Black Root of Sugar Beets and Possibilities for Its Control

G. H. COONS, J. E. KOTIL.A, and H.W BOCKSTAHLER[1]

In the humid area seedling diseases, commonly called black root, are the major factor responsible for poor slands of sugar beets. These diseases occur in this area in far more aggravated form than in most sugar beet districts of western United States, presumably because soil moisture conditions are not subject to the control that is possible if the crop is grown under irrigation. In irrigated districts there is reasonable assurance that if the seed is properly planted in a suitably prepared and watered seedbed, the sugar beet plants will emerge and be regularly distributed in the row. In the humid area there is no such assurance. Emergence may be extremely irregular or the majority of the plants that do appear may die because of seedling diseases. Extremely gappy stands are the rule rather than the exception. Careful hand thinning may in part repair such a situation, but it is obvious that mechanical thinning may not safely be applied to fields in which the drill rows show extensive plant skips. If sheared seed is planted sparsely in order that the stand of seedlings may be mechanically blocked without hand thinning, loss of individual plants by seedling diseases may be so serious as to preclude this mechanized operation.

It is commonly recognized that introduction of mechanization in the growing of sugar beets is essential if, in the post-war period, the domestic industry is to survive the impact of world competition. Therefore the problem of adequate initial stands of sugar beets for the humid area is of paramount significance. Unless progress is made towards obtaining improved initial stands the industry in this area may not be able to advance comparably with other areas in its mechanization program.

The diseases responsible for poor stands in the humid area do more than cause abandonment of acreage, replanting, or attempts to grow a crop with inadequate plant populations. Their effects are not limited merely to killing of seedlings and making it difficult to obtain enough plants to constitute a profitable beet field in which mechanized operations can be employed. Many of the relict plants constituting the post-thinning stand continue to suffer from a diseased condition of the roots, traceable to infections contracted in the seed-

[1]Principal Pathologist, Senior Pathologist, and Assistant Pathologist, respectively, Division of Sugar Plant Investigations, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Department of Agriculture.

ling stages. The black root problem thus expands into a general root rot problem whose control must begin with attainment of an initial stand of healthy plants that can be carried to harvest without serious disease loss. It is, therefore, not too much to say that development of adequate control measures for the black root complex as a whole is essential if the sugar beet industry in the humid area is to be maintained.

Pathogens Causing Black Root

Sugar beet growers designate the entire complex of seedling diseases that decimate their stands of sugar beets as black root, a descriptive name based upon the appearance of the dead or dying plants. Many fungi have been found capable of causing death of seedlings *(2, 3, It, 5, 10, 11, 12, 19, 20, 24)*[2]. Among these, *Ppthium* spp., *Phoma betae* (Oud.) Frank. *Rhizoctonia solani* Kuehn (*Pellicularia filamentosa* (Pat.) Kogers, and *Aphanomyces chochlioides* Drechs. appear most important.

Because of the relation to control, a differentiation of black root into its acute and its chronic phases is made. If the sugar beet plant is attacked and killed during germination or in a week or two after emergence from the soil, the designation of such attack as acute is, of course, appropriate. All the organisims listed are capable of producing such effects under certain climatic and soil conditions. Attention has been called to the possibility that disease of plants in later stages of growth may trace back 1o infections contracted in the seedling stage (8, *10)*. Buchholtz and Meredith have described the sequence of infection of P. *debaryanum* Hesse and *A. cochlioides (4)*. For *Phoma betae* a type of commensalism between the fungus and sugar beet has been reported by Edson *(13)*. However, under drought, conditions or during storage, rotting of the roots by this fungus may occur (17, *23)*. *Rhizoctonia solani* commonly produces cankering of the hypocotyls and roots. A subsequent recrudescence of growth of the fungus in these cankers leads to crown rot *(6, 8)*. Necrosis of the lateral roots or terminal portions of the tap root as caused by *A. cochlioides* has been described *(3, 9, 11, 16, 22)*. These various disease aspects are chronic phases of black root that may persist throughout the life of the sugar beet plant.

The chronic effects of *A. cochlioides* are particularly serious. Plants affected with this fungus show great lag in growth in comparison with healthy plants. This slow-down in growth is attributable to the continuing attack by the fungus upon the lateral rootlets *(1.6)*. When an affected plant is taken from the soil the absence of an adequate complement of feeding roots is apparent. In the early

-Italic numbers in parentheses refer to literature cited.

stages, leaf effects simulating a mosaic may appear. Affected plants remain dwarfed and many never reach marketable size. Under wet soil conditions terminal portions of the tap root may rot. Necrosis of the root tissue and lack of adequate root connections with the soil bring about wilting and death of the plants.

Both acute and chronic forms of the attack of *A. cochlioides* and of the other pathogens occur commonly in the beet fields of the humid area. The initial stand is reduced by acute attack, but, in spite of heavy loss of seedlings, careful thinning may retain a more or less adequate stand. But the plants that remain may continue to be subject to the chronic phases of black root.

Samples of diseased seedlings from any field may give isolations of any or all of the pathogens. Only extensive laboratory work in cultivating the fungi from the samples and consideration of the quantitative relations among the organisms obtained, together with deductions based on knowledge of the types of attack of the different pathogens, permit decision as to the particular organism (or organisms) doing primary or major damage in a given situation. Studies of this character in the humid area over the past 15 years have resolved the problem into its essential components leading to differentiation among the organisms as to their types of attack, their relative importance, and control measures applicable.

Among the organisms causing black root, only *Phoma betae* is known to be seed borne. Black root in subsequent crops has not been traced to earlier introductions of this fungus. The other species cited as important in the black root complex probably occur naturally in all agricultural soils and are present to a greater or lesser extent in any field likely to be planted to sugar beets. The degree of soil infestation, therefore, is a factor influencing prevalence of black root. Along with Ihe degree of soil infestation, climatic and soil conditions, including the fertility level of the soil, are factors determinative of the extent to which black root may affect the crop. The interplay of these factors in relation to incidence of black root has been discussed elsefwhere *{8, .9*) and is generally recognized by specialists on sugar beet diseases *{1, 11, 12, 21, 24)*.

Possibilities for Black Root Control

Direct Measures

Treatment of sugar beet seed with a fungicide constitutes a practical means for reducing injury from black root (*10,14,18, 20)*. The importance of treatment for sheared, or segmented, seed has been pointed out by Leach *(18)*. Protective effects against the seed-borne fungus, *Phoma betae.*, are comparable to those obtained in treating of grain with fungicides. The protective effects against soil-borne organisms depend upon the disinfectant or warding-off action of the fungicide in the zone of soil surrounding the seed *(10).*

Many fungicides have been shown to have value for sugar beet seed treatment-- copper compounds, mercury compounds, and, more recently, non-metallic fungicides such as, carbonates and quinolic derivatives. The results from a series of replicated tests in the period 1938-1942 (table 1) are typical of those obtainable from seed treatment experiments. The data are expressed in terms of Ceresan (2-percent ethyl mercury chloride) treatment. It, will be noted that in any year in which seedling diseases were a factor, nearly all the fungicides used for seed treatment gave significantly better stands than were obtained from untreated seed. Tn cases in which disease impact was minor, the treatments at least did not. depress the stands. No treatment tested over several years in this series was outstandingly superior to Ceresan, but several did not differ significantly.

It is characteristic of results from treatment of seed with an effective fungicide that very often a reasonably good stand of sugar beets is maintained until, thinning time. The seed treatments do not, however, assure plant health over a long period. Post-thinning stands have sometimes deteriorated badly *{1, 5, 10).* Frequently no significant differences could be shown at harvest time between treated and untreated plots. Such results have tended to obscure whatever of benefit may have accrued from the treatment. Apparently the chief value of seed treatment is the prevention or reduction of the acute phases of black root. But this protection, even if limited, warrants general adoption of the treatment of sugar beet seed with some appropriate fungicide and is especially required for sheared seed planted at the customary low planting rates.

Indirect Measures

Crop Sequence in Relation to Black **Root.**—Certain crops grown preceding the sugar beet crop may have decisive effect on the prevalence in the soil of the pathogens causing black root. Legumes such as alfalfa, sweetclover, and the clovers have been found to harbor the organisms that attack the sugar beet. The roots and residues from these legumes favor the growth in the soil of these organisms. Weeds, such as red root pigweed and other species of *Amaranthus* also favor the increase of the black root organisms. On the other hand, crops such as corn, soybeans, and to some extent small grains exercise a sanitative effect, repressing the sugar beet pathogens, probably because residues from these crops support a different fungus flora in the soil. This relationship of the crops preceding the sugar beet to inci-

Table 1.—Sugar beet seedling stands* in seed treatment experiments, 1938 to 1942. Data of the individual, replicated tests in Michigan, Ohio, and Virginia in 1938, and in Michigan 1989-1942, inclusive, are given as percentages of counts obtained from Ceresan-treated seed.

Chemical dust treatment	Dosage of chemical to seed	1938 Mich.	1938 Ohio	1938 Va.	1939 Mich.	1940 Mich.	1941 Mich.	1942 Mich.	Average
		Percentage	Percentage	Percentage	Percentage	Percentage	Percentage	Percentage	Percentage
Ceresan (2-percent ethyl mercury chloride)	1:80	100	100	100	100	100	100	100	100
Ceresan, copper carbonate, 2:1	1:80	85	106	80	112	94	91	100	96.7
New Improved Ceresan, (5-percent ethyl mercury phosphate)	1:300	82	102	93	92	108	88	99	94.8
New Improved Ceresan, copper carbonate 1:1	1:300	......	......	......	106	94	91	88	94.7
Copper carbonate	1:60	77	92	118	102	82	78	......	91.5
Cuprocide	1:50	102	93	97	102	......	92	112	99.7
Mercuric iodide, talc 1:14	1:100	84	105	73	......	......	......	......	87.3
Mercuric iodide, copper carbonate 1:14	1:100	94	100	79	69	100	88	99	89.6
Mercuric iodide, ($CuCO_3$ + Celite 1:1)1:14	1:100	......	......	......	......	114	100	100	104.7
Mercury bichloride, copper carbonate, urea 1:1:1	1:60	74	93	91	62	86	84	......	81.3
Mercury bichloride, copper carbonate, urea 1:7:4	1:60	50	77	67	......	......	......	......	64.7
Arasan (Du Bay 1205)	1:100	......	......	......	......	......	......	117	117.0
Spergon	1:33	......	......	......	......	......	......	62	62.0
Check		30	98	78	68	71	22	78	63.6
Difference required for significance, odds 19:1		15.6	11.7	13.5	7.3	14.7	16.3	9.4	

*Stand records were obtained in the various years either by counting all seedlings in a given row-length or by determining the inches of row containing seedlings in some fixed row-lengths.

dence of black root was first pointed out in 1924 (6*) on the basis of field observations near Caro, Mich. Confirmatory experimental evidence was reported in 1935 (7).

A rearrangement of fields on the farm, or the throwing' together of two fields to form one field, affords the opportunity to see sugar beet plantings that are otherwise comparable except for the difference in the cropping history of sections or strips of the field. Two fields in which legume-sugar beet and corn-sugar beet sequences occurred under otherwise comparable conditions are shown in figures 1 and 2.

Figure 1.-Effect of crop sequence on sugar beet black root. The sugar beets in the foreground followed a previous crop of sweetclover; those in the background followed corn. Two fields were thrown together prior to preparation for the beet crop. The break between poor stands and poor growth of sugar beets and good stand and good growth came at the old fence line. *A.* W. Smith farm. Malinta, Ohio.

In the portions of the photographs in which the stands are adequate, the sugar beets are grown following corn; the sections with poor stands mark to the row the portions of the field in which legumes immediately preceded the sugar beets.

Results from a replicated crop-sequence experiment conducted in 1942 and 1943 at Beltsville, Md., illustrate the effects on stands attributable to, crop sequence. In this experiment a split-plot design was used to contrast manuring vs. no manuring in connection with the different crop sequences, but no significant interaction of crops x manuring was found. The entire experimental area was spring plowed. It will be noted that the land that was held fallow (clean culture in 1942) gave, for the conditions of the test, a fair stand of sugar beets. The stands when sugar beets followed corn and soybeans were significantly better than on the fallowed plots, whereas sweetclover, and a mixture of corn and sweetclover, as preceding crops showed significantly depressed stands (table 2).

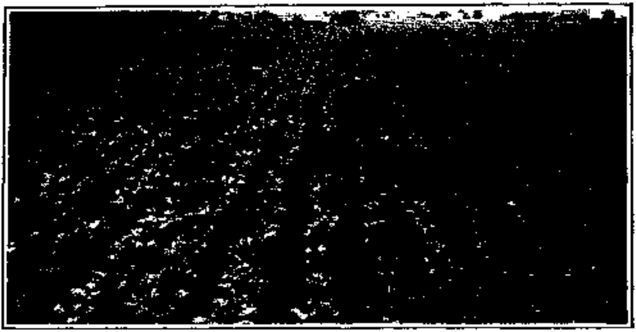

Figure 2.—Effect of crop sequence on sugar beet black root. The sugar beets at the left were grown following corn. The nine rows at the right fell on land that was in sweetclover the previous year. Blocking operations on these nine rows were delayed 2 weeks because of retarded growth of the sugar beet plants. H. S. Gray farm. Malinta, Ohio.

In a small three-time-replicated test conducted in the same field, similar trends were shown, but significant differences were not obtained between corn as a preceding crop and sweetclover or red clover as preceding crops. The outstanding result in this experiment was the depressed stand when *Amaranthus retroflexus* was allowed to grow as a dense stand in 1942 and was followed by sugar beets in 1943 (table 3).

Table 2.— Stands (22 inches x 22 inches) obtained with sugar beets grown following various preparatory crops or on fallowed plots Random block arrangement, five replications. Plot area 15 feet x 110 feet, of which center four rows were counted. In each crop sequence half-plots (55 feet long) received manure (10 tons per acre). Plots plowed for sugar beets on March 29, 1043. (Results given as five plot averages.)

Preparatory crop or treatment	Stand after mechanical blocking 22 inches by 22 inches		
	Manured	No manure	Total
Sweetclover	36.0	32.4	68.4
Corn	68.2	58.0	126.2
Mixed stand of corn and sweetclover	40.8	35.0	75.8
Soybeans	69.6	60.6	130.2
Fallow	50.2	52.4	102.6
Difference required for significance, odds 19:1			17.76

Table 3.—Stands of sugar beets obtained in crop sequence test involving- a number of crops grown in 1942 and followed by sugar beets in 1943. Plots 15 feet x 33 feet. Three replications. Beltsville, Md., 1942-1943.

Preceding crop or treatment	Seedlings*				Stand (22 inches x 22 inches) in four rows			
	1	2	3	Aver.	1	2	3	Aver.
Corn	154	143	162	153.0	41	42	57	46.7
Sweetclover	82	70	200	117.3	41	43	36	40.0
Red clover	111	109	111	110.3	31	43	49	41.0
Ladino clover	144	123	127	131.3	40	31	45	38.7
Amaranthus retroflexus	81	35	110	75.7	9	5	29	14.3
Fallowed	75	121	91	95.7	36	42	26	34.7
Sweet corn	79	98	148	108.3	33	43	50	42.0
Soybeans	142	138	142	140.7	51	48	48	49.0
Cowpeas	122	109	141	124.0	46	40	58	48.0
White pea bean	116	73	129	106.0	38	18	49	35.0
Difference required for significance, odds 19:1				43.4				13.5

*In rows 5 and 7 of each plot, beet-containing inches for a total of 400 inches were determined.

The effects on subsequent sugar beet crops of the sod-forming legumes as contrasted with those from corn or soybeans occur irrespective of soil types. They have been duplicated under controlled conditions in the greenhouse with a substratum of autoelaved quartz sand supplied with Eaton's mineral nutrient solution. As the experiment was set up there were three series of preparatory treatments —one in which corn seedlings were grown, one in which sweetclover seedlings were grown, and the control consisting of the substratum without crop plants. Each series comprised 28 crocks. Seven inoculation treatments, four times replicated, were used. These treatments consisted, for each series, of (1) control, (2) inoculation with a pure culture of *Rhizoctonia solani,* (3) inoculation with a pure culture of *Aphanomyces cochlioides,* (4) inoculation with non-pathogenic organisms *(Rhizopus* spp., *Penicillium* spp., and others), (5) addition to the crocks of macerated, damped-off sugar beet seedlings (chiefly by *A. cochlioides),* (6) inoculation with a pure culture of *R. solani* mixed with non-pathogens, and (7) inoculation with a pure culture of *A. cochlioides* mixed with the non-pathogens. In all, 84 crocks were used in the experiment and these were kept on rotating tables m the greenhouse in order to equalize environmental conditions. The corn and sweetclover crops were grown for 36 days; then the tops were cut and removed. Thirty-seven days later 50 sugar beet seed balls were planted in each crock. The results after 3 weeks are shown in table 4.

In the control series with only quartz sand and mineral nutrients present, the pathogenic organisms that were introduced did not in-

Table 4.-Influence of corn and sweetclover on damping-off of sugar beets by various organisms. Quartz sand plus nutrient substratum was inoculated with organisms: then corn or sweetclover was grown for 30 days and then tops removed. One series was maintained without green plant growth. Sugar beet seed was planted 37 days after top removal. 50 seed balls per 3-gallon culture jar: Data are given as seedling counts per culture jar after 3 weeks. Arlington, Va. (Data given as four-culture averages.)

		Average number of sugar beet seedlings after the preparatory treatments		
No.	Inoculation treatments	Fallow	Corn grown 36 days	Sweetclover grown 30 days
1	None	67.2	48.7	64.1
2	Rhizoctonia solani (Pure culture)	71.2	48.7	30.5
3	Aphanomyces cochlioides (Pure culture)	73.7	50.2	10.0
4	Non-pathogenic organisms (Mixed cultures)	64.5	60.2	55.2
5	Damped-off sugar beet seedlings (macerated)	48.0	46.0	2.0
6	R. solani (Pure culture) plus non-pathogenes of No. 4	76.0	64.2	24.2
7.	A. cochlioides (Pure culture) plus non-pathogenes of No. 4	72.0	48.0	34.2
	Average	67.5	53.6	31.5

Differences required for significance
Between inoculation treatments 19.4
Between preparatory treatments 12.8

crease to any considerable extent, judging by the nearly normal stands obtained. In the series in which corn was grown as a preparatory treatment, the corn roots did not greatly increase the pathogenic content of the quartz sand substratum judging by the stands of seedlings obtained. On the other hand, the growing of sweetclover did very decidedly increase the damping-off of sugar beets by the organisms initially added. *A. cochlioides* and the undetermined organisms from the damped-off seedlings reduced the stands by the greatest extent, but *Rhizoctonia* also was significantly effective. It was expected that the non-pathogenic organisms might repress the pathogens, but under the conditions of this test they had limited but probably positive effects on *A. cochlioides.*

Plowing Legume Sods at the **Proper Time.**—The deleterious effects assignable to increase in the degree that the soil is infested with the black root organisms because of the growth and the residues from the sod legumes or from such weeds as *Amaranthus retroflexus* growing in thick stands seem to be associated with the usual timing of plowing in preparation for the beet crop.

Reports of successful sugar beet crops following alfalfa indicated upon close study that the period when the legume sod was plowed may be an important factor. Replicated experiments in Colorado.

South Dakota, Ohio, and at Beltsville, Md., gave evidence on the definite relationship between the plowing date of the alfalfa sod and the amount of black root injury in the subsequent sugar beet crop, independently conducted experiments by Morris and Afanasiev *(21)* in Montana have also given very striking evidence of this relationship.

Table 5.— Stands (22 inches *x* 22 inches) of sugar beets on sweetclover sods, as influenced by dates of plowing. Main plot area 15 feet x 110 feet, of which the center four rows were counted. For each plowing date, half-plots received manure (10 tons per acre). Beltsville, Md., 1942, 1943 (Results given as five-plot averages.)

Date of plowing sweetclover sod	Stand of sugar beets		
	Manured	No manure	Total
August 26, 1942	39.2	50.4	89.6
September 15, 1942	67.8	66.2	134.0
November 10, 1942	44.8	38.6	83.4
February 23, 1943	40.0	34.0	74.0
March 29, 1943	36.0	32.4	68.4
April 5, 1943	41.2	28.0	69.2
Difference required for significance			18.80

Interaction of Manure Treatment x Time of Plowing was not, significant.

The results from the 1942-1943 Beltsville test are cited (table 5). In this replicated test, a split-plot design was used to superimpose the manure vs. no manure factor upon the main factor, time of plowing a sweetclover sod. The interaction of manuring and time of plowing was not significant in this test. The mean stand of the plots plowed February 23, March 29. and April 5, 1943, was significantly below the mean of the plots plowed in 1942. The relatively poor showing of the plots plowed August 26, 1942, is not understood, unless it is associated with uncontrolled weed growth that occurred after the plowing. The intermediate position with respect to stand as found for the Xovember plowing was not unexpected.

A plausible explanation of the relation between time of plowing the legume sods and degree of soil infestation can be drawn from soil microbiology studies. It is well known that, subject to soil temperature and moisture conditions, the addition to the soil of a crop residue or other nutrient favorable for the growth of a particular class of organisms is immediately followed by an enormous increase in these organisms. From a relatively minor group they may become the dominant forms. When these organisms have exhausted their food supply, then other organisms follow in the cycle, disintegrating what is left and crowding out the former dominant forms. If a legume sod, or other residue, that steps up the prevalence of the sugar beet pathogens be plowed very late in the fall or in early spring, then the peak of development of the organisms pathogenic to sugar beets is very likely to coincide with the planting dates for sugar beets. On the other hand, if alfalfa or sweetclover sods are turned under in August, September, or possibly even later, and if soil conditions permit disintegration of the residues, then the peak of the pathogen development may come and go and thus be entirely out of step with sugar beet planting dates. Under such a system of handling legume sods, the adverse effects on sugar beet stands may not occur.

Blanket recommendation to plant sugar beets on legume sods without specification as to time of turning under these sods is ill-advised. In the humid area, legume sods are so commonly plowed under in late fall or early spring that such an unqualified recommendation invites a black root outbreak. But the deleterious effects from legume sods can be avoided, and the benefits from the legume-sugar beet sequence obtained, if proper timing in plowing under the legume sod is observed. The sods must be turned under early enough in the preceding year so that decomposition of the legume residues may be completed and the fungi pathogenic to sugar beets be replaced by non-pathogenic forms. Under normal conditions in the humid area, this means late August or September plowings to prepare an alfalfa, sweetclover, or clover field for sugar beets.

Application of Phosphate Fertilizer.—Field observations have indicated rather definite relationship between level of soil fertility and incidence of black root *(8)*. Results from a replicated tested in 1932 at Malinta, Ohio, on Brookston clay soil so heavily infested with black root producing organisms that untreated plots failed completely, gave striking evidence of the efficacy of phosphate applications in black root control (figure 8). These leads were subsequently followed in field tests at various locations with similar demonstration of effectiveness of phosphate applications if these were adequate in amount. Results from a representative test conducted in 1942 in cooperation with the Ohio Agricultural Experiment Station at Holgate, Ohio, are summarized in table 6. Young (2.)) has reported results of tests at Elmore and at Holgate, Ohio, of the same import.

Experimental evidence on the decisive influence of phosphate nutrition in bringing about recovery of sugar beet plants from attack by *Aphanomyces cochlioides* was obtained in a. replicated greenhouse test in which sugar beet plants, inoculated with a pure culture of *A, cochlioides* or with debris from diseased plants (chiefly *A. cochlioides* infection), were grown on a nutrient solution added to quartz sand. The details of the test have been reported *(16)*. The diagrammatic summary omitted from the earlier report is shown as figure 4. In this test, an attempt was made to superimpose water level effects in the

Figure 3.— Effect of phosphate fertilizer on black root. Rows 65 and 66, shown at the center, received, respectively, a complete fertiliser high in phosphate and superphosphate, both at the rate of 500 pounds per acre. Those treatments were outstanding in this replicated test. Seed treatment without fertilizer, and potash and nitrogen as single element treatments were not effective. Malinta. Ohio, 1032.

cultures, but results attributable to this factor were not pronounced and can be disregarded. The diagram shows the pronounced effect of phosphate in bringing about recovery of plants infected with *A. cochlioides*.

The increase of the *Aphanomyces* form of black root in many districts is very probably related to the progressive lowering of available phosphate that has taken place in many soils of the humid area. Deficiency of phosphate appears to lower the resistance of the sugar beet plants to *A. cochlioides*. but that the action is of this type has not as yet been positively demonstrated. Evidence has been given by Larmer *(17)* that a low status of phosphate nutrition reduces the resistance in storage of sugar beet roots to rotting caused by *Phoma betae.*

Abundant evidence is at hand, therefore, that raising the fertility level of the soil, particularly with respect to phosphate, can bring about very decisive reduction of the losses caused by *A. cochlioides*. Although the fertilizer practice with sugar beets has shown marked improvement in recent years, there is still need to break down the tendency to use the phosphate fertilizers so sparingly that little or no benefit is obtained.

Breeding for Black Root Resistance

So long as control of black root by breeding involved taking into account the entire group of pathogens capable of attacking in the

Table G.—Results from soil treatment experiment, Holgate, Ohio, in 1942 (cooperative with Ohio Agricultural Experiment Station). 12 x 8 randomized block design; plots consisted of four rows (21 inches) 48 feet long. Center rows harvested.

	Acre yield		Sucrose	Purity	Inches of row containing seedlings	Stand after thinning	Harvested stand
	I. A. sugar	Roots					
	Pounds	Tons	Percent	Percent	Percent	Percent	Percent
No-Phosphate Series:							
Check, seed treated Ceresan	1,404*	6.78*	12.79*	80.50*	11.8*	34.7*	20.7*
Check, seed not treated	1,504*	7.20*	12.83*	80.85*	14.3	41.7*	33.6*
$(NH_4)_2SO_4$, 80 pounds N per acre, seed not treated	1,315*	6.52*	12.62*	80.16*	6.5*	24.1*	21.7*
K_2SO_4, 82½ pounds per acre, seed not treated	1,774*	8.25*	13.13	81.80	16.3	45.1	37.8*
Phosphate Series:							
0-45-0, 180 pounds per acre, seed not treated	2,400	11.06	13.58	82.85	16.5	50.4	47.8
0-45-0, 180 pounds per acre, seed treated	2,255	10.15	13.43	82.72	15.4	52.0	44.9
0-20-0, 200 pounds per acre, seed not treated	2,618*	11.37*	13.77	83.74*	13.3	54.3*	49.8*
0-20-0, 400 pounds per acre, seed not treated	2,840*	11.91*	14.14*	84.07*	25.0*	64.0*	58.6*
0-20-0 + 3% ZnO, 400 pounds per acre, seed not treated	2,906*	12.99*	13.72	84.07*	28.1*	69.2*	61.0*
0-20-0 + 6% ($CuSO_4$ and CaO, 1:1) 400 pounds per acre, seed not treated	2,501*	12.41*	13.00*	84.03*	24.8*	67.0*	60.4*
Ammophos:							
11-48 Ammophos, 167 pounds per acre, seed not treated	1,003*	4.90*	12.54*	80.10*	5.0*	16.6*	15.0*
Complete Fertilizer:							
2-16-8, 500 pounds per acre, seed not treated	3,280*	13.98*	13.97*	84.25*	23.2*	65.9*	61.6*
Difference required for significance,							
odds 19:1	310	1.35	.48	1.2	4.3	5.9	6.5
General mean	2,300	9.8	13.37	82.5	16.7	48.9	43.5

*A value marked with an asterisk differs significantly from the general mean.

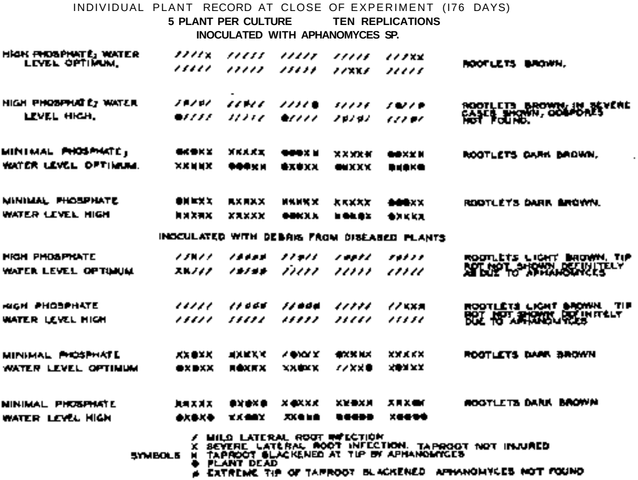

Figure 4.— Effect of phosphate nutrition in producing recovery of sugar beet plants from Aphanomyces cochlioides infection. The sugar beets wore grown in 3-gallon crocks to which a nutrient solution high in phosphate was added to half the cultures. the other half receiving nutrient with a minimal amount of phosphate. Different water levels were superimposed on the nutrition factor, but effects from this factor were not pronounced. Inoculum was of two types: a pure culture of A. cochlioides and debris from plants known to be infected with this organism.

seedling period and persisting in the later stages of growth, the outlook for obtaining blanket resistance to all pathogens seemed hopeless. Strains resistant to one fungus could not be expected to show similar resistance to other non-related organisms. With the resolution of the complex into its factors, and in view of the success of seed treatments in preventing the acute stages, it is now possible to center attention in breeding investigations on the chronic phases of *A. cochlioides.*

Observations made on the agronomic evaluation tests of U. S. leaf spot resistant varieties in 1940 and 1941 in Michigan, Ohio, Wisconsin, and Minesota, and confirmed by the records taken in 1940 by J. H. Torrie in connection with the evaluation tests in Wisconsin and the observations by A. R. Downie and J. O. Culbertson in Minnesota, indicated that U. S. 216, a leaf spot resistant inbred line, had definite resistance to the chronic phase of *A. cochlioides* attack. Furthermore, hybrids of U. S. 216 with other inbreds in which resistance had not been noted also were found to be comparable in resistance to U. S. 236. The resistance of U. S. 216 was manifested by its relatively better seedling stand in comparison with that from European sugar beet varieties or from U. S. 200 x 215, and the relative freedom from rotting of the terminal portion of the tap root, a condition that was pronounced in some other inbred lines and in mass selected material.

In 1941 many of the U. S. varieties in the leaf-spot-resistance evaluation tests had U. S. 216 as a component variety. These were resistant to chronic phases of *A. cochlioides.* One variety, SP 1-9-00, was produced by allowing the inbred lines U. S. 215 and 8-266-0 to intercross. No resistance had been noted for these two inbreds. In the comparative tests in Michigan, Ohio, and Minnesota, SP 1-9-00 was so conspicuously dwarfed by *A. cochlioides* that the variety could be identified by the depressed growth alone. Whereas this variety showed excellent tonnage in the tests under irrigation, in nearly all tests in the humid area its susceptibility to *A. cochlioides* was so great that it fell significantly below the other varieties in root yield and sugar production. The susceptibility and poor performance were in marked contrast to the resistance and excellent performance, of another hybrid, SP 0-281-00, produced by crossing U. S. 216 with the inbred 8-266-0.

In 1943 and 1944, plantings were made on heavily infested soil to obtain further information and to make selections. No phosphate fertilizers were used and the seed was unlreated. Extremely wet weather brought about such loss of seedling stand by the acute phases of black root, including *Pythium* spp., that these tests yielded little except evidence that the seedlings must be protected by seed treatment from impact of the other damping-off organisms if any plants are to be available in the field for selection against the chronic phase of *A. cochlioides.* The progress made in 1945 investigations is reported by Henderson and Bockstahler *(15).*

The degree of resistance found in U. S. 216 and its hybrids is limited. Under severe exposures the yields may be as low as 5 tons per acre, but under these conditions susceptible varieties may almost fail. The factors for resistance therefore make definite contribution. The situation may not, be unlike that which was faced when U. S. 1. the first curly top resistant variety, was introduced. It was necessary to plant U. S. 1 early, make adequate fertilizer applications, and provide proper cultural conditions in order to utilize to the full its rather limited curly top resistance. Continued selections have now resulted in sugar beet varieties very greatly improved in curly top resistance.

Varieties with the degree of resistance now found may be expected to show advantage in withstanding the chronic type of attack and to grow in spite of *A. cochlioides.* Utilization with them of the helpful direct and indirect measures for black root control is essential and should result in alleviation of the disease losses sustained with non-resistant sorts. The discovery that factors for resistance exist in strains of sugar beet that are also leaf spot resistant makes the outlook for ultimate control of both diseases promising.

Literature Cited

1. Afanasiev, M. M. Seedling Diseases, Phosphate Deficiency and Fusarium Yellows of Sugar Beets in the Rotations at the Huntley Field Station in Montana. Proc. Amer. Soc. Sug. Beet Tech., pp. 219-223. 1940.

2. Buchholtz, W. F. Factors Influencing the Pathogenicity of Pythium de Baryanum on Sugar Beet Seedlings. Phytopath. 28:448-475. 1938.

3. Buchholtz, W. F. and Meredith, C. H. Pathogenesis of *Aphanomyces cochlioides* on Tap Roots of Sugar Beet. Phytopath. 34:485-489. 1944.

4. Buchholtz. W. F. and Meredith, C. H. The Sequence of Infection of a Seedling Stand of Sugar Beets by Pythium de Baryanum and *Aphanomyces cochlioides.* Phytopath. 34.490-496. 1944.

5. Campbell, Leo. Black Root of Sugar Beets in the Puget Sound Section of Washing. Wash. Agr. Exp. Sta. Bul. 379. 14 pp. 1939.

6. Coons, G. H. The Root Diseases of the Sugar Beet. Michigan Sugar Beet Institute, pp. 28-34. (Michigan Agricultural College.) 1924.

7. Coons, G. H. and Kotila, J. E. Influence of Preceding Crops on Damping-off of Sugar Beets. Phytopath. 25:13. 1935.

8. Coons, G. H. and Kotila, J. E. Sugar Beet Seedling Diseases and Root Rot. In J. G. Lill, Sugar Beet Culture in the Humid Area. U. S. Dept. Agr. Farmers' Bul. 1637:38-44. 1939. Also Sugar Beet Journal 4:110-113-116. 1939.

9. Coons, G. H., Kotila, J. E., and Bockstahler, H. W. Black Root Investigations in Michigan and Ohio. Proc. Amer. Soc. Sug. Beet Tech. Eastern Regional Meeting, p. 35. 1941.

10. Coons, G. H. and Stewart, Dewey. Prevention of Seedling Diseases of Sugar Beets. Phytopath. 17 :259-296. 1927.

11. Drechsler Charles. The Beet Water Mold and Several Related Root Parasites. Jour. Agr. Res. 38:309-361. 1929.

12. Edson, H. A. Seedling Diseases of Sugar Beets and Their Relation to Root Rot and Crown Rot. Jour. Agr. Res. 4:135-168. 1915.

13. Edson, H. A. Histological Relations of Sugar Beet Seedlings and *Phoma betae.* Jour. Agr. Res. 5:55-57. 1915.

14. Gaskill, J. O. and Kreutzer, W. A. Treatment of Segmented Seed Greatly Reduces Damping-off of Seedlings. Colo. Agr. Exp. Sta. Farm Bui. 6(2) :2. March-April 1944.

15. Henderson, R. W. and Bockstahler, H. W. Reaction of Sugar - Beet Strains to *Aphanomyces cochlioides* Drechsler. Proc. Amer. Soc. Sug. Beet Tech., pp. . . . .1946.

16. Kotila, J. E. and Coons, G. H. Aphanomyces Root Rot of Sugar Beets as Influenced by Phosphate Application. Proc. Amer. Soc. Sugar Beet Tech., pp. 223-225. 1941.

17. Larmer, F. G. Keeping Quality of Sugar Beets as Influenced by Growth and Nutrition Factors. Jour. Agr. Res. 54:185-198. 1937.

18. Leach, L. D. Treatment of Sheared Beet Seed. Spreckels Sugar Beef Bul. 6:65-68. 1942.

19. LeClerg, E. L. Parasitism of *Rhizoctonia solani* on Sugar Beet. Jour. Agr. Res. 49:407-431. 1934.

20. LeClerg, E. L. Treatment of Sugar Beet Seed Increases Stand and Yield. Minn. Ext. Circ. 57. 7 pp. 1937.

21. Morris, H. E. and Afanasiev, M. M. The Effect of Alfalfa on Succeeding Sugar Beets at Huntley (Montana) Field Station. . Through the Leaves 31 (3) :15-19. May-June 1943.

22. Peters, L. Leber die Erreger des Wurzelbrandes. Arb. K. Biol. Anst. f. Land. u. Forstw. 8:211-259. 1911.

23. Tompkins, C. M. and Pack D. A. Effect of Temperature on Rate of Decay of Sugar Beets by Strains of *Phoma betae.* Jour. Agr. Res. 44:29-37. 1932.

24. Young, H- C. Fertilizer and Sugar Beet Black Root. Sugar 39, No. 4,: 36; 38, No. 6,: 28-31. April and June 1944.