OKLAHOMA
AGRICULTURAL AND MECHANICAL
COLLEGE

AGRICULTURAL EXPERIMENT STATION
STILLWATER, OKLAHOMA

BULLETIN NO. 131 JULY, 1920

BACTERIAL BLIGHT OF BEANS

A TECHNICAL STUDY BY C. W. RAPP

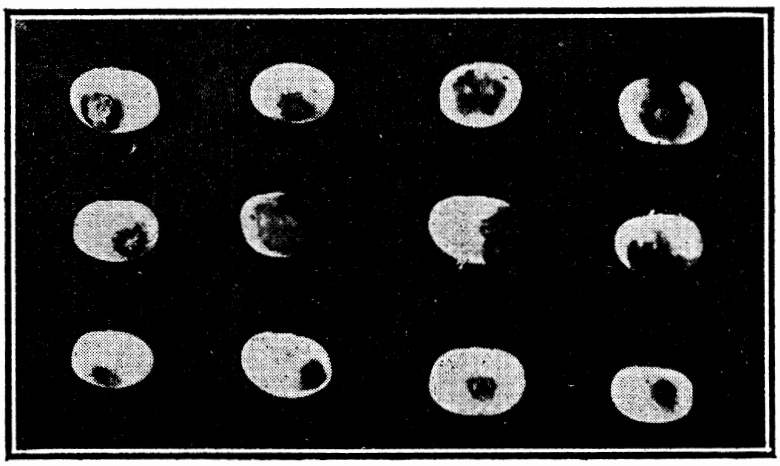

FIG. 1. BADLY DISEASED BEAN SEED

The publications of the Station are sent free to residents of Oklahoma on request. All communications should be addressed, not to individuals or departments, but to the EXPERIMENT STATION, Stillwater, Oklahoma.

OUTLINE OF CONTENTS

BACTERIAL BLIGHT OF BEANS

A TECHNICAL STUDY*

BY C. W. RAPP

Bacterial blight of beans is a disease of major importance in Oklahoma. The extreme seriousness of the disease was first realized in 1915, when the plants in our variety test plot were badly blighted. It was deemed of such importance that in 1916 a detailed study was begun. **

Up to this time no work had been done by this Station upon bacterial blight. Other workers at various Stations had described the field characters as found under their conditions. The cultural and morphological characters of the organism had been partially described. The methods of survival from year to year in the field had not been proven by experimental evidence. The factors of infection and dissemination had received little attention. Many measures for control had been attempted, but none had been successful.

A review of the findings of previous investigators may be found in another part of this paper.

The objects of our work have been to study the field characters of bacterial blight under Oklahoma conditions to prove by experimental evidence the means by which this organism passes the winter to complete the etiological study of the organism to determine the various modes of infection and dissemination, and if possible to evolve some practical control measure.

I—HOST PLANTS

Bacterial Blight is one of the most common, widespread and destructive diseases of the bean. In our work we have found that it attacks the common snap bean (Phaseolus vulgaris, Linn.), the Runner beans (Phaseolus multiflorus, Willd.), the two Limas (Phaseolus lunatus, Linn., and Phaseolus lunatus var. macrocarpus), the Pinto bean (a type of Phaseolus vulgaris Linn.), and occasionally the black-eyed cowpea (Vigna sinensis *L* Endl.).

II—THE DISEASE

Names

Several names have been applied to this disease—bacterial blight of beans. Those most commonly used are bean blight, blight, rust, scald, pod spot, speck and anthracnose. The names rust and anthracnose are of course misnomers used by those who confuse bacterial blight with these diseases. The other names are evidently used because of the appearance of the disease upon the leaves and pods. "Bean Blight" is the name most commonly used.

Author's Acknowledgment

*The writer wishes to express his indebtedness to Dr. F. M. Rolfs, under whose direction the work was performed.

**Work on this problem was begun early in the spring of 1916 and continued until the summer of 1917, when the writer entered the army. The study was resumed in February of 1919; also presented to the Faculty of the Oklahoma A. and M. College July, 1921, as a thesis in partial fulfillment of the requirements for the degree of Master of Science.

History

So far as is known the disease is of American origin. Its presence was first reported by Beach (4) * New York, in 1892. The same year Halstead (12), New Jersey, described the disease and stated that it had been known in that state as early as 1886. These workers described the effects of the disease upon the plants, and as a result of microscopic examinations ascribed the cause to bacteria. Dr. E. F. Smith (23) U. S. D. A. in 1897 isolated, named and briefly described the organism. Delacroix (6) in 1896 described the same or a very similar disease, occuring on varieties of beans grown on the outskirts of Paris.

In 1901, Dr. E. F. Smith, (24) U. S. D. A., published a brief account of the growth of this organism on certain media. Halstead, (13) New Jersey, in the same year briefly described the field characters of this disease and experimented with irrigation, shading, sprinkling, old and new land and ridging as control measures. He also mentions varietal disease resistance. Sackett, (22) of the Michigan Station, in 1905 published a very brief account of the disease, and in 1906 Whetzel (26) New York, published a similar work. Little new data on control was embodied in these papers. In 1908 Fulton (10), of Louisiana, described the field characteristics of the disease and took up the matter of prevention and of control by seed treatment with hot water, spraying, and disease resistant varieties. Edgerton and Moreland (8), also of the Louisiana Station, in 1913 presented further data on bacterial blight. Their work showed the bacteria markedly resistant to dying. Inoculation experiments were successful. They recommended the use of home grown seed and tried seed treatment with hot water and various chemicals. Muncie (17 and 18), of Michigan, in 1914 and 1917 describes the disease in the field, and discusses its relation to weather conditions and the mode of dissemination. He proves that the bacteria survive the winter in the soil and on diseased bean trash. Control with chemical solutions, and wet and dry heat were tried and resulted in failure. Spraying was tried. The use of clean seed of western grown Michigan beans is recommended.

*Reference numbers refer to literature cited (see page 38).

Geographical Distribution

The disease occurs in all parts of Oklahoma. Its distribution over the United States is general. The Plant Disease Survey reports the occurrence of bean blight from New York, Oregon, South Carolina, Tennessee, West Virginia, New Hampshire, Vermont, Massachusetts, Connecticut, New Jersey, Pennsylvania, Delaware, Maryland, Virginia, North Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, Texas, Arkansas, Ohio, Indiana, Michigan, Wisconsin, Minnesota, North Dakota, South Dakota, Nebraska, Montana, Colorado, New Mexico, Arizona and Idaho. It is also known to be present in Washington and California. It is found in Ontario, and Muncie (18) reports that South American white beans showing characteristic blight discolorations and lesions have been shipped into this country from Brazil. Its presence in Europe is shown by the report of Delacroix (6), blight being present in bean fields near Paris. It has lately been reported from South Africa,* and also from the Philippines.**

Economic Importance

Blight rivals anthracnose as the most important disease of the bean. The reduction in yield of dry, edible beans, due to bacterial blight was in 1917, estimated (19) at 512,000 bushels, or a yield reduction of 2.48 percent.

*Doidge, E. M., So. African Jour. Sci., 15 (1919), No. 7, pp. 503-505.
**Reinking, O., Phytopathology, 9 (1919), No. 3, p. 131.

This estimate does not include the blight loss to snap beans, which is also great. It is not uncommon for snap beans examined on the market to show from ten to ninety per cent infection.

Symptoms

The disease may be found upon the leaves, the stem, the pods, and upon the bean within the pods. In all cases the lesions are characteristic.

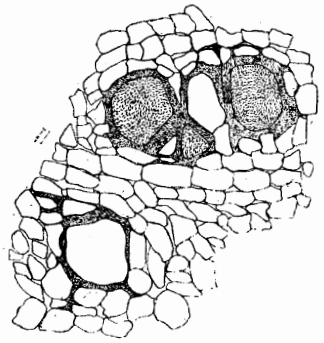

FIG. 2. Cross section from a bean stem showing vessels occupied by Bacterium phaseoli. The lignified connective tissue is represented by dotted areas. Drawings made with aid of camera lucida.

On the Seed. The blight organism lives over winter in the infected seed. In case of severe attack the seed may be smaller in size and more or less shrivelled. The diseased seed may be distinct yellow in color. Badly infected seed, when planted, frequently rots. This is especially true if the weather is wet. Whenever diseased beans are used, the percentage of germination is low. Seed that is lightly attacked is discolored by light yellow blotches with indefinite margins. The discolorations of anthracnose or frost should not be confused with that of blight. Anthracnose usually produces a distinct grayish or black blotch with a rather definite outline, while frosted seed varies in color from greenish-yellow to greenish-gray.

On the Cotyledons. Edgerton (8) states that as soon as the bean takes up moisture in the ground and starts to germinate, bacteria which have been dormant all winter, begin to multiply. This is doubtlessly true, for blight infected seedlings are found. These, when they appear above the ground, bear small amber colored spots or blotches generally with indefinite margins. These may enlarge, the spots involving both cotyledons. In rare cases light yellow bacterial slime or ooze may be found upon infected areas.

On the Stem. Stem infection may occur in two ways. In a few cases stem infection has been observed on young seedlings. This is doubtlessly due to bacteria washing down from infected cotyledons. On the seedling, shallow reddish-brown cankers are produced. These do not have the deep color or the definite margins characteristic of anthracnose cankers. Cankers have also been observed to develop later in the season. These lesions are very similar to those on the young seedling. They first appear as small water soaked areas. Gradually the spots change, the color becoming dull reddish-brown. The margins are definite. In some cases girdling occurs. In this case the water soaked area enlarges encircling the stem. As in the ordinary stem cankers the entire diseased area later becomes dull reddish-brown. After rains accompanied by winds, it is not unusual to find these

plants broken off at the girdled area. It has not been determined whether these cankers are due to stomatal infection or whether the disease enters the stem by way of a leaf stalk, as stated by Jones (14). In a few cases it has been observed that blight cankers have been established in old stem injuries.

On the Leaves. The first signs of infection are minute, dark green spots upon the under leaf surface. These would escape all but the most careful examination. At the time of the appearance of these spots the upper leaf surface appears normal. The minute spots upon the under suface increase rapidly in size and become irregular in outline. The deep green color continues. Within a short time after the appearance of the

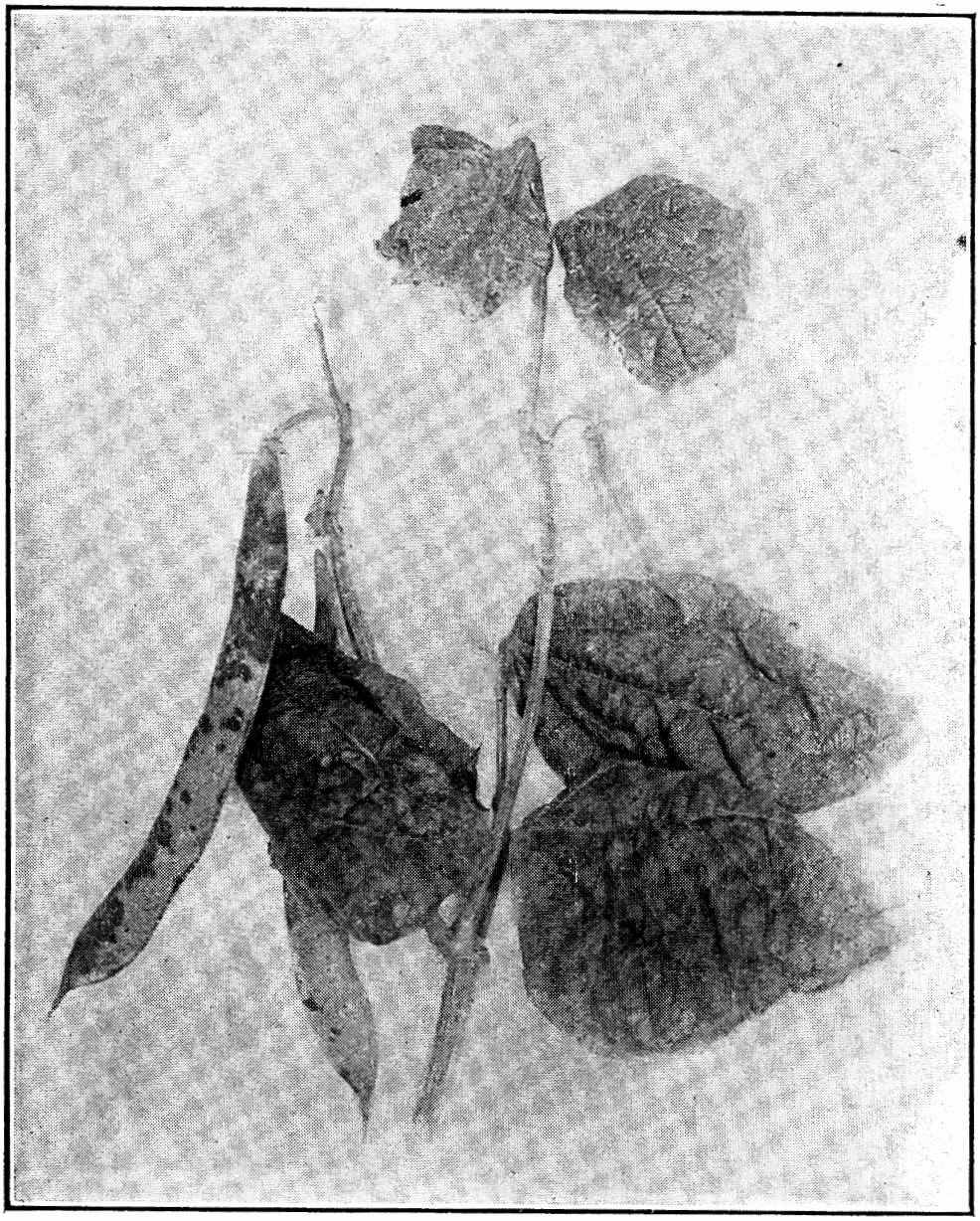

FIG. 3. Typically blighted branch.

spots upon the under side of the leaf similar dark green water soaked spots appear on the upper surface. During the early appearance of the disease upon the upper leaf surface it takes the closest examination to discern the spots. When viewed from above it is impossible to see them at a distance of more than fifteen to eighteen inches, so well does the diseased area blend with healthy leaf tissue. When held to the light the diseased areas become very evident. The spots are conspicuous as translucent dots in contrast with the impervious normal leaf surface and the irregular transparency of most insect injuries. When this stage is reached the spots vary in number from a very few, in cases of light infection, to between seventy-five and one hundred when the degree of infection is great. The spots generally increase in size simultaneously on both sides

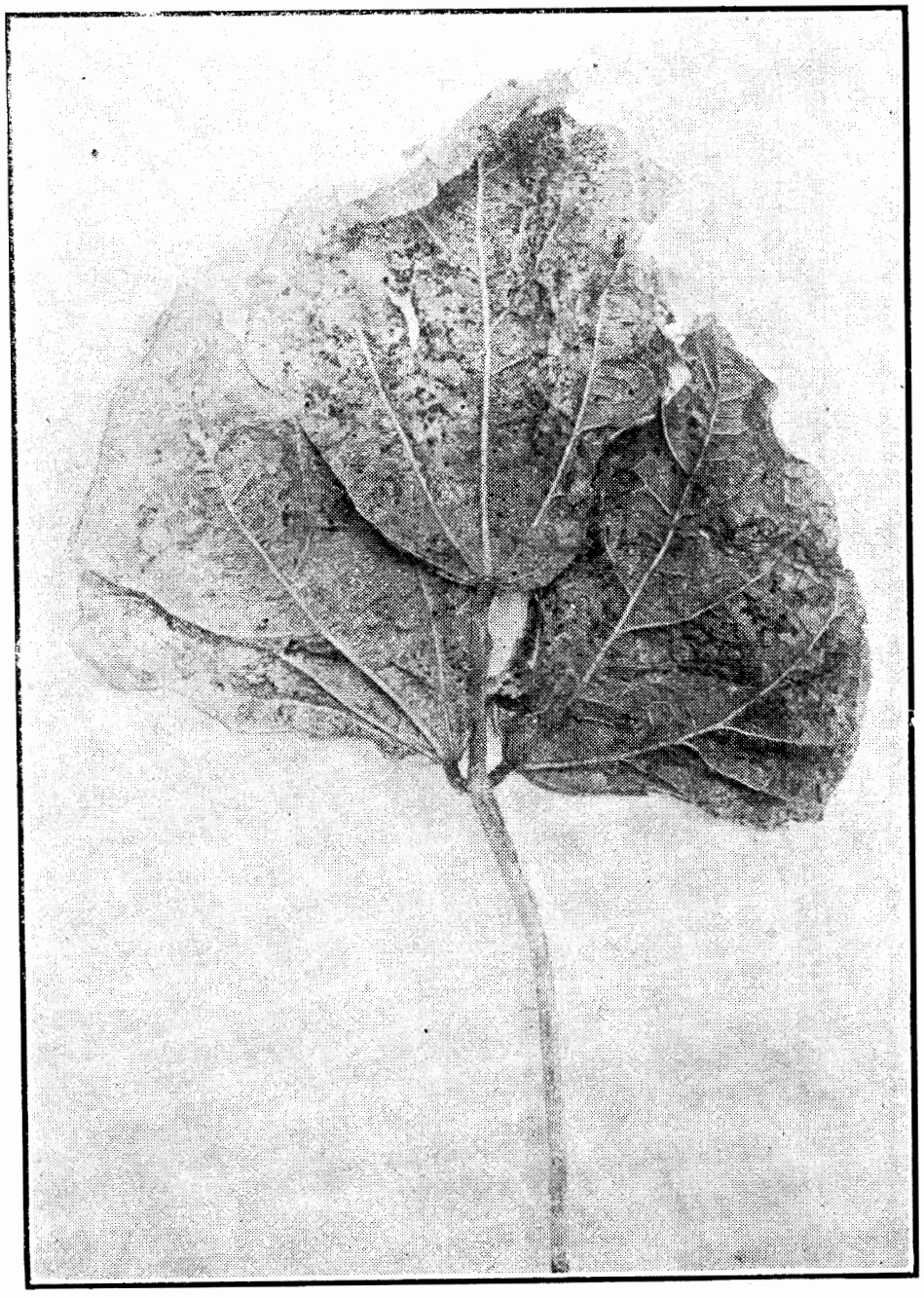

FIG. 4. Characteristically blighted leaf, lower surface.

of the leaf. Individual spots seldom increase to a size larger than two to three millimeters in the longest dimension. The larger, more conspicuous spots are formed by a merging of smaller ones. These merge until a dozen or more may coalesce forming one large, dark-green, water soaked area. The spots sometimes advance along, but never across, the veins. It is not uncommon for light yellowish bacterial ooze to be present in such quantity as to make the leaf surface sticky. Dirt is frequently splashed from about the base of the plant and adheres to the diseased spots. In cases of bad infection, practically the entire under surface of low-hanging leaves may be covered with dirt particles.

Distortion of the leaves is sometimes noticeable. When attacked in the early stages of development, leaves are frequently curled and otherwise misshapened. Leaves when attacked after full development, are not distorted.

The spots on the upper leaf surface change color before those on the under side. The centers first collapse and brown. This central area is

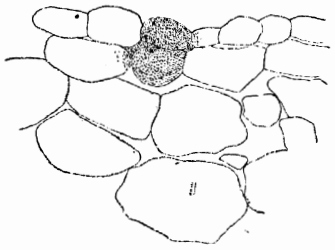

FIG. 5. Cross section of bean leaf attacked by Bacterium phaseoli. Section taken from the border of a surface canker.

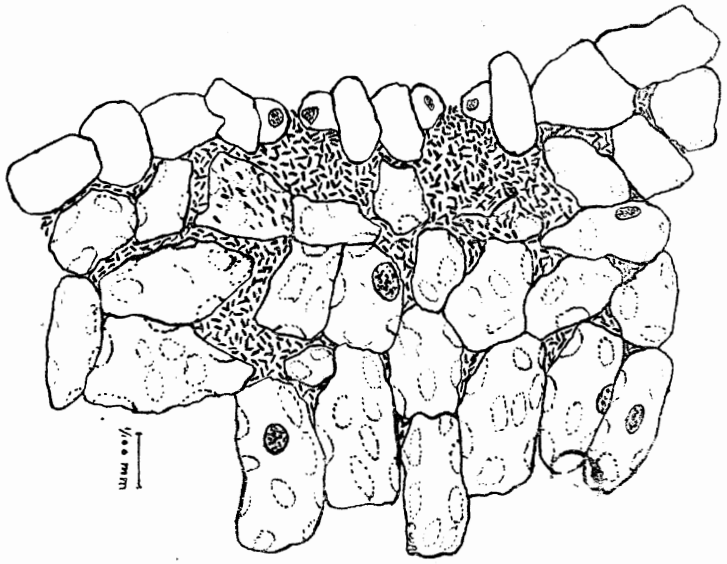

FIG. 6. Cross section of bean leaf attacked by Bacterium phaseoli. Natural infection which apparently took place through stomata. Drawn with aid of camera lucida.

bordered with collapsed yellowish to red leaf tissue. This in turn is bordered by a darker, water soaked area in which the bacteria are yet active. As the spot ages and increases in size the central area dries. Irregular dark lines, traversing the diseased area mark the boundary of successive stages in the progress of the bacteria. In Lima beans distinct areas of yellow and red are especially prominent.

On the underside the spot becomes first a greenish brown in the central area. The dark green border characteristic of the young spot persists. The central area gradually browns, but the narrow dark green border, shading to yellowish green and then brown, remains until the last stage of development. It is in this border that the activity of the organism persists longest. When the border finally disappears, brown displaces it, giving a sharp outline to the diseased area. In many cases the entire leaf is involved, gradually browning and drying as the disease progresses. The leaflets dry and shrivel while adhering to their leaf stalks, which later also shrivel. Though the entire leaf may not be involved, when the spots are numerous, the leaves soon wither and dry. Later these leaves fall to the ground. In our variety plots, practically all leaves are dead by August 1 and most of them have fallen. When weather conditions are favorable

new leaves may be produced following defoliation. In cases where drought follows a severe blight attack, new leaves are frequently not set except with Lima beans. Lima beans have proven capable of shedding many leaves, producing new foliage and yielding beans late in the fall.

On the Pods. On the pods, as on the leaves, minute dark green spots are the first indication of the disease. These gradually increase in size and assume a water soaked appearance. In the first stages the larger

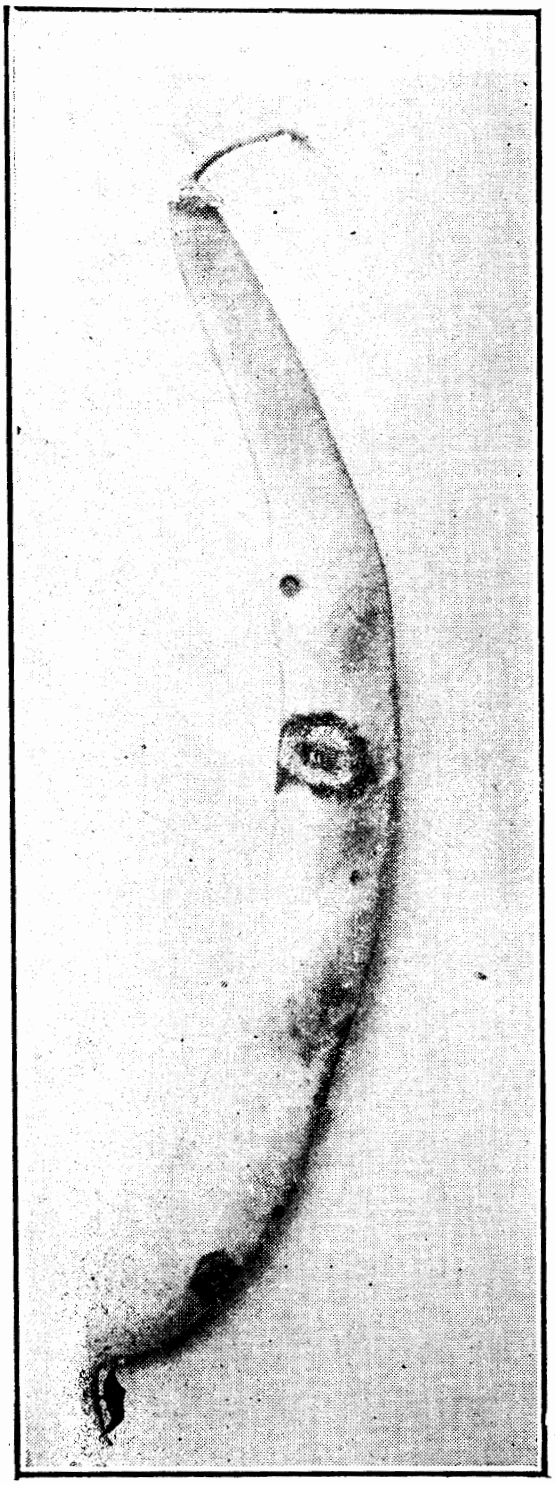

FIG. 7. Typical blight lesions on pods of wax beans.

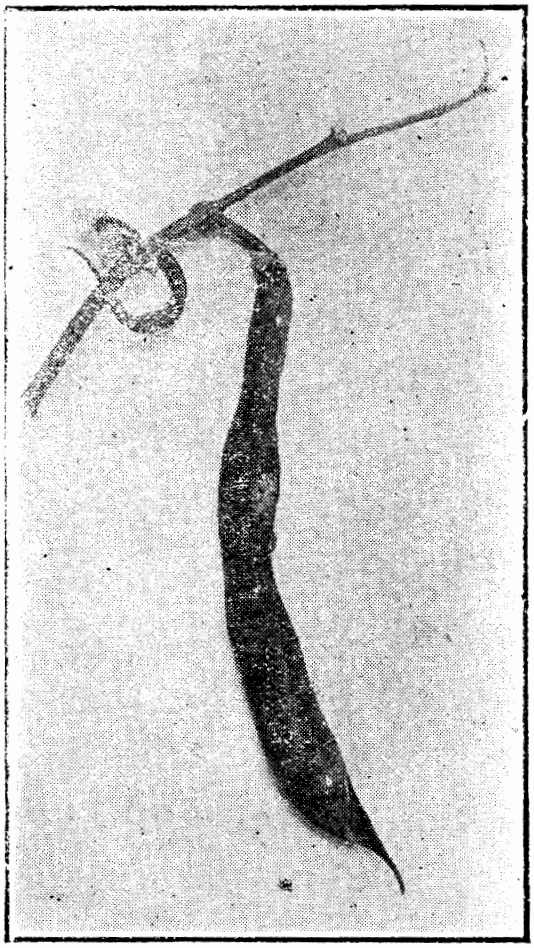

FIG. 8. Characteristic blighted pod showing bacterial ooze and incrustations.

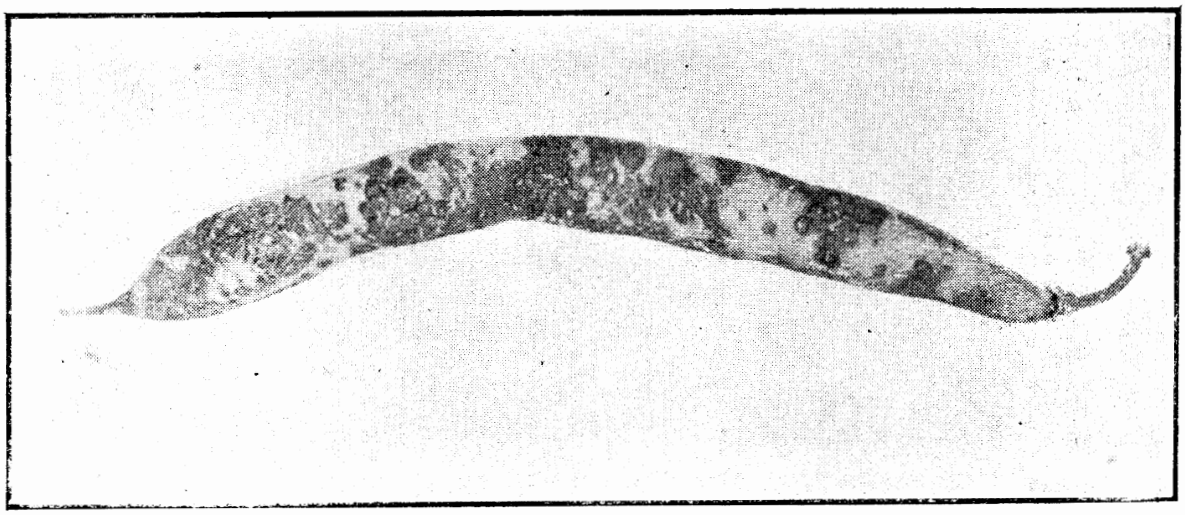

FIG. 9. Severely blighted pod.

water soaked areas are neither raised nor sunken, but as the disease progresses tissue collapses and they may become slightly sunken. In cases of severe infection it is not unusual for this water soaked area to cover an entire side of a pod. On many of the small water soaked spots and on most of the larger water soaked areas light yellow bacterial ooze appears. In small spots this ooze generally forms in the center, while in case of larger areas ooze may be present over the entire water soaked surface as minute yellowish droplets. In some cases this bacterial exudate is present in such abundance as to cause the hands of the picker to become sticky. The ooze gradually darkens and dries, forming a chrome yellow crust; or in other cases small lumps over the diseased area.

A few days after the appearance of the dark green spots the diseased areas become reddish in color. In the early stages of this development the central dark green, water soaked area is commonly surrounded by a distinct reddening. Later this ring darkens, the diseased tissue collapses and the central area browns. In darkening the color of the infected area progresses through several stages of brown, and in some cases becomes rather purplish. At the same time this diseased area becomes flattened and the surface irregular. On badly diseased beans an entire side may be discolored. Secondary fungi frequently gain entrance to the bacterial lesions during the later stages of the disease, and greatly complicate the coloration.

In wax beans the various steps in the progress of the disease are much more marked. The water soaked areas appear rather greasy lemon colored in clear contrast to the normal tissue. As the disease progresses these areas become darker, a dirty straw color. The bacterial ooze then appears and is rather inconspicuous against the yellow background. In darkening, the coloration changes through various stages of pink and red. These are very conspicuous. The red coloration in turn becomes first a light and then a deeper brown. Infection is frequently severe along the hinge.

The pods may be attacked during any stage of development. Very small pods not an inch long, and which have not yet shed the blossoms, are sometimes spotted. In our variety plots almost no healthy pods are produced. Very few beans mature. In pods that do mature, many beans are yellowed or shriveled. In many cases the pods become either limp and shriveled or dwarfed during development. Later they curl and dry. In the early stages of the disease this injury to the pods is the result of direct infection. In the later stages this cause is supplemented and aided by lack of nutrition, due to the activity of the disease.

FIG. 10. Pods killed by blight. Typical of severe infection.

FIG. 11. Cross section of bean pod stunted by Bacterium phaseoli. Natural infection. Drawing outlined by aid of camera lucidae.

Injury due to sunscald should not be confused with that due to blight. Sunscald is noticeable as brown and reddish spots or streaks upon the pods. It sometimes causes water-soaked tissue, and in some cases slightly sunken areas. Sunscald also causes leaf and stem injury. This trouble is quite common in the southwest. Sunscald has been fully described by MacMillan (15).

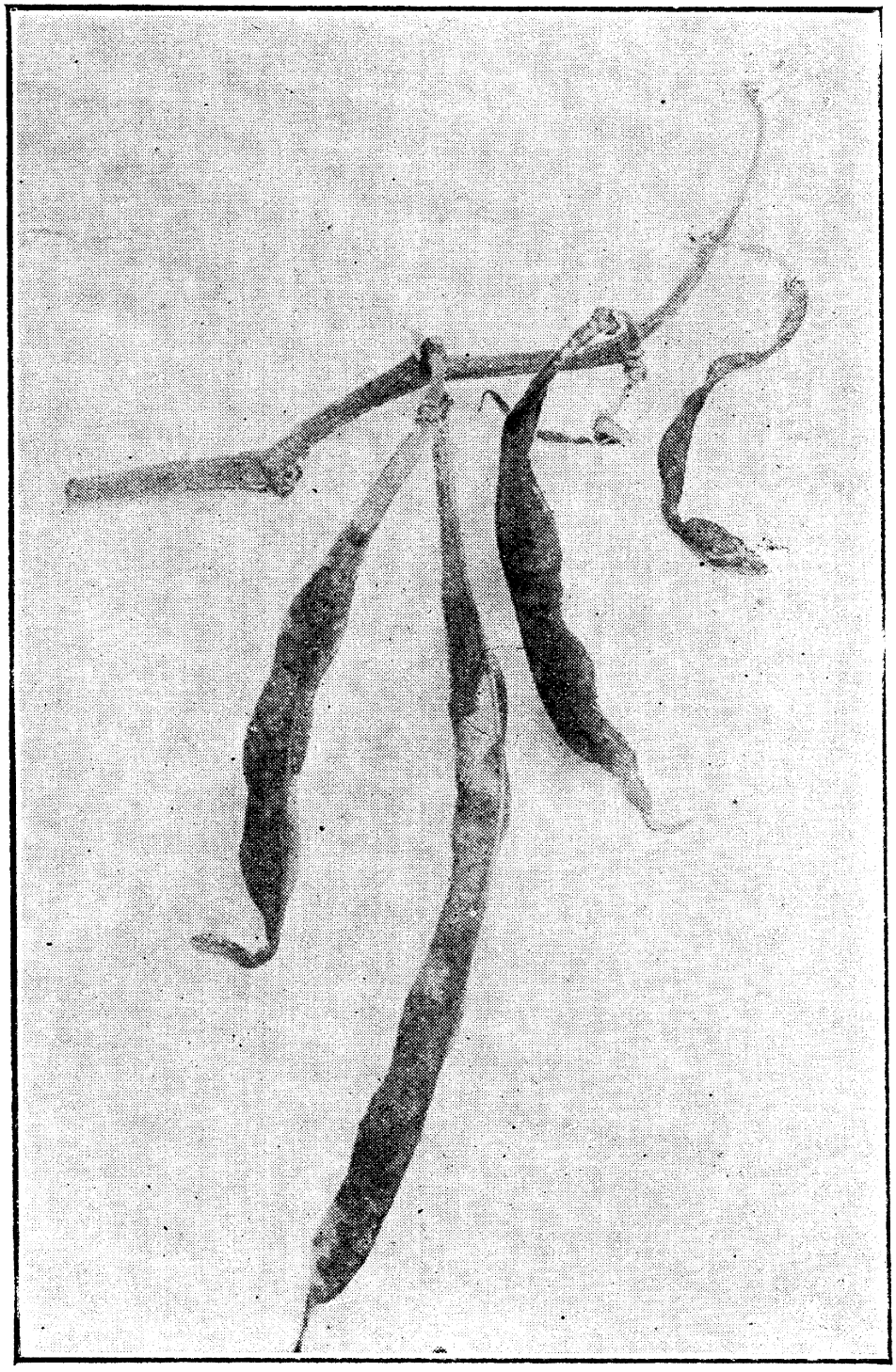

FIG. 12. A typical cluster of badly blighted pods.

On the Plant.—In our experiments, bean blight in the average year, does not become conspicuous until the first pods are about full-grown. The poor stands in occasional wet years are due, in many cases, to blight-infected seed.

When weather conditions are favorable, the disease progresses very rapidly. In one case within two days, after but slight traces of blight were found, it became very prevalent over the entire field. Within a

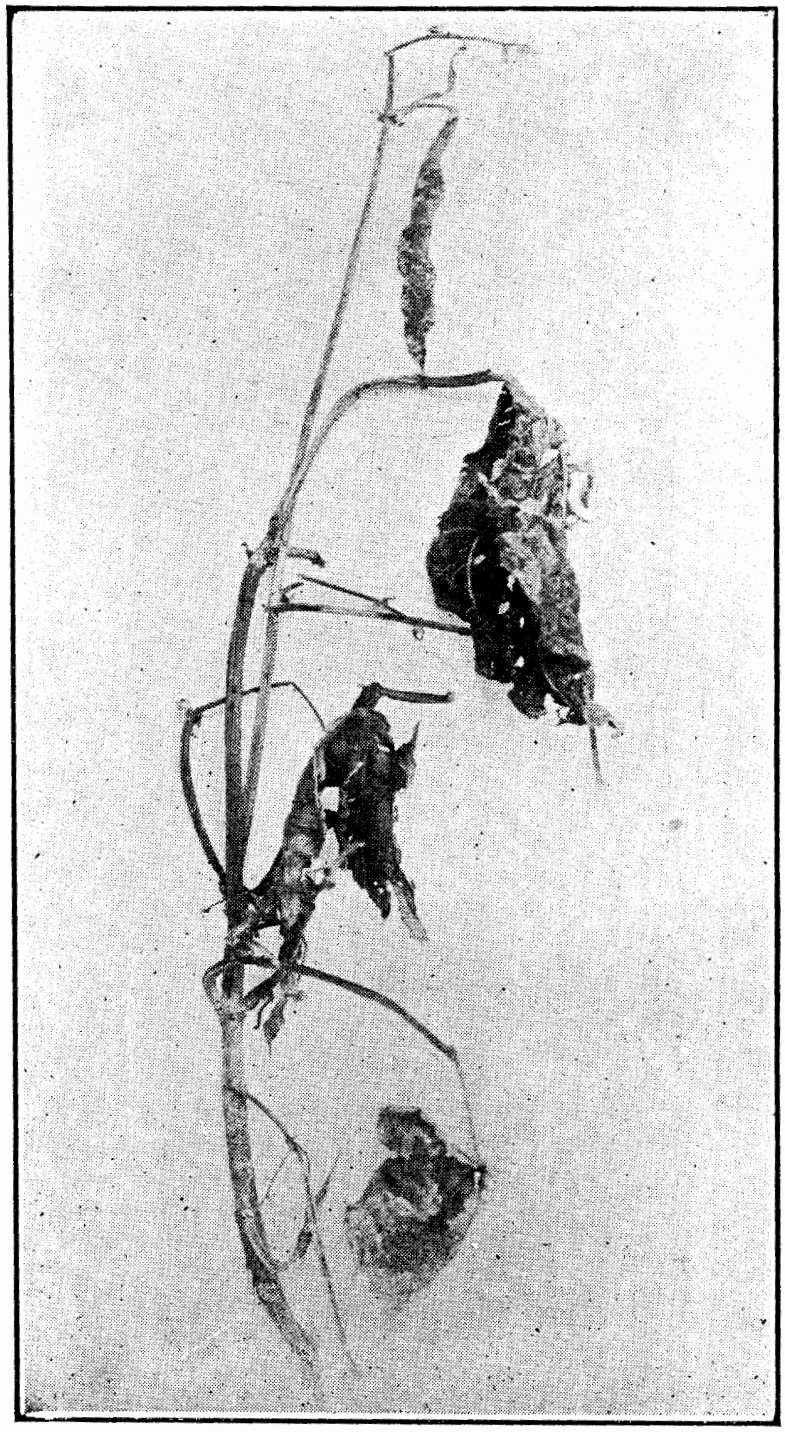

Fig. 13 Bean stalk characteristic when blight infection is severe.

week many leaves had browned and fallen, and within three weeks the majority of the plants in the field were almost completely defoliated. In many cases the plants were dead. The manner in which the organism causes the death of these plants has not yet been fully determined. Whetzel (26) states that "The bacteria increase in such numbers that finally they may fill up the sap tubes in the stem, cutting off the water supply and so cause the entire plant to wilt and die". Muncie (17) gives as his opinion that the root system of the seedling is sometimes injured by the blight organism, and states that "Plants so injured lack a deep root system and are dependent wholly upon the side roots near the surface of the

FIG. 14. Rods of Bacterium phaseoli showing flagella.

ground. In cases of early drouth, such plants turn yellow or wilt, or may even die, thus causing bare spots in the field". Our results show that a small percentage of plants may die due to these causes. Under our conditions the blight attack is almost invariably followed by weeks of dry weather. It seems probable that the plants, greatly weakened and almost defoliated by the blight, are killed because of the lack of leaf surface and moisture.

III—ETIOLOGY

Name of Parasite

The disease is caused by the bacterial parasite, Bacterium phaseoli E. F. Sm. The organism was first described by Smith (23) 1897 under the name of Bacillus phaseoli n. sp. Later the generic name was replaced by that of Pseudomonas and finally Bacterium phaseoli when Smith substituted the generic name Bacterium Cohn emend.

Pathogenicity

The pathogenic nature of this organism has repeatedly been proven. Successful inoculations have been made upon leaves, stems and pods. Pod-infection appears in from six days to three weeks after inoculation, and the characteristic lesions are produced. Leaf-infections sometimes appear the second day after inoculation.

Morphology

Vegetative Cells.—The organism is a rather short rod, with rounded ends. It is found singly, in pairs, and occasionally in liquid media, in short chains. Individuals from growing, active lesions are from 0.5 u to 0.9 u in length and from 0.2 u to 0.5 u in width according to our measurements.

Endospores—No endospores have been observed.

Flagella—The organism is motile by means of one polar flagellum.

Capsules—No capsules have been observed.

Zoogloeae—Zoogloeae are produced on various media.

Involution Form—No involution forms have been observed.

Gram's Stain—Not successful.

Acid-fast—Is not acid fast.

Cultural Characters

Other workers (24) have previously presented data on the cultural characters of this organism. This work is, however, incomplete. We have repeated and verified the most of the previous culture work. In addition new material is presented. It was the original intention to give a detailed description of the cultural characters of this organism. This material is available, but is not presented because it is not deemed of interest to the average reader.

Source of Cultures—Five strains of the causal organism were used in these tests. They are:

No. 1. From a leaf spot, Round Yellow Six Weeks.
No. 2. From a leaf spot, Texas Speckled Lima.
No. 3. From a stem canker, Extra Early Refugee.
No. 4. From a pod spot, Black Valentine.
No. 5. From bacterial ooze from a pod, Webber Wax.

In the preparation of media cistern water was used. All media were titrated one percent acid, +10 on Fuller's scale. Titrations were made with N/20 sodium hydroxide, with phenolphthalein as the indicator.

Cultures were held at a temperature of about 28 degrees C.

The organism grows on all standard media.

Agar Slant—Growth on plain agar is very moderate as compared with growth on sugar agars. In some cases the growth is feeble. The color is darker than on sugar agars. In most cases the growth extends down the entire length of the slant and the streak varies from 5 to 8 millimeters at the widest dimension. The white chemical film characteristic of this organism on sugar free agar media is present. The wet, flowing character especially characteristic on sugared Hiss media and noticeable on some sugar agar media is entirely absent.

One Percent Hiss Sugar Slants—Growth vigorous. Most with saccharose closely followed by that on dextrose. Next in order of development come maltose, dextrin, lactose, mannite and plain Hiss. The yellow color varies slightly with each sugar. That of dextrose is darkest. The colors vary through various degrees of wax and chrome yellow.

Potato Plug—Grows readily on potato plugs. The entire plug is covered with abundant waxy yellow growth which darkens with age. The water of precipitation is filled with the yellowish precipitate.

Agar Stab—Development very similar to that of Hiss Glucose stab, but growth is less vigorous. The surface colony developing at the point of puncture rarely covers the entire surface. This yellow bacterial colony is completely surrounded by the whitish chemical film characteristic of sugar free agar cultures of this organism. The media was not liquified or softened.

Gelatin Stab—Growth is very moderate. The line of puncture is visible after thirty hours, but does not develop further. Surface growth is not vigorous. A smooth, moist, pale yellow colony from 2 to 5 millimeters in greatest diameter develops at the point of puncture. As liquification slowly develops, this colony is found at the bottom of the crateriform depression. The liquified gelatin has a rather clouded appearance.

Hiss Glucose Stab—Growth is moderate. The line of puncture is visible after thirty hours. It develops but little further. A circular surface colony is formed at the point of inoculation. This colony frequently covers the entire surface. In some cases the growth extends from 3 to 6 millimeters up the sides of the tube. No liquification nor softening of media.

Nutrient Broth—No signs of growth at twenty-four hours. There is a very slight precipitate at forty-eight hours. A few whitish flakes are in suspension. The surface ring is a mere whitish line. There is a slight increase in development of the surface ring at seventy-two hours. The precipitate is scant, whitish and almost entirely flaky. There is continual development of ring growth at ninety-six hours. The precipitate is greater in quantity and more viscid. At one week there is a trace of cloudiness. The surface ring varies in width from a trace, to three millimeters. It is almost white. There is a very moderate whitish precipitate. In eighteen days the surface ring has increased in development and darkened in color. The precipitate has increased. There is marked cloudiness. This is most dense at the top.

One Percent Sugar Broths.—Growth in these media is varied. Judging from ring development, precipitate and degree of cloudiness it is evident that the best growth takes place on saccharose, dextrose and maltose in order as given. Dextrin, lactose and glycerine follow next in order. Growth is poorest with mannite and plain broth. In no case was there any characteristic odor or sign of gas development.

Milk.—Casein is thrown down slowly. No acid nor gas production.

Lab Ferment.—The throwing down of casein in milk cultures without visible acid production indicates the presence of lab ferment.

Agar Plates.—Within thirty-six hours, small, pale yellow colonies appear. These gradually increase in size and darken slightly in color. On the fifth day the surface colonies are from 1 to 4 millimeters in the longest dimension. They are pale wax yellow, smooth and glistening. The margins are thin but distinct. The colonies are very slightly convex. The buried colonies are very small, from 0.5 to 0.3 by 0.3 to 0.6 millimeters, mostly elliptical. The margins are distinct though rather irregular. At ten days the colonies continue regularly rounded with definite margins. They range from 3 to 10 millimeters in the longest dimension. The color has slightly darkened. The surface continues smooth and glistening, but is slightly more convex. Some colonies have merged. Rings are plainly visible in the colonies. There is a distinct, homogenous, central circular area surrounded by a very definite zone, darker in color. The periphery of the colony is formed by a narrower third zone, which is generally homogenous; the buried colonies continue small, and are almost unchanged. They are slightly darker in color and the margins slightly more roughened. Some have broken through to the surface.

Gelatine Plates.—This media was little used in our work. Hiss Dextrose was substituted. No extensive gelatine plate tests were run.

Hiss Dextrose Plates.—The growth of this organism upon Hiss Dextrose plating media was very similar to that on agar. The development was, however, much more rapid and the growth more vigorous. Colonies appeared in twenty-four hours. These gradually increased in size, and by the tenth day the surface colonies were from 4 to 12 millimeters in diameter in the longest dimension. The buried colonies differed from those on agar only in being slightly larger. The zone differentiation of surface colonies was more distinct than on agar plates.

Nutrient Starch Jelly.—Grows abundantly.

Uschinsky's Solution.—Growth is feeble.

Nitrates.—There is no reduction of nitrates to nitrites.

Indol.—Tests of peptone cultures for indol on the fifth, tenth, twentieth and thirtieth days all were negative.

Diastase.—Exerts a very strong diastaic action on starch. This is well illustrated by the vigorous action on potato plugs.

Invertase.—Cane sugar is inverted readily.

Aerobic.—So far as tested, Bacterium phaseoli is strictly aerobic.

Gas.—No gas production has been observed.

Acid.—Titrations have shown decreased acidity in sugar broth cultures. This is no doubt due to the ammonification of peptone for the sugar-free broth cultures show similar reductions of acidity.

Toleration of Acids.—No growth was secured in nutrient broth containing more than 3 percent acid.

Special Media.—In our work we have made use of a special media—a decoction of stems and leaves of the bean. It has been of especial value in renewing old cultures. Growth is vigorous.

Resistance to Drying.—Edgerton (8) has shown that the bacteria are very resistant to drying. In his work, cover slips were treated with bacterial suspension and dried. These were cultured from time to time. A plate made after 217 days of drying gave some colonies. In our work we have been unable to successfully plate colonies, from cover slips, after more than seventy days of drying, though cultures have been plated from dried beans held in storage for eleven months.

Effect of Sunlight.—Hiss, dextrose plates inoculated from a five-day old bouillon culture were poured into petri dishes and placed in bright sunlight. One-half of each plate was covered with black paper. The plates were exposed at a temperature of from 30 degrees to 33 degrees C. Exposure was for twenty, thirty and forty minutes. There were four plates in each lot. After three days the plates exposed, for thirty and forty minutes, showed no growth on the uncovered area. A few colonies developed on the uncovered area of the plates exposed for twenty minutes.

Thermal Death Point.—Smith (24) placed the thermal death point of this organism at about 49.50 degrees C. Our experiments also place the thermal death point of this organism at about the same figure.

In this work, five lots of six thin-walled test tubes, each containing 10 cc. of bouillon, were inoculated from a five-day-old bouillon culture. These tubes were plunged into water held at constant temperature. The lots were exposed at temperatures of 47 degrees, 48 degrees, 49 degrees, 50 degrees and 51 degrees C. They were removed after exactly ten minutes of exposure, cooled to room temperature, and held at 28 degrees C. for eight days. In three days growth had begun in the test tubes held at 47 degrees, 48 degrees, and in four of the tubes held at 49 degrees C. No growth occurred in those held at 50 degrees and 51 degrees C.

IV—EFFECT OF ENVIRONMENTAL FACTORS

Weather conditions have an important bearing upon the development and spread of bacterial blight. In our varietal plots the disease always becomes prevalent following a period of warm, wet, muggy weather. Such conditions seem ideal. Until such conditions occur, this disease is of no importance in our plots. Cool, wet weather does not favor its development. Warmth seems essential. Following warm, wet weather, the disease continues to spread so long as the bean plants remain alive, though the spread is not as rapid after the weather becomes dry and the plant tissues harden.

The progress of the disease in our variety plots during the years 1916, 1917 and 1919* is shown in Tables I, II and III. The percentage of blight was determined from leaf infection. The actual percentage was found by counting leaves on twenty-five average plants selected at random in each variety plot.

The year 1916 was ideal for the development of bacterial blight. The weather during the latter part of June was warm and wet. Lack of sufficient rainfall hindered development of the blight in 1917, and injury was not so great as in 1916.

TABLE I

Percentage of Infection of Bacterial Blight on Variety Bean Plots, 1916

Plot Number	VARIETY	Percentage of Blight Infection									
		June 27	June 30	July 6	July 8	July 10	July 13	July 16	July 27	Aug. 5	Aug. 28
1	Grenell's Improved Rustproof Golden Wax	5	24	50	60	60	80	95	100	100	100
2	Southern Prolific	0	4	15	20	20	25	30	70	80	95
3	Light Red Kidney	3	15	40	50	60	70	70	95	100	100
4	Northern Grown Pea	3	30	80	80	80	83	85	90	95	95
5	Bolgano's New Pearl Wax	5	30	45	50	60	60	65	85	95	100
6	Texas Speckled Lima	0	5	20	25	25	25	20	20	20	15
7	New Revenue Pea	0	5	10	10	10	10	10	10	8	5
8	California Pea	15	65	80	85	85	88	90	90	95	95
9	Webber Wax	5	30	70	80	90	95	100	100	100	100
10	Early Mohawk	5	40	75	75	75	80	80	90	95	100
11	Tepary	0	0	0	0	0	0	0	0	0	0
12	Improved Red Valentine	3	30	65	73	73	75	78	80	95	100
13	New Hudson Wax	3	5	40	40	45	50	55	65	70	100
14	Navy	3	30	65	70	75	80	90	95	95	98
15	Boston Small Pea	15	45	65	65	70	85	95	100	100	100
16	Golden-Eyed Wax	5	30	50	60	60	80	90	100	100	100
17	Universal Wax	3	30	40	60	65	80	80	95	100	100
18	Earliest Red Valentine	3	25	50	60	65	80	80	90	100	100
19	Black Wax Improved	5	30	75	80	80	80	80	95	100	100
20	Hodson Long Pod	3	5	30	30	40	60	65	70	90	100
21	Large White Marrowfat	10	35	50	55	55	60	70	80	85	95
22	Round Yellow Six Weeks	3	12	50	60	70	80	95	100	100	100
23	Early Yellow Six Weeks	5	25	70	75	75	85	90	100	100	100
24	Extra Early Refugee	15	45	80	85	85	90	95	95	100	100
25	Currie's Rustproof Golden Wax	18	55	90	95	95	100	100	100	100	100
26	Small Carolina	0	5	10	10	10	10	10	10	10	5
27	Goddard	5	30	50	60	65	70	75	80	95	100
28	White Marrowfat	18	45	60	60	60	70	70	80	80	100
29	Davis White Wax	3	15	30	60	65	92	100	100	100	100
30	Burger's Green-Pod Stringless	3	25	60	65	65	75	80	90	90	98
31	Refugee Wax	3	10	25	50	60	70	75	90	95	100
32	Dwarf Horticultural	18	65	80	80	80	85	90	100	100	100
33	Giant Stringless Green-Pod	3	10	25	50	55	65	90	100	100	100
34	Rustproof Golden Wax	5	30	50	65	70	85	95	100	100	100
35	Prolific Dwarf Black Wax	5	20	30	45	55	65	70	75	90	100
36	Henderson's Bush Lima	0	5	15	15	15	15	15	15	15	10
37	Extra Early Refugee	18	30	60	60	70	80	90	95	100	100
38	Giant Stringless Green-Pod	3	8	30	40	60	70	95	100	100	100
39	Black Valentine	15	40	80	85	90	95	100	100	100	100
40	Longfellow	5	35	75	75	80	80	95	100	100	100
41	Early Marrow Pea	8	45	70	70	75	80	85	90	95	95
42	Sondereger's Giant Stringless	3	5	22	40	55	65	90	95	100	100

*Results from 1918 are not available due to the absence of the author while in military service.

TABLE II

Percentage of Infection of Bacterial Blight on Variety Bean Plots, 1917

Plot Number	VARIETY	Percentage of Blight Infection					
		June 15	June 20	June 25	July 5	July 13	Aug. 3
1	Boston Pea	0	0	0	0	5	30
2	Michigan Wonder Pea	0	0	0	3	10	30
3	White Marrowfat	0	0	3	5	10	30
4	Burpee's White Wax	0	0	5	10	15	45
5	Currie's Rustproof Golden Wax	5	10	15	35	80	90
6	White Marrowfat	0	3	5	10	15	65
7	Dwarf Horticultural	0	5	10	35	70	90
8	Early Yellow Six Weeks	3	5	10	20	30	45
9	Burpee's Stringless Green-Pod	3	5	10	15	15	30
10	Rustproof Golden Wax	0	5	10	30	35	75
11	Longfellow	5	10	15	20	25	60
12	Giant Stringless Green-Pod	5	10	15	20	20	25
13	Black Valentine	10	15	25	40	50	95
14	Hopkins' Improved Round Red Valentine	5	10	20	30	35	75
15	Dwarf German Wax	0	5	10	20	70	90
16	Unrivaled Wax	0	0	0	10	25	30
17	Davis Kidney Wax	0	3	10	25	60	95
18	Ventura Wonder Wax	0	5	10	50	75	95
19	French Mohawk	0	0	0	10	15	50
20	Canadian Wonder	0	0	0	8	25	65
21	Kentucky Wonder	0	0	0	5	20	30
22	Scarlet Runner	0	0	0	5	10	25
23	Burger's Green-Pod Stringless	0	0	0	10	20	35
24	Small Carolina	0	0	0	5	5	5
25	Burpee's New Giant Podded Lima	0	0	0	5	5	5
26	Early Leviathan Lima	0	0	0	trace	trace	trace
27	Lewis' Lima	0	0	0	trace	trace	trace
28	Dreer's Wonder Lima	0	0	0	trace	trace	trace
29	Burpee's Improved Lima	0	0	3	5	5	5
30	Fordhook Lima	0	0	0	trace	trace	trace
31	Improved Henderson Lima	0	0	0	trace	trace	trace
32	Texas Speckled Lima	0	0	0	3	5	5
33	Burpee's Bush Lima	0	0	0	5	5	5
34	Henderson's Bush Lima	0	0	0	trace	trace	trace
35	Dreer's Bush Lima	0	0	0	3	5	5
36	Monstrous Lima	0	0	0	3	5	5
37	Los Angeles Wonder Lima	0	0	0	trace	trace	trace
38	Tepary	0	0	0	0	0	0
39	Lentils	0	0	0	0	0	0
40	Garvanzas	0	0	0	0	0	0
41	Broad Windsor	0	0	0	0	0	0
42	Soy	0	0	0	0	0	0
43	Jack	0	0	0	0	0	0

TABLE III

Percentage of Infection of Bacterial Blight on Variety Bean Plots, 1919

Plot Number	VARIETY	Percentage of Blight Infection: On Leaves June 10	June 20	July 1	July 7	July 21	July 28	On Pods June 25	July 9
1	Hopkins' Red Valentine	0	10	50	70	80	95	5	55
2	Early Mohawk	0	2	30	35	50	85	25	65
3	Giant Stringless Green-Pod Valentine	0	1	45	55	65	90	2	20
4	Extra Early Refugee	10	30	40	50	70	90	30	45
5	Keeney's Stringless Refugee	0	5	10	20	30	55	2	50
6	Longfellow No. 2	3	30	50	60	85	100	30	85
7	Black Valentine	3	40	75	80	95	100	70	95
8	Burpee's Stringless Green-Pod	20	25	35	40	70	95	25	30
9	Henderson's Black Valentine	0	40	50	75	90	100	50	100
10	Early Bountiful	3	20	50	70	85	100	50	80
11	Extra Early Red Valentine	2	20	50	55	80	95	10	35
12	Early Yellow Six Weeks	0	5	60	65	90	100	5	60
13	Burpee's Fordhook Favorite	0	3	25	50	70	90	5	30
14	Round Yellow Six Weeks	0	15	70	75	80	100	2	30
15	Refugee	0	5	5	5	20	35	—	50
16	Tennessee Green-Pod	0	30	75	90	90	100	50	90
17	Henderson's Bountiful	0	10	50	70	85	100	2	35
18	Hodson Wax	0	1	5	15	30	50	0	15
19	Burpee's Brittle Wax	0	15	20	35	70	90	2	40
20	New Pencil-Pod Black Wax	0	10	20	50	70	95	2	40
21	Burpee's Saddle-Back Wax	0	5	80	85	95	100	35	60
22	Challenge Dwarf Black Wax	0	25	45	75	90	100	5	50
23	Scarlet Flageolet Wax	3	15	85	90	95	100	40	70
24	Michigan White Wax	0	5	60	70	90	100	10	45
25	Webber's Wax	0	15	50	75	90	100	5	40
26	Rustproof Golden Wax	0	15	50	75	85	100	3	15
28	Currie's Rustproof Golden Wax	0	10	30	60	80	90	5	30
28	Cunii's Rustproof Golden Wax	0	5	30	40	75	95	1	80
29	Burpee's New Kidney Wax	0	1	20	40	80	90	2	70
30	New Prolific German Wax	3	15	40	75	85	100	5	70
31	Celestial Wax	0	5	45	60	80	95	15	70
32	Davis White Wax	0	10	30	70	90	100	20	80
33	Burpee's White Wax	0	15	35	60	80	95	1	20
34	Wardwell's Kidney Wax	0	10	55	75	90	100	10	60
35	Hodson Long Pod	0	0	10	20	45	60	0	35
36	Burger's Green-Pod Stringless	0	10	20	25	50	60	0	35
37	White Crease-Back	0	1	5	5	20	30	—	0
38	Golden Cluster Wax	0	5	5	10	10	20	—	10
39	Kentucky Wonder	0	1	5	10	60	75	0	75
40	Lazy Wife	0	10	15	25	50	60	0	20
41	Mammoth Stringless Green-Pod	0	5	45	50	70	90	2	20
42	Unrivaled Wax	0	5	25	50	70	85	2	30
43	French Mohawk	0	10	30	40	75	90	—	75

V—VARIETAL SUSCEPTIBILITY

Our observations show that the different varieties of kidney or snap beans exhibited considerable variation in their susceptibility to bacterial blight. Of the many varieties which we have grown, Burpee's Stringless Greenpod, Hodson Greenpod, Hodson Wax, Refugee Wax, Unrivaled Wax, Kentucky Wonder, White Marrowfat, Boston Pea, Michigan Wonder Pea and Southern Prolific have proven markedly superior to other varieties in blight resistance. Currie's Rust Proof, Black Valentine, Prolific Black Wax, Dwarf German Wax, Dwarf Horticultural, Davis Kidney Wax, Ventura Wonder Wax and Early Mohawk have proven very susceptible to blight attack. The Runner beans have also proven rather blight-resistant.

Lima beans have not only proven very blight-resistant, but have been able to outgrow its effects and produce good crops of beans. When weather conditions are favorable for blight development, the Limas have

not been badly diseased, and when wet weather is lacking, they have in some cases almost escaped blight attack.

VI—MODES OF INFECTION AND DISSEMINATION

By the Seed.—Bacterial blight is carried over from year to year by the seed. By means of diseased seed also, it is introduced into new localities. Once introduced it becomes established. The use of home-grown seed from infected plants insures the presence of the disease.

There is no question but that bean seed is an important factor in the dissemination of bacterial blight. Beach (4) in 1892, when he reported bacterial blight as a new disease, stated that the bacteria probably wintered over in the seed. Halstead (12) in 1901 states that infected seed transmits the disease from crop to crop. Almost every later publication mentioning this disease has made similar statements. There is also experimental evidence to prove this point. Giltner (11) in 1915 found that discolored beans which had been kept for one year in a dry room at room temperature contained living bacteria. In our work we have successfully cultured Bacterium phaseoli from beans held in storage at room temperature for eleven months. In our greenhouse experiments we have proven that bacterial blight of beans is carried over from year to year by the seed. Bean seed from carefully selected, disease-free pods, when planted in soil composted for two years and inclosed in screen and cloth-covered cages, produced disease-free plants. Diseased seed from blighted pods, when planted under identical conditions, germinated poorly. Such plants as were produced were carefully watched, and in almost every instance developed bacterial blight.

The cycle of the disease might be said to begin with the seed, spreading at germination to the cotyledons, then to the true leaves, and from the leaves to the pods and stems. From the pods the seed is infected, the organism again carried over winter, and the cycle repeated the following year.

By Bean Straw.—Early investigators also suggest that the disease might live through the winter on infected vines and pods. Barlow (1), 1904, stated that "A field where beans have sickened with this disease is unfit for growing beans for at least one season, as the germ lives over at least one winter in the stems and leaves left on the ground". Fulton (10), 1909, states that "The bacteria can live over at least one winter in stems and leaves left on the ground", and McCready (16), 1911, states that "The disease is carried over from year to year in the seed from a diseased crop, in the soil on which a diseased crop has been grown, or straw from infected bedding or manure". In no case does the writer conclusively prove this point. Muncie's (18), 1917, observations are that the disease winters through on diseased straw, and his experiments tend to prove this point. In our work we have successfully cultured Bacterium phaseoli from leaves and pods wintered over in the field. While bacterial blight was at its worst, badly diseased leaves and pods were picked. These were allowed to become thoroughly dry, and were then placed in small cotton bags. During August, part of these bags were hung to wires in the vineyard. The remainder were placed in small bundles of bean straw. These bundles were placed along a fence row. This material was left until May of the following spring. After repeated failures, successful cultures were obtained from diseased areas of both leaves and pods. Bacterium phaseoli was also successfully cultured from pods stored in our laboratory for ten months at room temperature.

By the Soil.—It has long been thought that Bacterium phaseoli winters over in the soil. Barlow (1), 1904, suggests this. Sackett (22),

1905, states that "The distribution of the disease is further affected by dead vines and leaves carried on the wind, by the soil, and through the seed", but does not mention any experiments proving these points. McCready (16), 1911, previously quoted, states that the disease is carried over from year to year in the soil on which a diseased crop has been grown. Muncie (18), 1917, has, by means of pot experiments, proven beyond reasonable doubt that the blight organism may winter over in the soil.

Dew as a Factor.—Dew is undoubtedly an important factor in dissemination of and infection by Bacterium phaseoli. Bacterial blight is an example of stomatal infection. Smith (25), 1911, states that "The spot disease of beans caused by Bacterium phaseoli is another example of stomatal infection. Serial sections through very young spots demonstrated this to me beyond reasonable doubt." Our experiments have verified this observation. Stomatal infection is the common mode of inoculation.

Our observations have shown that infection almost invariably occurs on the lower leaf surface, and that such infection is stomatal. This fact is of interest in view of the results of Duggar (7), 1911, who shows that of the stomates to the square millimeter of leaf surface in Phaseolus vulgaris, 281 occur on the lower and 40 on the upper surface.

The possibility of dews as a factor in the dissemination of bacterial blight was commented upon by Halstead (13), 1901, who states that "It is not unlikely that the germs were carried from the diseased leaves to the pods by dripping dews". Sacket (22), 1905, states that "Rain and dew are doubtless agents in spreading the germs from one part of the plant to another by washing them from old lesions onto unaffected parts", and Edgerton (8), 1913, "Many of the bacteria also ooze out to the surface of the leaf and are blown by the wind or carried by insects to other plants, or washed by the dews and rains to the portions of the plant below". Rolfs (20), 1915, in writing of a very similar organism, Bacterium malvacearum, states that "Wet weather, of course, materially aids in the dissemination of the organism. Even if the weather is excessively dry, the dew at night will often furnish sufficient water for inoculation." In writing of another similar organism, Bacterium Pruni, Rolfs (21), 1915, finds that "From the results it was evident that a moist lower surface is essential for inoculation and spread of the pathogene on the leaves. Observations show that dew plays quite as important a part in the dissemination of the pathogene as does rain. Rain and dew are not only important factors for inoculation, but they also carry the bacteria to the healthy leaves, twigs and fruit, and thus serve as agents of transportation."

Our observations regarding dew as a factor in the inoculation, infection and dissemination of Bacterium phaseoli are similar to those of Rolfs on Bacterium's Pruni and malvacearum. Moisture seems essential for inoculation by Bacterium phaseoli. Widespread infection first becomes evident in our plats following warm, rainy weather. Dews and rains that follow, further aid inoculation and dissemination. Heavy dews are common, and if the weather is extremely dry, dew often furnishes sufficient moisture for inoculation. Heavy dews dropping from leaf to leaf carry the pathogene. In this manner also, pods are infected and the spread of the disease from plant to plant in the row is doubtless largely due to dews. At night or early morning, while leaves are wet, the pathogene passes from leaf to leaf, and plant to plant along the row. It has frequently been observed that infection spreads along a row in both directions from an infected plant, and dew is doubtless a big factor in this dissemination.

By Dust.—Dust is probably another factor in the dissemination of bacterial blight. Bacteria which ooze out upon leaves and pods are washed to the ground. Diseased leaf tissue dries, crumples and falls. When the

weather becomes dry, dust forms around the base of the plants. The pathogene doubtless adheres to dust particles and on bits of leaf tissue incorporated therewith. During the growing season it is not uncommon for a film of dust to cover the entire lower leaf surface. It is probable that some of these dust particles carry the pathogene. When heavy dews form or rain falls, inoculation doubtless occurs. Because of the large amount of wind and dry weather occurring under our conditions, and since infection continues during dry weather, it seems probable that dust is a factor in the dissemination of this disease.

By Rain.—The possibility of rain as a factor in the dissemination of bacterial blight was mentioned by Sackett(22), 1905, and Edgerton (9), 1913, as previously noted. There can be no doubt that rain is a factor in disseminating the pathogene from leaf to leaf, leaf to pod, and plant to plant, in the same row. Our observations also show that wind-driven rain is sometimes a factor in disseminating bacterial blight from row to row. Faulwetter (9), 1917, in his work on angular leaf spot of cotton has noted the same point. In our work we have found that following a rain, accompanied by wind, bacterial blight from a center of primary infection, spreads to the greatest extent in a southeasterly direction. This is accounted for by the fact that wind-driven rain is commonly blown in that direction, and undoubtedly carries the pathogene from row to row, and in some cases across a number of rows.

By Insects.—The part which insects play in the dissemination of bacterial blight is unknown, though they are undoubtedly a factor in spreading the disease. Various workers have mentioned insects as a possible factor in the dissemination of bacterial blight, and Sackett (22), 1905, states that "Insects play an important part in disseminating the trouble, consequently any measures which tend to check these pests will aid in controlling bacteriosis". But there is no experimental evidence bearing on this point. In our work we have closely observed the work of various insects present. Our observation is that leaf-eating insects are of little importance in disseminating the pathogene. Rarely does infection occur at an insect injury. It is possible that insects might be a factor in dissemination by carrying the pathogene from infected to uninfected areas on their legs and bodies. Jassids are usually abundant, and it has been thought that they might in this way be a factor in the dissemination of bacterial blight. In view of the work of Faulwetter (9), 1917, on angular leaf spot of cotton, it seems probable that jassids are not a great factor in the dissemination. At best, insects can be of but minor importance in the dissemination of bacterial blight. Its spread during favorable weather conditions is so rapid and widespread that the possibility of insects being the primary means of dissemination is obviously impossible.

By Overflow.—A case of the dissemination of this disease by overflow was very noticeable in our pinto bean plots during 1917. No trace of bacterial blight was found in this plot until seven days after an overflow, following a heavy rain. At this time it became noticeable along the bottom and sides of a shallow draw crossing the plot. The disease was traced along the draw, but no signs of infection could be found except where water had touched the vines. Because of this peculiar circumstance the plot was closely watched. The disease continued to develop and spread in the overflowed area. One week after infection was first noticed, the disease centered and was conspicuous in the overflowed area. Gradually the blight spread from plant to plant along the rows radiating from this area of primary infection, and within three weeks traces of bacterial blight could be found over the entire field.

The closest bean plot was 200 yards away. This plot was badly infected. Diseased leaves were drying and crumbling. Water drained from

this diseased plot was carried across the pinto plot. There can be little doubt but that the infection of the pinto beans was the result of this overflow. Bacteria were doubtless washed from plot to plot on fallen leaves, on trash, and probably on soil particles, and carried by the water itself.

VII—CONTROL MEASURES

Since the time when bacterial blight has become of importance as a serious bean disease, various measures for its control have been attempted. These measures have largely centered on spraying, seed treatment, evolving of immune or blight-resistant varieties, and the securing of disease-free seed. In our experiments, work has been continued along these lines with the addition of several new phases of these factors.

Spraying.—Though sprays have been rather extensively used in attempts to control bacterial blight, the results have not always been conclusive or entirely satisfactory. For this reason spraying was included in our control experiments during the seasons of 1916 and 1917.

During both seasons fungal and insecticidal sprays were used. The fungal sprays were, of course, used to control bacterial blight by direct methods. The insecticidal sprays were used in hopes of preventing the spread of the pathogene by various insects, and in this way to reduce, if possible, the amount of bacterial blight infection. These sprays were in some cases combined.

During the season of 1916 the spraying work was rather extensive. Two varieties of beans, Early Yellow Six Weeks and Northern Grown Pea were planted in separate plots. The beans were planted about 6 inches apart in rows 3 feet apart. Each plot was further divided into blocks for spraying and check. The blocks contained three rows, each 30 feet long. Blocks were separated from one another by an unsprayed row on either side and a 3-foot unplanted space at either end.

Three applications of sprays were made. The first application, two weeks after germination, the second two weeks later, and the last after another two-week interval.

All liquid sprays were applied with a knapsack sprayer, a mist-nozzle being used.

In applying powdered sprays, a Liggett's powder gun was used.

In all Black Leaf "40" sprays the proportion was 1½ teaspoonfuls to 1 gallon of water.

Lead arsenate was used in powdered form; 1 pound being added to each 50 gallons of solution.

All Bordeaux sprays were prepared as indicated by formula. When Bordeaux was used in combination with other sprays, the 4-4-50 mixture was used.

Adhesive was prepared from 2 pounds of resin and 1 of sal soda. This was added to 100 gallons of solution.

Lime, when added to liquid sprays, was used at the rate of 4 pounds to each 50 gallons of solution.

Paris green was used at the rate of 1 pound to each 150 gallons of water.

Kerosene emulsion was prepared by the usual formula.

The lime-sulphur used was commercial, testing 30 degrees Baume.

Self-boiled lime-sulphur was prepared by the 8-8-50 formula.

The powdered sulphur was that used in ordinary orchard dusting.

In determining percentages of infection, 100 plants were selected at random in each plot. The results obtained are shown in Tables IV and V.

TABLE IV

Percentage of Infection of Bacterial Blight on Sprayed Bean Plots, 1916

Block 1

EARLY YELLOW SIX WEEKS

Plot Number	SPRAY USED	PERCENTAGE OF BLIGHT INFECTION				
		July 1	July 6	July 10	July 16	Aug. 5
1	Black Leaf "40"	3	46	100	100	100
2	Black Leaf "40" and lead arsenate	1	53	100	100	100
3	Black Leaf "40" and Bordeaux	8	43	92	100	100
4	Bordeaux 3-3-50	3	49	100	100	100
5	Bordeaux and lead arsenate	6	54	100	100	100
6	Bordeaux and adhesive	4	46	100	100	100
7	Lime and adhesive	9	58	100	100	100
8	Lime (liquid)	7	54	100	100	100
9	Lead arsenate (liquid)	10	62	100	100	100
10	Lead arsenate and lime (liquid)	2	39	96	100	100
11	Paris green (liquid)	Foliage injured by spray				
12	Paris green and lime (liquid)	Foliage injured by spray				
13	Bordeaux 4-4-50	5	48	100	100	100
14	Bordeaux 5-4-50	Foliage slightly injured				
15	Kerosene emulsion	Foliage destroyed by spray				
16	Lime-sulphur 1-50	Foliage slightly injured				
17	Lime-sulphur 1-60	5	53	100	100	100
18	Lime-sulphur 1-70	6	51	91	100	100
19	Lead arsenate (powder)	12	64	100	100	100
20	Lime (powder)	14	51	100	100	100
21	Self-boiled lime-sulphur	2	43	100	100	100
22	Sulphur (powder)	8	66	100	100	100
23	Check	11	56	100	100	100

TABLE V

Percentage of Infection of Bacterial Blight on Sprayed Bean Plots, 1916

Block 2

NORTHERN GROWN PEA

Plot Number	SPRAY USED	PERCENTAGE OF BLIGHT INFECTION				
		July 1	July 6	July 10	July 16	Aug. 5
1	Black Leaf "40"	4	37	93	100	100
2	Black Leaf "40" and lead arsenate	12	66	100	100	100
3	Black Leaf "40" and Bordeaux	10	48	100	100	100
4	Bordeaux 3-3-50	11	59	100	100	100
5	Bordeaux and lead arsenate	8	61	100	100	100
6	Bordeaux and adhesive	2	41	95	100	100
7	Lime and adhesive	14	66	100	100	100
8	Lime (liquid)	5	57	100	100	100
9	Lead arsenate (liquid)	13	62	100	100	100
10	Lead arsenate and lime (liquid)	5	41	100	100	100
11	Paris green (liquid)	Foliage injured by spray				
12	Paris green and lime (liquid)	Foliage injured by spray				
13	Bordeaux 4-4-50	12	54	100	100	100
14	Bordeaux 5-4-50	Foliage slightly injured				
15	Kerosene emulsion	Foliage destroyed by spray				
16	Lime-sulphur 1-50	Foliage slightly injured				
17	Lime-sulphur 1-60	10	46	100	100	100
18	Lime-sulphur 1-70	9	57	100	100	100
19	Lead arsenate (powder)	6	52	100	100	100
20	Lime (powder)	10	61	100	100	100
21	Self-boiled lime-sulphur	13	58	100	100	100
22	Sulphur (powder)	7	47	93	100	100
23	Check	14	100	100	100	100

The sprays used during 1916 in repelling and controlling insects proved of little value. In no case did any spray prove of marked value in the control of bacterial blight.

During 1917 all duplicate sprays and those which seemed impractical were dropped. The sprays used were prepared in the same manner as as those of the previous season.

Two varieties of beans, Extra Early Refugee and Early Yellow Six Weeks, were again used. These were planted in plots and blocks similar to those of 1917.

Four applications of sprays were made during 1916, the first two weeks after germination, and the others at two-week intervals.

The percentage of infection was obtained in the same manner as during 1916. Results are shown in Tables VI and VII.

TABLE VI

Percentage of Infection of Bacterial Blight on Sprayed Bean Plots, 1917

Block 1

EXTRA EARLY REFUGEE

Plot Number	SPRAY USED	PERCENTAGE OF BLIGHT INFECTION				
		June 17	June 20	June 25	July 5	July 13
1	Bordeaux 4-4-50	2	11	64	90	100
2	Bordeaux and lead arsenate	0	15	76	97	100
3	Black Leaf "40"	0	6	51	88	100
4	Lead arsenate (liquid)	0	12	59	91	100
5	Check	1	9	73	96	100

TABLE VII

Percentage of Infection of Bacterial Blight on Sprayed Bean Plots, 1917

Block 2

EARLY YELLOW SIX WEEKS

Plot Number	SPRAY USED	PERCENTAGE OF BLIGHT INFECTION				
		June 17	June 20	June 25	July 5	July 13
1	Bordeaux 4-4-50	0	14	75	93	100
2	Bordeaux and lead arsenate	0	12	68	96	100
3	Black Leaf "40"	2	19	83	100	100
4	Lead arsenate (liquid)	0	6	72	91	100
5	Check	0	10	66	89	100

From these results it may be seen that spraying did not check bacterial blight. We do not believe that bacterial blight can be controlled by spraying. The mode of inoculation is primarily stomatal, and infection spraying. The mode of inoculation is primarily stomatal. Most of the stomates occur upon the lower leaf surface. Our work has shown that in ordinary spraying it is almost impossible to cover more than one-fifth to one-sixth of the total lower leaf surface. Even where an angle nozzle is used and spraying is done with special care, only about one-half of the total lower leaf surface is coated with spray. The large amount of foliage makes effective spraying impossible. It is doubtful whether sprays will ever prove of value in controlling bacterial blight.

Distance Plantings.—Because of the fact that the pathogene passes from leaf to leaf and plant to plant, an experiment in planting at differ-

ent distances was conducted. It was thought that if plants were separated from one another by a short interval the spreading of the disease from infected to healthy plants might be checked.

Plantings were made at intervals of 6, 12 and 18 inches, and in hills 15 inches apart.

Seed of Extra Early Refugee was used. Rows were 50 feet long and 4 feet apart.

Percentage of infection was determined as in previous experiments. The results of the season of 1916 are shown in Table VIII.

The experiment was repeated in 1917. Details were in every way similar to those of 1916. The results are shown in Table IX.

These results show that the distance between plants in the row has no influence upon the percentage of bacterial blight infection. From the

TABLE VIII

Percentage of Infection of Bacterial Blight on Distance Plantings of Beans

1916

EXTRA EARLY REFUGEE

Plot Number	DISTANCE OF PLANTING	PERCENTAGE OF BLIGHT INFECTION July 3	July 10	July 16	Aug. 5
1	6-inch intervals	20	38	72	100
2	12-inch intervals	17	50	68	100
3	18-inch intervals	10	38	62	100
4	Hills—15 inches apart	22	40	68	100

TABLE IX

Percentage of Infection of Bacterial Blight on Distance Plantings of Beans

1917

EXTRA EARLY REFUGEE

Plot Number	DISTANCE OF PLANTING	PERCENTAGE OF BLIGHT INFECTION June 20	June 25	July 5	July 10
1	6-inch intervals	20	46	62	80
2	12-inch intervals	12	33	58	75
3	18-inch intervals	15	30	53	72
4	Hills—15 inches apart	17	41	65	84

theoretical standpoint, the greatest percentage of infection should be found upon the thick plantings. Actual experiments do not bear out the theoretical deductions. Not only was bacterial blight as prevalent in beans planted at 12 and 18-inch intervals, and in hills, but the yields were much less than in the 3 and 6-inch plantings.

Seed Treatment.—In our seed treatment experiments, three methods of control were tried, namely, the use of chemicals, hot water and dry heat. It was thought that some method might be evolved whereby the blight organism could be killed and the germination power of the seed not injured. The evolving of a successful method of seed treatment is beset with many difficulties. When beans are soaked for a time, the seed coats loosen and slip off. Such seeds are of small value for planting. For this reason hot

water or chemical solutions must be used with great care. Bacterium phaseoli is found on the surface of infected seeds, beneath the seed coat, and between the cotyledons. To kill the blight pathogene without at the same time injuring the seed germ, lying just beneath the seed coat, is indeed a difficult problem.

The following methods of seed treatment were used:

1. Formalin.—Seed was soaked in 40 percent formaldehyde, dilution 1-100. Temperature was 24 degrees C.
2. Mercuric Chloride.—Seed was soaked in a mercuric chloride solution, dilution 1-1000. Temperature was 24 degrees C.
3. Dry Heat.—Seed was heated in an electric oven and held at constant temperature during treatment.
4. Sulphuric Acid.—Seed was treated with sulphuric acid Sp. Gr. 1.840. After treatment the seed was washed for fifteen minutes in running water.
5. Hot Water.—Seed was held in hot water at constant temperature. After treatment the seed was cooled to room temperature.

Seed used in this experiment was Extra Early Refugee, hand-picked, 1 year old.

Immediately after treating, a germination test was run. All testing was done in thoroughly sterilized Geneva testers. These were kept in an electric incubator, held at a temperature of 82 degrees F. Fifty seeds of each lot were tested. The results are shown in Table X.

TABLE X

Percentage of Tester Germination of Treated Bean Seed, Tested Immediately After Treatment

Lot Number	TREATMENT GIVEN	GERMINATION RECORD BY DAYS								Number of Seeds Germinating	Percentage
		1	2	3	4	5	6	7	8		
1	40 percent formaldehyde solution, 1-100, 20 minutes	0	2	30	3	0	0	0	0	35	70
2	40 percent formaldehyde solution 1-100, 30 minutes	0	3	15	3	0	0	0	0	21	42
3	Mercuric chloride solution 1-1000, 20 minutes	0	5	20	3	5	0	0	0	33	66
4	Mercuric chloride solution, 1-1000, 30 minutes	0	1	15	0	0	0	0	0	16	32
5	Dry heat, 58 degrees C., 45 minutes	0	3	30	8	0	0	0	0	41	82
6	Dry heat, 75 degrees C., 30 minutes	0	8	17	13	2	0	0	0	40	80
7	Dry heat, 50 degrees C., 2 hours	0	8	30	2	0	0	0	0	40	80
8	Sulphuric acid, 5 minutes	0	13	27	0	0	0	0	0	40	80
9	Sulphuric acid, 10 minutes	0	10	13	0	0	0	0	0	23	46
10	Sulphuric acid, 15 minutes	0	15	15	0	0	0	0	0	30	60
11	Sulphuric acid, 20 minutes	0	7	10	0	0	0	0	0	17	34
12	Hot water, 72 degrees C., 5 minutes	0	10	20	0	0	0	0	0	30	60
13	Hot water, 72 degrees C., 10 minutes	0	8	12	0	0	0	0	0	20	40
14	Hot water, 72 degrees C., 15 minutes	0	0	0	0	0	0	0	0	0	0
15	Hot water, 72 degrees C., 20 minutes	0	0	0	0	0	0	0	0	0	0
16	Hot water, 50 degrees C., 8 minutes	0	12	18	5	0	0	0	0	35	70
17	Hot water, 50 degrees C., 20 minutes	0	12	20	2	0	0	0	0	34	68
18	Hot water, 65 degrees C., 20 minutes	0	2	3	2	0	0	0	0	7	14
19	Check	0	10	32	8	0	0	0	0	50	100
20	Check	0	3	37	6	0	0	0	0	46	92

From the results obtained in this germination test it may be seen that seed treatment by means of chemical solutions, hot water and dry heat,

has in every instance lowered the germinating power of the seed. In most methods the injury is so great as to make their use impractical.

Immediately after treating, also, treated seed was planted in the field. One hundred seeds of each lot were planted under ordinary field conditions. A good rain following planting. Thereafter no rain fell for three weeks. The results of this test are shown in Table XI.

TABLE XI

Percentage of Field Germination of Treated Bean Seed

Plot Number	TREATMENT GIVEN	July 13		Aug. 3		
		Number of Plants	Percentage of Plants	Number of Plants	Percentage of Plants	Increase or Decrease in Number of Plants
1	40 percent formaldehyde solution, 1-100, 20 minutes	20	20	18	18	— 2
2	40 percent formaldehyde solution, 1-100, 30 minutes	17	17	16	16	— 1
3	Mercuric chloride solution, 1-1000, 20 minutes	37	37	35	35	— 2
4	Mercuric chloride solution, 1-1000, 30 minutes	32	32	29	29	— 3
5	Dry heat, 58 degrees C., 45 minutes	32	32	25	25	— 7
6	Dry heat, 75 degrees C., 30 minutes	55	55	44	44	—11
7	Dry heat, 50 degrees C., 2 hours	44	44	37	37	— 7
8	Sulphuric acid, 5 minutes	18	18	17	17	— 1
9	Sulphuric acid, 10 minutes	5	5	4	4	— 1
10	Sulphuric acid, 15 minutes	1	1	1	1	same
11	Sulphuric acid, 20 minutes	2	2	2	2	same
12	Hot water, 72 degrees C., 5 minutes	3	3	3	3	same
13	Hot water, 72 degrees C., 10 minutes	1	1	1	1	same
14	Hot water, 72 degrees C., 15 minutes	0	0	0	0	same
15	Hot water, 72 degrees C., 20 minutes	0	0	0	0	same
16	Hot water, 50 degrees C., 8 minutes	29	29	26	26	— 3
17	Hot water, 50 degrees C., 20 minutes	11	11	10	10	— 1
18	Hot water, 65 degrees C., 20 minutes	1	1	1	1	same
19	Check	89	89	89	89	same
20	Check	94	94	93	93	— 1

The percentages of germination under actual field conditions are, in every case, less than in the laboratory test. In most cases the germination percentage is much less. This must be ascribed to the weakening of the seed germ by seed treatment. The laboratory germination test, conducted under almost ideal conditions, proves that seed treatment lowers the percentage of germination. This lower percentage of field germination may be accounted for by the weakening influence of seed treatments. Such treatments so injure the seed that the germinating power of some is entirely killed, others germinate only under the most favorable conditions, and still others germinate under field conditions, but produce weak plants. The death of young plants noted in Table XI is undoubtedly due to this last factor. Seed treatment injures the seed, but there is sufficient vitality for germination. These young plants, which later die, are noticeably small and spindly, appearing generally stunted. Under ideal conditions they might produce plants, but during the period of dry weather, which followed their germination, these weak plants were unable to survive.

The weakening influence of seed treatment is further shown by another laboratory germination test conducted one month after the seed was treated. Fifty seeds were tested as before in sterilized Geneva testers. Conditions were in every way identical to those of the first test. The only difference was that the treated seed had been held for one month at ordinary room temperature. The results of this test are shown in Table XII.

TABLE XII

Percentage of Tester Germination of Treated Bean Seed, Tested One Month After Treatment

Lot Number	TREATMENT GIVEN	GERMINATION RECORD BY DAYS							Number of Seeds Germinating	Percentage
		1	2	3	4	5	6	7		
1	40 percent formaldehyde solution, 1-100, 20 minutes	0	8	15	0	0	0	0	23	46
2	40 percent formaldehyde solution, 1-100, 30 minutes	0	10	3	0	0	0	0	13	26
3	Mercuric chloride solution, 1-1000, 20 minutes	0	15	20	3	2	0	0	40	80
4	Mercuric chloride solution, 1-1000, 30 minutes	0	5	7	5	0	0	0	17	34
5	Dry heat, 58 degrees C., 45 minutes	0	7	25	0	0	0	0	32	64
6	Dry heat, 75 degrees C., 30 minutes	0	17	23	0	0	0	0	40	80
7	Dry heat, 50 degrees C., 2 hours	0	15	20	0	0	0	0	35	60
8	Sulphuric acid, 5 minutes	0	2	7	0	0	0	0	9	18
9	Sulphuric acid, 10 minutes	0	10	2	0	0	0	0	12	24
10	Sulphuric acid, 15 minutes	0	9	1	0	0	0	0	10	20
11	Sulphuric acid, 20 minutes	0	14	3	0	0	0	0	17	34
12	Hot water, 72 degrees C., 5 minutes	0	7	5	0	0	0	0	12	24
13	Hot water, 72 degrees C., 10 minutes	0	5	2	0	0	0	0	7	14
14	Hot water, 72 degrees C., 15 minutes	0	0	0	0	0	0	0	0	0
15	Hot water, 72 degrees C., 20 minutes	0	0	0	0	0	0	0	0	0
16	Hot water, 50 degrees C., 8 minutes	0	5	5	0	0	0	0	10	20
17	Hot water, 50 degrees C., 20 minutes	0	7	1	0	0	0	0	8	16
18	Hot water, 65 degrees C., 20 minutes	0	0	0	0	0	0	0	0	0
19	Check	0	6	35	8	0	0	0	49	98
20	Check	0	9	30	1	0	0	0	48	98

From a study of this table it may be seen that in almost every case the germination percentage is less than in the test conducted immediately after seed treatment. In all but a few instances the month of storage has greatly reduced the percentage of germination. As a whole, the seeds which did germinate, grew with less vigor than did those in the previous test. A comparison of germinating percentages under these various conditions is found in Table XIII.

TABLE XIII

Comparison of the Germination Records of Treated Bean Seed

Lot Number	TREATMENT GIVEN	DATE OF SEED GERMINATION TEST		
		July 3	Aug. 3	Field Germination
1	40 percent formaldehyde solution, 1-100, 20 minutes	70	46	18
2	40 percent formaldehyde solution, 1-100, 30 minutes	42	26	16
3	Mercuric chloride solution, 1-1000, 20 minutes	66	80	35
4	Mercuric chloride solution, 1-1000, 30 minutes	32	34	29
5	Dry heat, 58 degrees C., 45 minutes	82	64	25
6	Dry heat, 75 degrees C., 30 minutes	80	80	44
7	Dry heat, 50 degrees C., 2 hours	80	60	37
8	Sulphuric acid, 5 minutes	80	18	17
9	Sulphuric acid, 10 minutes	46	24	4
10	Sulphuric acid, 15 minutes	60	20	1
11	Sulphuric acid, 20 minutes	34	34	2
12	Hot water, 72 degrees C., 5 minutes	60	24	3
13	Hot water, 72 degrees C., 10 minutes	40	14	1
14	Hot water, 72 degrees C., 15 minutes	0	0	0
15	Hot water, 72 degrees C., 20 minutes	0	0	0
16	Hot water, 50 degrees C., 8 mniutes	70	20	26
17	Hot water, 50 degrees C., 20 minutes	68	16	10
18	Hot water, 65 degrees C., 20 minutes	14	0	1
19	Check	92	98	93
20	Check	100	96	89

Because of the low percentage of germination in all methods of seed treatment, no accurate record of the percentage of bacterial blight infection was made. The block, however, was kept under careful observation during the entire growing season. No plot was blight-free.

In view of these results, seed treatment, with chemical solutions, hot water or dry heat, must be regarded as of doubtful value. All methods tried greatly reduced the percentage of germination, and none completely controlled bacterial blight. Both hot water and dry heat at certain temperatures kill the seed and, when they do not, the bacteria are not always destroyed. The fact that bacteria are present beneath the seed coat and between the cotyledons makes any present method of chemical treatment impractical. In killing the blight pathogene, the germinating power of the seed is either greatly weakened or totally destroyed. No present method of seed treatment can be regarded as satisfactory.

Aged Seed.—In his work on cotton anthracnose, Barre (2) found that diseased cotton seed kept in storage for three years gave disease-free plants when planted in the field. With this fact in mind, similar work was begun with beans to determine whether blight-free plants might be secured from seed stored for a number of years. The first problem was to determine the length of time over which bean seed may practically be stored. To this end germination experiments were conducted in both laboratory and field.

Healthy, hand-picked seed, 1, 2, 3 4 and 5 years old, was used. Each year's seed was represented by four varieties. Fifty seeds of each variety were tested.

All laboratory testing was done in sterilized Geneva testers, kept in an electric incubator, and held at a temperature of 82 degrees F.

Tester germination records are shown in Table XIV.

TABLE XIV

Percentage of Tester Germination of Bean Seed of Different Ages

Lot Number	VARIETY	GERMINATION RECORD BY DAYS							Number of Seeds Germinating	Percentage
	ONE YEAR OLD	1	2	3	4	5	6	7		
1	Longfellow	0	15	32	3	0	0	0	50	100
2	German Black Wax	0	13	27	5	1	0	0	50	100
3	White Marrowfat	0	12	30	2	0	0	0	47	94
4	Round Yellow Six Weeks	0	16	32	2	0	0	0	50	100
	Average									98.50
	TWO YEARS OLD									
5	Longfellow	0	13	24	7	4	0	0	48	96
6	German Black Wax	0	14	31	5	0	0	0	50	100
7	White Marrowfat	0	11	27	4	1	0	0	43	86
8	Round Yellow Six Weeks	0	9	34	1	0	0	0	44	88
	Average									92.50
	THREE YEARS OLD									
9	Longfellow	0	12	23	4	0	0	0	39	78
10	Burpee's White Wax	0	12	26	3	0	0	0	41	82
11	White Marrowfat	0	10	34	5	1	0	0	50	100
12	Rustproof Golden Wax	0	15	32	2	1	0	0	50	100
	Average									90
	FOUR YEARS OLD									
13	Extra Early Refugee	0	10	25	4	2	0	0	41	82
14	Hodson Long-Pod	0	8	18	5	1	0	0	32	64
15	White Marrowfat	0	15	31	4	0	0	0	50	100
16	Round Yellow Six Weeks	0	12	27	5	0	0	0	44	88
	Average									83.50
	FIVE YEARS OLD									
17	Universal Wax	0	0	0	0	0	0	0	0	0
18	Early Yellow Six Weeks	0	13	16	4	0	0	0	33	66
19	White Marrowfat	0	5	4	1	0	0	0	10	20
20	Longfellow	0	10	9	5	3	0	0	27	54
	Average									35.00

From these results it would seem that the use of 3 and 4-year-old bean seed might be practical, provided plants free from bacterial blight could be secured in this way. In order to further test the practicability of the use of aged seed, a similar experiment was conducted under field conditions. Previous experience had shown that tester results on bean seed germination are very frequently unsatisfactory.

This experiment was in every way similar to the other, except that the beans were planted in the soil. Conditions were almost ideal.

The results of this test are shown in Table XV.

TABLE XV

Percentage of Field Germination of Bean Seed of Different Ages

Lot Number	VARIETY	GERMINATION RECORD BY DAYS																		Number of Seeds Germinating	Percentage
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18		
	ONE YEAR OLD																				
1	Longfellow ...	0	0	0	0	0	0	0	2	7	13	13	6	1	0	1	0	1	0	44	88
2	German Black Wax	0	0	0	0	0	0	0	0	0	11	21	14	0	0	0	1	0	0	47	94
3	White Marrow-fat	0	0	0	0	0	0	0	0	4	12	15	12	2	0	1	1	0	0	47	94
4	Round Yellow Six Weeks..	0	0	0	0	0	0	0	0	5	24	12	3	1	0	0	1	0	0	46	92
															Average						92
	TWO YEARS OLD																				
5	Longfellow ...	0	0	0	0	0	0	0	0	1	0	12	11	7	9	4	1	1	0	46	92
6	German Black Wax	0	0	0	0	0	0	0	0	1	27	17	1	0	0	0	0	0	0	46	92
7	White Marrow-fat	0	0	0	0	0	0	0	1	2	14	13	11	0	2	0	0	0	0	43	86
8	Round Yellow Six Weeks..	0	0	0	0	0	0	0	2	19	19	6	1	0	0	0	0	0	0	47	94
															Average						91
	THREE YEARS OLD																				
9	Longfellow ...	0	0	0	0	0	0	0	0	0	3	22	7	0	0	0	0	0	0	32	64
10	Burpee's White Wax	0	0	0	0	0	0	0	0	0	2	15	9	1	0	1	0	1	0	29	58
11	White Marrow-fat	0	0	0	0	0	0	0	6	16	10	6	0	0	3	0	0	0	0	41	82
12	Rustproof Golden Wax ..	0	0	0	0	0	0	0	0	0	4	24	7	4	0	0	0	0	0	39	78
															Average						70.50
	FOUR YEARS OLD																				
13	Extra Early Refugee	0	0	0	0	0	0	0	0	0	1	4	2	2	1	1	0	0	0	11	22
14	Hodson Long-Pod	0	0	0	0	0	0	0	0	0	1	7	9	3	1	1	1	0	0	23	46
15	White Marrow-fat	0	0	0	0	0	0	0	0	2	9	6	0	0	0	1	0	0	0	18	36
16	Round Yellow Six Weeks..	0	0	0	0	0	0	0	0	3	25	11	3	3	2	0	0	0	0	47	94
															Average						49.50
	FIVE YEARS OLD																				
17	Universal Wax	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	2	4
18	Early Yellow Six Weeks..	0	0	0	0	0	0	0	0	0	0	0	1	8	14	14	3	1	0	41	82
19	White Marrow-fat	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	2
20	Longfellow ...	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
															Average						22

From a study of this table it may be seen that 2-year-old bean seed is as good as 1-year-old, that 3-year-old seed is often of doubtful value for planting, and that 4 and 5-year-old seed are of no practical value. The tester and actual field germination tests in no way agree. A comparison of these tests is given in Table XVI.

TABLE XVI

Comparison of the Germination Records of Bean Seed of Different Ages

Lot Number	VARIETY	Tester Percentage of Germination	Field Percentage of Germination
	ONE YEAR OLD		
1	Longfellow	100	88
2	German Black Wax	100	94
3	White Marrowfat	94	94
4	Round Yellow Six Weeks	100	92
	Average	98.50	92.00
	TWO YEARS OLD		
5	Longfellow	96	92
6	German Black Wax	100	92
7	White Marrowfat	86	86
8	Round Yellow Six Weeks	88	94
	Average	92.50	91.00
	THREE YEARS OLD		
9	Longfellow	78	64
10	Burpee's White Wax	82	58
11	White Marrowfat	100	82
12	Rustproof Golden Wax	100	78
	Average	90	70.50
	FOUR YEARS OLD		
13	Extra Early Refugee	82	22
14	Hodson Long-Pod	64	46
15	White Marrowfat	100	36
16	Round Yellow Six Weeks	88	94
	Average	83.50	49.50
	FIVE YEARS OLD		
17	Universal Wax	0	4
18	Early Yellow Six Weeks	66	82
19	White Marrowfat	20	2
20	Longfellow	54	0
	Average	35.00	22.00

As a result of these germination results, plots of 2 and 3-year-old seed were planted during the years 1917 and 1919. No plots were planted during 1918 because of the absence of the writer in army service.

The beans planted were secured from blight-infected lots. They were planted on soil which had not grown beans for at least four years. There was no drainage from other bean plots.

Duplicate plots were planted during the spring of 1917. The distance from all other bean plots was such that infection by any method of infection was thought impossible. Despite this fact, during 1917 a low percentage of infection occurred in one of the 3-year-old seed plots. The other plots were blight-free.

Duplicate field plantings of infected seed 2 and 3 years old, during the fall of 1917, gave all blight-free plants.

During early spring of 1919, greenhouse plantings of infected seed, 2 and 3 years old, gave all blight-free plants.

Plantings of infected seed 2 and 3 years old during 1919 in the varietal plots, when protected by cages covered with both screen and cheesecloth, gave blight-free plants, though surrounded by diseased plants.

Greenhouse plantings of infected seed 2 and 3 years old during the early summer of 1919, in cages covered with both screen and cheesecloth, gave blight-free plants, though many infected plants were near.

Duplicate field plantings of infected seed 2 and 3 years old during the spring of 1919 gave all blight-free plants.

A study of these results shows that a total of nine plantings of 2 and 3-year-old infected seed were made. All plants in eight of these plantings were blight-free. The appearance of a few blighted plants in one of the early 3-year-old plantings must, in view of the latter results secured, be regarded as due to chance or accidental infection. In all plantings made

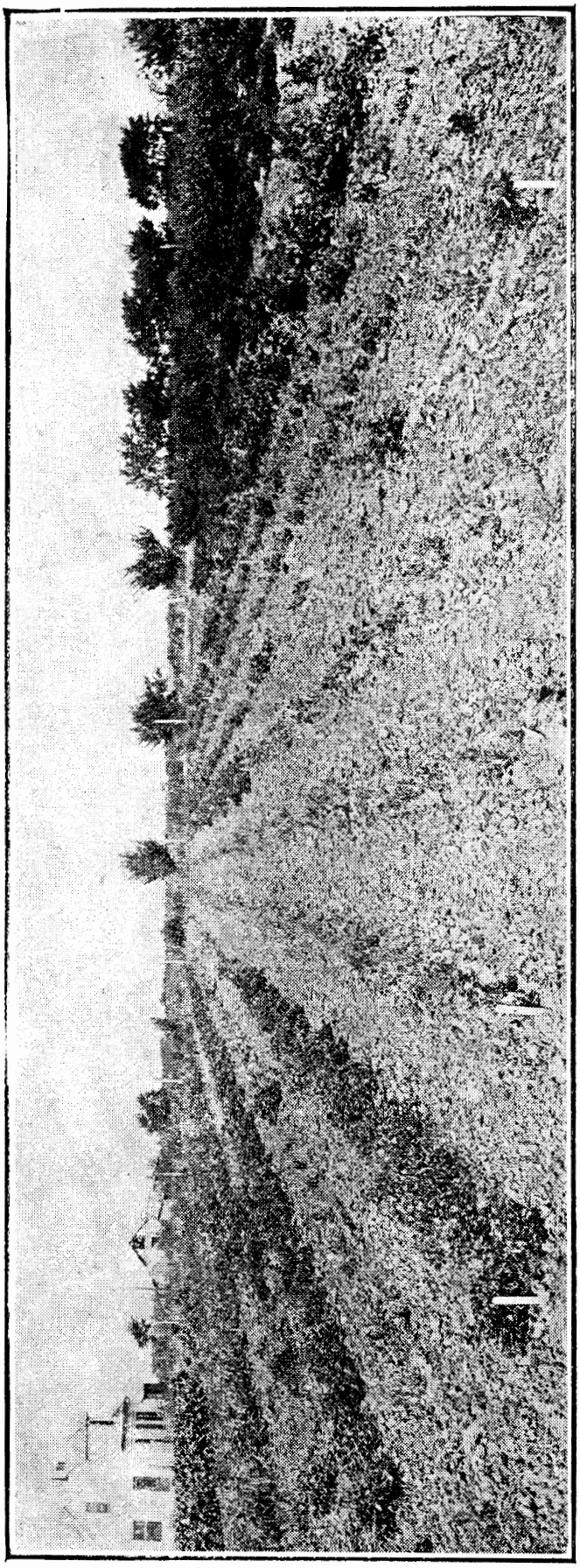

FIG. 15. Variety bean plot 1919. A number of blight resistant varieties can be noted.

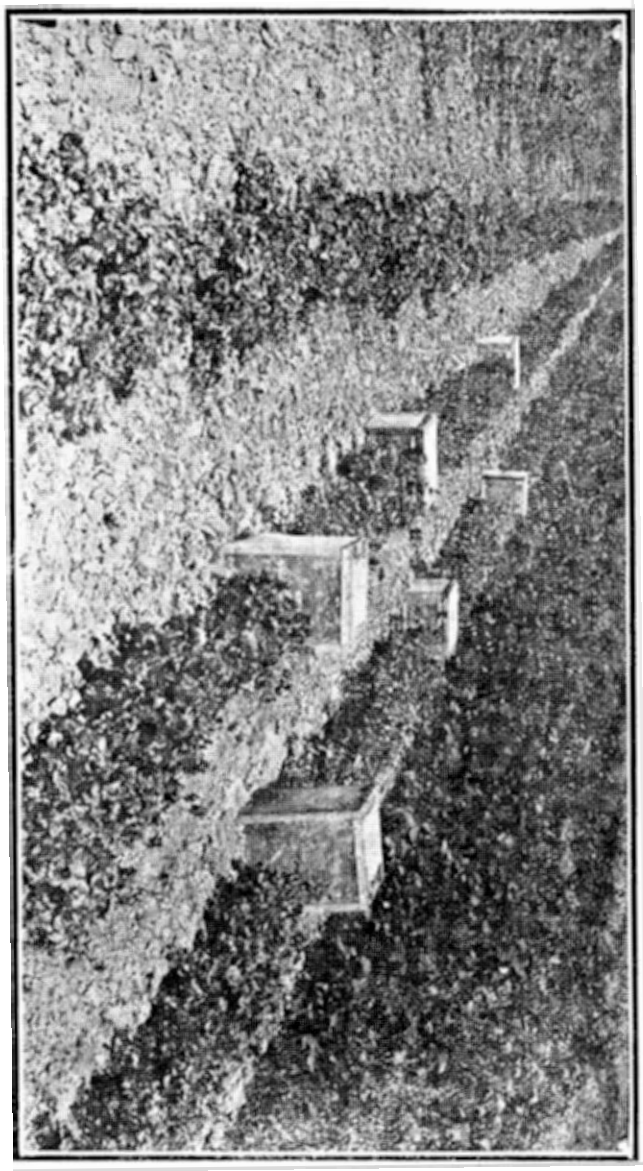

FIG. 16. Type of field cages used in experimental control work.

during 1919 every possible precaution was taken to prevent infection from outside sources.

In view of the results secured, the only conclusion which can be drawn is that the use of aged seed offers a practical method of securing bean plantings free from bacterial blight. Two-year-old seed must be considered superior to 3-year-old seed, because of its higher percentage of germination. Seed more than 3 years old has, in our work, proven impractical for planting because of its low percentage of germination.

No possible method of bacterial blight control appears more easy and practical than the holding of bean seed over a two-year period. Our results indicate that such practice will give blight-free plantings, provided there is no infection from soil or other outside sources.

Foreign Grown Seed.—In our experiments we have grown beans from seed procured from all bean seed growing sections of the country. In no case have any of these plantings shown marked freedom from bacterial blight. Bean-growing is, at present, not of sufficient importance in this

state to justify the growing of extensive plantings of beans, in other parts of the state, or in other states, for seed purposes. At best, this is but a temporary solution of the problem.

Seed Selection.—Seed selection has long been regarded as a means of blight control. For this purpose it is not effective. At best, seed selection must be regarded as an excellent precautionary means. Beans that are noticeably diseased may be removed in seed selection, but bean seed without any discoloration and apparently disease-free may contain bacteria. In our work we have cultivated Bacterium phaseoli from seed apparently free from bacterial blight. Giltner (11), 1915, found that "healthy looking, clean beans from diseased pods may contain, a few weeks after ripening, from 100,000 to 3,000,000 bacteria per bean. Of twenty-one such beans tested—six pods—nine were infected." Thus it will be seen

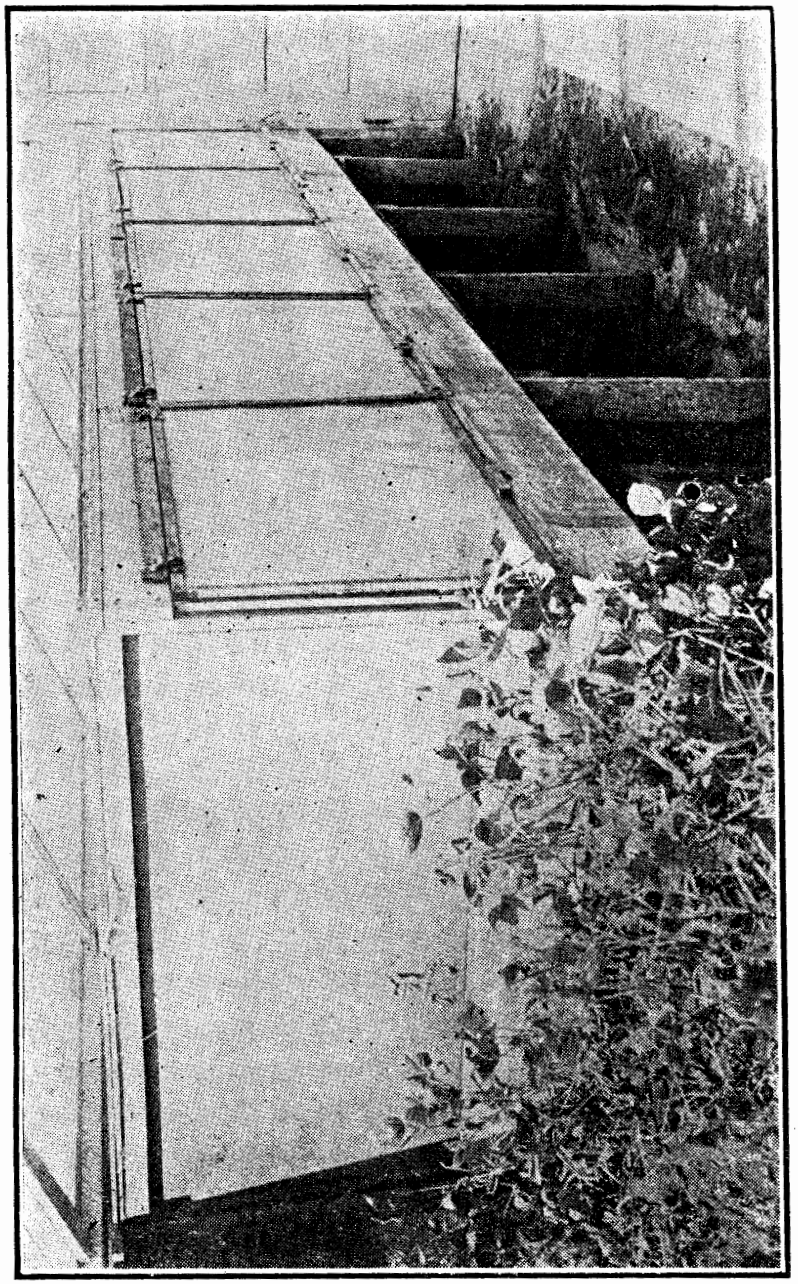

Fig. 17. Greenhouse cages used in control experiments.

that seed apparently disease-free may not produce disease-free plants. Seed selection is of some value, but cannot be regarded as an effectual control measure.

Pod Selection.—Pod selection, though tedious, affords a practical means of obtaining disease-free seed. When the beans are mature, some pods will be found free from disease. These pods should be picked and used the following year. If disease-free pods are sufficiently abundant they should be selected only from the most vigorous, healthy and high-yielding plants. In order to prevent any chance infection, these pods may be treated for ten minutes in a 1-1000 solution of mercuric bichloride. After dipping, the pods should be dried in the sun, taking care that no accidental infection occurs. After shelling, the beans should be stored in suitable containers. This seed should be planted on soil which has not grown beans for a number of years. No other beans should be grown near. The crop from this seed should be disease-free. It should be possible to continue the growing of disease-free beans year after year, unless the crop is infected through the soil or from other bean fields. In case diseased plants appear, they should be pulled out and burned. Pod selection and the use of 2-year-old seed are at the present time, we believe, the most practical means of controlling bacterial blight.

Blight Resistant Strains.—As has previously been noted, resistance to bacterial blight has been shown by a number of varieties of beans grown in our plots. The development of resistant strains is the most satisfactory method of controlling plant diseases. That resistant varieties of beans may be developed has been shown by the work of Barrus (3), 1915, with red kidney beans, by the development of a strain of Robust beans, immune to Mosaic; by the development of an anthracnose resistant white marrow bean by Burkholder (5), 1918, and by other recent work upon disease resistance in beans.

In our work we are using the varieties which have shown blight-resistance, and by selection we hope to produce a bean resistant or immune to bacterial blight, Mosaic and drouth. Along this line lies the greatest possibility for permanent control of bacterial blight.

VIII—SUMMARY

1. Bacterial blight is a widespread and destructive bean disease, caused by Becterium phaseoli E. F. Sm.
2. The bacteria often survive the winter in, or on, the seed, in the soil and on bean straw.
3. From infected seed the disease is transmitted to the young plant.
4. Stem girdling may occur.
5. The disease generally becomes of importance when the pods are developing.
6. The bacteria generally gain entrance through the stomates.
7. Cankers upon both leaves and pods are characteristic.
8. The appearance of bacterial blight as a serious disease is dependent upon weather conditions. Warm, wet weather favors its development.
9. Spraying has proven of no value as a control measure.
10. Seed treatments by chemicals, hot water and dry heat are impractical.
11. Two and 3-year-old seed has, in our work, given blight-free plants.
12. Foreign seed has not proven of special value. In no case has it been markedly blight-free.
13. Seed selection is of small value as a control measure. Bacteria are found in seeds apparently disease-free.

14. Pod selection, though tedious, gives seed free from bacterial blight.

15. Marked blight resistance has been noted in some varieties. In the development of these varieties along the lines of blight, mosaic and drouth-resistance, are the greatest possibilities for permanent control.

IX—LITERATURE CITED

1. Barlow, B.
Some Bacterial Diseases of Plants Prevalent in Ontario. Agr. Col. Bul. 136. 1904.
2. Barre, H. W.
Report of the Botanist and Plant Pathologist. Twenty-Ninth Ann. Report of S. C. Exp. Sta., p. 17, 1916.
3. Barrus, M. F.
An Anthracnose-resistant Red Kidney Bean. Phytopath. 5:303-311. 1915.
4. Beach, S. A.
Some Bean Diseases. N. Y. Agri. Exp. Sta. Bul. 48. New Series, 1892.
5. Burkholder, Walter H.
The Production of an Anthracnose-resistant White Marrow Bean. Phytopath. 8:353-359. 1918.
6. Delacroix, G.
La Graisse, maladie bacterienne des haricots Compt. Rend. Acad. Sci. Paris, 129 p. 656. 1899.
7. Duggar, B. M.
Plant Physiology p. 91. 1911.
8. Edgerton, C. W., and Moreland, C. C.
The Bean Blight and Preservation and Treatment of Bean Seed. La. Agr. Exp. Sta. Bul. 139. 1913.
9. Faulwetter, R. C.
Dissemination of the Angular Leaf Spot of Cotton. Journal of Agr. Research, Vol. VIII, No. 12, pp. 457-475. 1917.
10. Fulton, H. R.
Diseases of Pepper and Beans. La. Agr. Exp. Sta. Bul. 101. 1908.
11. Giltner, Ward.
Report of the Bacteriologist—Reprint from the Annual Report of The State Board of Agriculture (Michigan). 1915.
12. Halstead, B. D.
A Bacterium of Phaseolus. Rept. of Bot. Dept., N. J. Exp. Sta. for 1892. pp. 283-285.
13. Halstead, B. D.
Bean Diseases and Their Remedies. N. J. Agr. Exp. Sta. Bul. 151. 1901.
14. Jones, D. H.
Bacteria—Friends and Foes. Ontario Agr. Col. Bul. 265, p. 83. 1908.
15. MacMillan, H. G.
Sunscald of Beans—Reprint from Journal of Agricultural Research. Vol. XIII, No. 12, 1918.
16. McCready, S. B.
Bacterial Blight. Ann. Rept. Ont. Agr. Col. and Exp. Farm. 1910-11.
17. Muncie, J. H.
Two Michigan Bean Diseases. Mich. Agr. Exp. Sta. Spec. Bul. 68. 1914.
18. Muncie, J. H.
Experiments on the Control of Bean Anthracnose and Bean Blight. Mich. Agr. Exp. Sta. Tech. Bul. 38. 1917.

19. Plant Disease Bul., Vol. II, No. 1. Issued by the Plant Disease Survey, March 15, 1918.
20. Rolfs, F. M.
Angular Leaf Spot of Cotton. S. C. Agr. Exp. Sta. Bul. 184, pp. 14-19, 1915.
21. Rolfs, F. M.
A Bacterial Disease of Stone Fruits, Cornell Agr. Exp. Sta. Memoir 8, p. 416. 1915.
22. Sackett, W. G.
Some Bacterial Diseases of Plants Prevalent in Michigan. Mich. Agr. Sta. Bul. 230. 1905.
23. Smith, E. F.
Description of Bacillus Phaseoli, n. sp., with some remarks on related species. Proc. Am. Assoc. for Adv. of Sci., 1897, pp. 283-290.
24. Smith, E. F.
The Cultural Characters of Pseudomonas hyacinthi, Ps. campestris, Ps. phaseoli, and Ps. stewarti; Four one-flagellate yellow Bacteria parasitic on plants. U. S. D. A. Div. Veg. Phys. and Path. Bul. 28. 1901.
25. Smith, E. F.
Bacteria in Relation to Plant Disease, Vol. II, p. 95. 1911.
26. Whetzel, H. H.
Some Diseases of Beans. Cornell Agr. Exp. Sta. Bul. 239. 1906.