) The following formula was used to produce the curve: \(y = a + bx + cx^2\). The correlation ratio was calculated and found to be .498.
Fig. 4. Scatter diagram showing the relation of winter injury lesions to bacterial wilt of alfalfa as determined by a study of 191 fields in 1931 and 1933. The curve represents the regression of bacterial wilt against winter injury. The circles mark the average per cent of wilt in each winter-injury group.

Available soil phosphorus and soluble soil salts in relation to bacterial wilt

Available soil phosphorus. The increasing interest in crop improvement by the application of phosphate fertilizers has led to numerous inquiries by alfalfa growers regarding the relationship of phosphorus deficiency to the thinning out of alfalfa stands. A correlation study was, therefore, made between available soil phosphorus and bacterial wilt. Samples of soils collected from 16 fields in 1930 and 73 fields in 1933 were tested for available phosphorus by the Truog modification of the blue colorimetric method in which N/0.002 sulphuric acid was used for extraction. The correlation coefficient obtained for the 16 fields of 1930 was .046. In 1933 for 73 fields it was found to be —.096. Both coefficients are small and are not significant.

9. The soil studies were conducted in cooperation with Mr. T. J. Dunnewald who made all of the phosphorus determinations and supervised those of soluble salts.
Samples of soils from 74 fields in 1931 were tested for available phosphorus by the method described by Bray. The average percentage of bacterial wilt and the average stand per square yard for all fields falling within each soil class are presented in the table which follows:

<table>
<thead>
<tr>
<th>Available phosphorus content of the soil</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>Doubtful</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of fields in each soil class</td>
<td>3</td>
<td>19</td>
<td>44</td>
<td>8</td>
</tr>
<tr>
<td>Average percentage of bacterial wilt</td>
<td>17 ± 11.3</td>
<td>35 ± 4.7</td>
<td>43 ± 3.1</td>
<td>35 ± 7.1</td>
</tr>
<tr>
<td>Average stand expressed in number of plants per square yard</td>
<td>30 ± 4.0</td>
<td>20 ± 2.0</td>
<td>23 ± 1.0</td>
<td>29 ± 4.0</td>
</tr>
</tbody>
</table>

These data indicate that there is no significant relationship either between available soil phosphorus and stand or between available soil phosphorus and bacterial wilt.

**Soluble soil salts.** The fact that many alfalfa soils of the state have a high content of soluble salts suggested the advisability of knowing whether any relationship existed between soil salts and bacterial wilt. Soluble salt determinations were, therefore, made with a Wheatstone bridge apparatus. Inasmuch as the soil samples were collected from different sections of the state and therefore had different combinations of soluble salts, the percentages of salt were based upon a curve constructed from readings taken with the same apparatus upon standardized solutions of the soluble salts extracted from alkaline soils near Laramie. The correlation coefficient for 27 fields of 1930 was found to be .255; for 73 fields of 1931 it was .089; and for 23 fields in 1933 it was .081. All three coefficients are small and none are significant. This indicates that there is no relationship between soluble salt content of the soil and bacterial wilt.

11. The figures representing average percentage of bacterial wilt and average stand are followed by their probable error.
12. Eliminated from comparison because of doubtful validity due to the high lime content of the soil samples.
Considerable information regarding farm practices was obtained during the course of the survey. This was analyzed for the purpose of determining whether any relationship existed between the use of any given practice and the prevalence of bacterial wilt. The results may be summarized as follows:

**Variety of seed used.** Records obtained on 149 fields showed that an average of 33.4 per cent of the plants were infected with bacterial wilt in 93 fields of common alfalfa and 32.5 per cent in 56 fields of Grimm alfalfa. The average age of the fields of common was seven years as contrasted with five years for those of the Grimm variety. The difference in the prevalence of bacterial wilt between the fields of the two varieties is thus very small and is not significant.

**Number of cuttings per year.** An average of $40 \pm 3.0$ per cent of the plants were infected with bacterial wilt in 46 fields cut twice per year as compared to $33 \pm 5.6$ per cent in 15 fields cut three times per year. The difference in average percentage of bacterial wilt between the fields of the two groups is not a significant one.

**Extent of pasturing.** In 63 fields, heavily pastured, an average of 31 per cent of the plants was infected with bacterial wilt; in 80 fields, slightly to moderately pastured, likewise 31 per cent of the plants were infected; and in five fields, not pastured, an average of 55.8 per cent of the plants was infected. Thus, there was no difference in wilt prevalence between those fields slightly to moderately pastured and those heavily pastured. Although the fields not pastured showed a much higher percentage of diseased plants, the number of such fields is very small so that there is no real evidence of a relationship between pasturing and wilt prevalence.

**Irrigation.** Very little information was obtained on the effect of different methods of irrigation upon bacterial wilt. Throughout most of the region in which the field studies were made the water supply was low and irrigation waters were used as economically as possible.
Rotations employed. Two methods of rotation were chiefly employed in the area surveyed, (1) that of seeding to small grains alone for 1-5 years between seedings of alfalfa, and (2) that of growing row crops such as sugar beets, beans, and potatoes for 1-4 years followed by one year of small grain before reseeding to alfalfa. No indications of differences in prevalence of bacterial wilt under the two systems of rotation were noted.

DISCUSSION

These investigations have shown that one of the most important problems confronting the alfalfa growers of the state is that occasioned by the gradual thinning out of stands. Field observations pointed to a close relationship between bacterial wilt and the prevalence of this type of loss. Correlation studies showed that such is the case with the stand decreasing as bacterial wilt increases. Considered in the light of field observations this correlation is interpreted as demonstrating a causal relationship between bacterial wilt and the thinning out of the alfalfa stands of the state.

It was also shown that a definite correlation exists between the percentage of plants affected with bacterial wilt and the age of the field, particularly for very young fields. Thus, it was found that the percentage of plants affected with bacterial wilt increased from 12 per cent in fields two years old to 45 per cent in those five years old. The decreased percentage of disease which was noted in fields from five to eight years of age is believed to be due to a rate of mortality among diseased plants higher than the rate of spread of the disease to healthy plants. The progressive increase in losses from bacterial wilt with increasing age of field is shown more directly by the correlation that was demonstrated between age and stand. Thus, it was found that losses in stand are evidenced early in the life of the field and steadily increase, so that by the time the field is five years old the stand has been reduced approximately 50 per cent, and by the time it is eight years old the reduction in stand is approximately 75 per cent. It is apparent that fields cannot long be profitably maintained after three-fourths of the original stand has died. This is illustrated by the fact that relatively few fields
older than eight years were met with during the course of the survey.

The importance of the bacterial wilt problem in the state is further shown by the studies on the distribution of this disease which revealed that it is widespread throughout the more important alfalfa-producing regions of Wyoming. Out of approximately 275 fields visited, bacterial wilt was observed in over 80 per cent of the fields with an average of more than 35 per cent of the plants in these fields affected with the disease.

It was demonstrated by the method of correlation that a close relationship exists between the prevalence of winter injury lesions and the percentage of plants affected with bacterial wilt. This is considered as additional evidence of the importance of these lesions in providing points of entry for the wilt bacteria.

No relationship could be detected between bacterial wilt and either available soil phosphorus or soluble salts. Whatever problem may be present in this state as a result of either of these two soil factors, it is apparent that each is distinct from that caused by the prevalence of bacterial wilt and that neither is related to the losses from this disease.

Observations were made to discover any relationship that might be detected between farm practices and the prevalence of bacterial wilt with the hope that losses from this disease could be reduced, at least in some measure, by variations of certain of these practices. It was found that fields of the Grimm variety were practically as severely affected as were fields of common alfalfa. Likewise no significant difference in prevalence of the disease was noted between fields cut twice per year and those cut three times per year; nor between fields heavily pastured, fields slightly to moderately pastured and fields not pastured at all. Similarly, no difference in disease prevalence was observed between the effects of two different systems of rotation employed. Although a complete study was not made along these lines, it appears from the results obtained thus far that little promise of disease control is offered by a modification of farm practices.

The present studies have not indicated any method for the control of this disease. It appears that the bacterial wilt problem
in this state is very similar to that in other states. As pointed out by practically all investigators who have worked on this problem elsewhere, the ultimate control of the disease lies in the use of disease-resistant types of alfalfa. Until such are available, alfalfa growers of this state can assure themselves of an adequate hay supply only by planning to hold fields for a relatively few years and by following such precautionary measures as have been pointed out for reducing the likelihood of the spread of this disease into and within a field.

**SUMMARY**

Studies undertaken to discover the cause of the alfalfa losses which had been so frequently reported by growers of the state revealed that most of such losses were due to a gradual thinning out of the stand caused by the bacterial wilt disease. This disease was found to be widespread throughout the more important irrigated farming regions of the state. By means of the method of correlation it was found that increases in the percentage of bacterial wilt were associated with decreases in stand and that as the age increased bacterial wilt increased while stand decreased.

Increases in the percentage of bacterial wilt were also found to be associated with increases in the percentage of plants affected with winter injury lesions. There was no evidence of a relationship between bacterial wilt and either available soil phosphorus or soluble soil salts.

No methods of control appeared to be available that could be based upon a modification of farm practices. The ultimate control of the disease in this state appears to be the same as that pointed out elsewhere, namely, the use of disease-resistant varieties of alfalfa.

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13. Wyoming Station Bulletin 177, already referred to.
The following publications of the Wyoming Experiment Station may be had upon request: (List of most recent bulletins.)

No.  BULLETINS—

101. Zygadenine, the Crystallin Alkaloid of Zygadenus intermedius.
110. Sweet Clover.
112. The Poisonous Properties of the Two-Grooved Milk Vetch (Astragalus bisulcatus.)
113. The Effect of Alkali upon Portland Cement.
116. Winter Grains.
134. Wintering Range Calves.
139. Climatological Data for Wyoming.
158. Use of Calcium Cyanide in the Apiary.
163. Results with Tree Planting at the Sheridan Field Station.
171. Varietal Tests with Wheat at Sheridan Field Station.
176. Mexican Bean Beetle.
177. Bacterial Wilt of Alfalfa.
180. Vegetable Cookery at High Altitudes.
182. Grain Mixtures Supplementary to Wyoming Native Hay for Milk Production.
185. Barley Tests at the Sheridan Field Station.
190. Drifting of Honeybees.
193. Arrow Grass—Chemical and Physiological Considerations.
194. Three Species of Zygadenus (Death Camas).
195. Grasses, Alfalfa, and Sweet Clover at the Archer Field Station.
196. Wool Inheritance in Hampshire-Rambouillet Crossbreds.
198. Influence of Storage upon the Bread Making Qualities of Wyoming Hard Wheat Flours.
199. Factors Influencing the Palatability of Hay.
200. Plants Poisonous to Livestock.
201. Infectious Abortion.
203. Poultry Feeding, Housing, and Lighting Experiments at the Wyoming Experiment Station.
204. The Micrometer Caliper for Measuring the Thickness of Wool Fibers.
205. Economic Studies of Irrigated Farms in Big Horn County.
207. A Five-Year Study of Hampshire Show Sheep.
208. Soil Erosion—Archer Field Station.
209. Forty Years of Weather Records.
210. Crossbreeding with Western Ewes.
211. The Wyoming Straw-Loft Poultry House.
212. Steer Feeding in Southeastern Wyoming.
213. Effect of Storage Upon the Vitamin C Content of Wyoming Potatoes.


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