THE RELATION OF SULFUR TO SOIL ACIDITY AND TO THE CONTROL OF POTATO SCAB¹

WILLIAM H. MARTIN

New Jersey Agricultural Experiment Station

Received for publication April 13, 1920

INTRODUCTION

Potato scab, caused by *Actinomyces chromogenus* Gasperini, is no doubt, the most common disease of this important agricultural crop. The disease was first mentioned in Loudon's Encyclopedia of Agriculture (18) as follows: "Scab, that is to say, the ulceration of the surface of the tubers, has never been explained in a satisfactory manner. Some attribute it to the ammonia from the dung of the horse, others to alkali, and certain others to the use of wood ashes on the soil. Not using diseased seed and planting on other soil are the only known means of preventing the malady." Since this first mention of the disease an extensive literature has appeared on the subject, a large portion of which has been devoted to control measures.

On the tuber, satisfactory control has been secured by treating with either formaldehyde or corrosive sublimate. Where the scab organism, is present in the soil, however, as is very frequently the case where potatoes are grown for a number of years on the same land, seed treatment is of little value. Where this condition exists, control measures must be based on eradicating the organism from the soil. This fact has long been recognized, and Halsted (10, 11, 12, 13, 14), one of the first to conduct investigations on this subject, found from his tests with various soil germicides that sulfur was the only one which gave results that would warrant its use for this purpose.

Further investigations by Halsted and others, have shown contradictory results in the use of sulfur for the control of scab. Halsted (10, 11, 12, 13, 14) reports a marked decrease in the amount of scab following an application of 300 pounds of sulfur per acre, while a similar quantity under different conditions had no beneficial effect. In another experiment, an application of 600 pounds of sulfur in 1896 had no effect on scab in that or the succeeding year; in 1898 however, the sulfur became effective, bringing about a reduction of 36.1 per cent in the amount of scab.

In an experiment conducted in the greenhouse, Garman (6) found no difference in the amount of scab where untreated seed pieces, and seed pieces

¹ Technical Paper No. 3 of the New Jersey Agricultural Experiment Stations Department of Plant Pathology.

rolled in sulfur flour, were planted in sterile soil. Field experiments where sulfur was used at the rate of 150 and 180 pounds per acre likewise showed no indicative results. His results were corroborated by Brooks (3) who reports failure in the use of sulfur for the control of scab.

As a result of a series of experiments, in which sulfur was used at the rate of 300 pounds per acre following an application of 600 pounds in the preceding year, Wheeler and Adams (22) conclude that: "The indications are that the sulfur treatment of contaminated soils may decidedly reduce the percentage of scab if enough sulfur is employed and the moisture and other soil conditions are such that it is able to exert its maximum effect."

The rôle that sulfur plays in the soil is an undecided question. Chancrin and Desriot (4) express the opinion that its beneficial effects may be due to action similar to that of partial sterilization by heat, carbon-bisulfide, toluene, etc. In its use for the control of scab its beneficial action would appear to be due to the fact that on its oxidation there is an increase in soil acidity, thus producing conditions unfavorable for the development of the scab organism. Numerous investigators, among whom might be mentioned Brioux and Guerbet (1), Brown and Kellogg (2) and Lipman and his co-workers (17) have demonstrated that the presence of sulfofying organisms as well as the moisture relations are factors of considerable importance in the oxidation of sulfur. Since it is a well established fact that the biological factor is influential in the process it is possible that some of the reported failures of sulfur applications to control scab may be explained on the ground that the sulfur was not oxidized.

In a series of carefully performed field experiments, Sherbakoff (19) applied sulfur at the rate of 450 and 900 pounds per acre. In every case there was a reduction in the amount of scab, the heavier application giving the greatest decrease. Included in these experiments were tests to determine the influence of the time of application of the sulfur. Most efficient control was secured where the sulfur was broadcasted just before the potatoes were planted. Mixing the sulfur with the fertilizer not only reduced the fungicidal effect of the sulfur but reduced the value of the fertilizer as well. In another paper Sherbakoff (20) reports that where heavy applications of sulfur were made injurious effects were apparent on clover the following year, the injury being in proportion to the amount of sulfur applied.

Lint (16) conducted field experiments with sulfur over a period of three years and found that any quantity over 600 pounds is not to be advised except under especially alkaline conditions. In cases where sulfur was applied at the rate of 600 and 800 pounds per acre in the row, Lint reports injury on the succeeding hay crop. Where smaller amounts were used, and the applications made broadcast the danger of injury was reduced to a minimum.

From the brief review of the previous investigations on the use of sulfur for the control of potato scab, it is apparent that the chief difficulty lies in

determining the amount necessary to change the soil reaction to a degree that will inhibit the growth of the scab organism without interfering with the proper development of the potato crop or of subsequent crops. That the soil acidity may be increased to this extent without injury to the potato crop, is evident from the work of Gillespie and Hurst (8). They have shown that while the Caribou loam soils of Maine are more acid than the Washburn loam soils, the potatoes grown on the former are not only free from scab but give larger yields.

In a recent paper having an important bearing on the question of the eradication of the scab organism from the soil, Gillespie and Hurst (9) show that an excellent correlation exists between the hydrogen-ion concentration and the occurrence of the potato scab organism. They examined a number of potato soils of different origin and type and found that those having a hydrogen-ion concentration as low as 5.2 rarely produced scabby tubers while potatoes grown on soils having higher exponents generally were scabby. Among the samples examined by them were two from the same field, a portion of which was limed in 1906 while the remainder received no lime. The limed portions produced scabby potatoes in 1906 and again in 1917, while the potatoes from the unlimed portion were clean both years. On determining the hydrogen-ion concentration of soil samples from the two sections, it was found that the limed and unlimed portions gave pH values of 5.7 and 5.05, respectively. In another paper Gillespie (7) reports the results of studies made of the viability of a number of strains of the scab organism in culture media adjusted to various hydrogen-ion exponents. He found that in a medium having a pH value of 5.2 growth was slower and generally less vigorous than it was in media having higher pH values. In some instances strains of the organism succeeded in growing well in a medium which had an initial pH value of 4.8 but the growth was accompanied by a decrease in acidity. The writer states that it is doubtful if more than a poor growth can occur at such exponents.

While the results of previous experiments with the use of elemental sulfur for the control of potato scab have been contradictory, the evidence as a whole indicates the possibility of its use in this connection. In view of the fact that potato scab is becoming more and more destructive, it was thought advisable that further research be conducted on this problem. Since the presence or absence of the scab organisms appears to be determined to a large extent by the soil reaction, in the experiments here reported particular attention was given to the relation of the organism to soil acidity as measured by the hydrogen-ion concentration and the relation of the latter to the amount of sulfur applied to the soil.

EXPERIMENTAL

During the summer of 1919, five field experiments were conducted. These experiments were performed on different soil types including sandy loam, Sassafras loam and Penn loam. In selecting the fields in which the experiments were conducted, care was taken to avoid any marked soil irregularities so that differences arising from soil variations might be reduced to a minimum. As an additional precaution check plots were left between each two treated plots and each treatment was repeated at least three times. The size of the plots in the different experiments varied from $\frac{1}{40}$ to $\frac{1}{80}$ acre. Except for the sulfur treatments all the plots of an experiment were treated alike as regards fertilization and cultivation.

Sulfur was used in amounts varying from 300 to 1200 pounds per acre. The sulfur used was the commercial flour sulfur. The applications were made broadcast after the land was harrowed and just before planting. In one of the experiments the sulfur was applied by hand, in two others a lime distributor was employed while in the remaining two the applications were made with a grain drill. The latter method proved the most efficient since the sulfur was thoroughly mixed with the surface soil and a more uniform distribution was secured.

Experiments were conducted with the varieties American Giant and Irish Cobbler. When the potatoes were harvested they were separated into two classes, primes and seconds, the latter including all tubers under $1\frac{1}{2}$ inches in diameter. The primes were then divided into classes depending on the degree of infection. In grading the primes of the American Giant variety, two classes were made, clean and scabby, the latter including all tubers showing any scab lesions. Three classes were made of the Irish Cobbler primes, namely, clean, salable scabby and unsalable scabby. The last class was made up of all tubers covered with the scab lesions while tubers showing only a moderate infection were designated as salable scabby. In this connection, it must be stated that the percentage of salable scabby tubers in the primes is not a fair index of the actual control of scab since the salable scabby tubers from the check plots showed considerably more scab than those from the treated plots. This is particularly true of the American Giant variety, the primes in the sulfur-treated plots not only showed less scab than those from the check plots but were of a much better color and texture.

Before making the sulfur applications, soil samples were taken in the area to be included in the experiment and the hydrogen-ion concentration of water extracts of the soil samples determined colorometrically, following the work by Clark and Lubs (5) in the preparation of the buffer mixtures, the selection of suitable indicators and general methods of procedure. When the crop was harvested, soil samples were taken in each plot and similar determinations were made. In taking the soil samples borings were made to a depth of $6\frac{1}{2}$ inches, at intervals of 15 feet. These individual samples were then thoroughly mixed and a sample taken to represent the condition of the plot in question.

In preparing the water extracts of the soil samples to be tested a method was adopted which was essentially the same as that employed by Gillespie and Hurst (9). To 15 gm. of air-dry soil which had been passed through a 1-mm. sieve was added 30 cc. of distilled water in a 100-cc. Erlenmyer flask. The flask was then shaken 75 times, and allowed to stand for a period of 8 to 12 hours. The supernatant liquid was then drawn off and distributed to test tubes.

The yields per acre as well as the percentage of scabby tubers will be presented in the following tables in which the data given are averages obtained from at least three replications of each treatment and of six check plots. The yields of second-size tubers are included in the tables; however, in view of the fact that the sulfur treatments appeared to have no influence on the number of seconds, they will not be discussed.

Experiments with the Irish Cobbler Variety

Experiment I. The soil on which this experiment was conducted is a sandy loam, typical of one of the best potato-growing sections of New Jersey. In 1912 an application of lime was made at the rate of 1200 pounds per acre; since that time succeeding potato crops have been severely scabbed, a large

TABLE 1
Influence of sulfur applications on total yield, per cent of scabby tubers and hydrogen-ion concentration

TREATMENT	TOTAL YIELD	YIELD OF PRIMES			YIELD OF SECONDS	pH VALUE OF SOIL EXTRACTS
		Salable		Unsalable, scabby		
		Clean	Scabby			
	<i>bushels per acre</i>	<i>bushels per acre</i>	<i>per cent</i>	<i>bushels per acre</i>	<i>bushels per acre</i>	
Check*.....	350.1	163.5	64.6	146.8	39.7	6.03
400 pounds sulfur per acre† . . .	339.1	265.8	29.4	30.2	42.6	5.20
600 pounds sulfur per acre† . . .	342.7	283.2	19.4	25.9	33.4	5.07

* Average of 6 plots.

† Average of 4 plots.

portion of the crop being unsalable in 1919. Soil samples taken before the sulfur applications were made showed a hydrogen-ion exponent of 6.15. In this experiment sulfur was used at the rate of 400 and 600 pounds per acre. Observations made at frequent intervals during the summer on this and the other experiments conducted failed to show any differences in vegetative growth that could be attributed to the sulfur applications.

The effects of the sulfur on total yield and scab control are shown in table 1. It will be seen that there was a slight decrease in yield on the treated plots as compared with the check plots; it is doubtful, however, if these differences

can be attributed to the action of the sulfur, since the decrease was greater for the 400 than for the 600-pound application. With both quantities of sulfur used, there was a marked gain in the number of salable primes with a corresponding decrease in the number of tubers rendered unsalable by scab. In addition to this the per cent of scabby tubers in the salable primes was greatly reduced by the sulfur applications.

FIG. 1. DIAGRAM SHOWING THE RELATION OF SULFUR TREATMENT TO HYDROGEN-ION CONCENTRATION AND THE PER CENT OF CLEAN, SALABLE AND UNSALABLE SCABBY TUBERS IN THE PRIMES—IRISH COBBLER VARIETY, EXPERIMENT I

The relation of the hydrogen-ion exponent to the per cent of clean, salable scabby and unsalable scabby tubers in the primes is shown in figure 1. The exponent of the check plots when harvested was found to be 6.03; as has

been stated, the original exponent for this soil was 6.15, indicating that little change occurred during the growing season. On the other hand, the plots receiving the sulfur applications showed a decided decrease in exponents, the decrease being more pronounced on the plots receiving the heavier applications. From the diagram it is apparent that with the decrease in the hydrogen-ion exponent there was a corresponding decrease in the per cent of scabby tubers as compared with the check plots. It will be observed, however, that even where the larger quantities of sulfur were used the crop was not entirely free from scab, this despite the fact that the exponent of these plots was 5.07, slightly lower than that shown by Gillespie (7) to delay or inhibit the growth of the scab organism in culture media. This would indicate either that there was not a uniform distribution of the sulfur with the consequence that there was no resulting acidity in those areas not receiving sulfur, or that the organism will grow at lower exponents in soil than in culture media.

Experiment II. The soil on which this experiment was conducted is a sandy loam of a heavier type than that on which the first experiment was performed. Scab has been very severe in this field for a number of years. Sulfur was applied at the rate of 300 and 600 pounds per acre.

TABLE 2

Influence of sulfur on total yield, per cent of scabby tubers and hydrogen-ion concentration

TREATMENT	TOTAL YIELD	YIELD OF PRIMES			YIELD OF SECONDS	pH VALUES OF SOIL EXTRACTS
		Salable		Unsalable scabby		
		Clean	Scabby			
	<i>bushels per acre</i>	<i>bushels per acre</i>	<i>per cent</i>	<i>bushels per acre</i>	<i>bushels per acre</i>	
Check*.....	174.0	70.4	57.6	85.9	17.7	5.57
300 pounds sulfur per acre†	181.4	144.6	22.4	24.1	12.7	4.77
600 pounds sulfur per acre†	171.9	132.0	23.8	22.9	17.1	4.82

* Average of 6 plots.

† Average of 4 plots.

The results of the sulfur treatments are given in table 2. On a basis of total yield, the plots receiving 300 pounds of sulfur showed an increase as compared with the untreated plots, while the plots treated with 600 pounds of sulfur per acre showed a slight decrease. The differences in either case are small, however, and it is doubtful whether any importance can be attached to them. As in the preceding experiment, there was a marked reduction of unsalable scabby tubers on the treated plots leading to an increase in the number of salable primes. The per cent of scabby tubers in the salable primes was likewise greatly reduced.

In figure 2 is shown the relation of the hydrogen-ion exponent to the per cent of salable and unsalable scabby tubers in the primes. The initial hydrogen-ion exponent of this soil was 5.6 as compared with 5.57 for the check plots at the time of harvesting. It will be seen from the diagram, that the exponent of the plots treated with 300 pounds of sulfur is slightly lower than that of the plots receiving double this amount. This indicates that the sulfur had not all been oxidized at the time of digging. This is corroborated by the work of Shedd (21) who has shown that after about four months the amount of sulfur oxidized was generally about 60 per cent of the total quantity present

FIG. 2. DIAGRAM SHOWING THE RELATION OF SULFUR TREATMENTS TO HYDROGEN-ION CONCENTRATION AND TO THE PER CENT OF CLEAN, SALABLE AND UNSALABLE SCABBY TUBERS IN THE PRIMES—IRISH COBBLER VARIETY, EXPERIMENT II

regardless of whether 100 or 500 pounds per acre had been added. It will further be seen from the diagram, that scab was approximately as well controlled on the plots receiving 300 pounds of sulfur per acre as it was on the plots where 600 pounds were used. It thus appears from the results of this experiment that, for this particular soil type, having the hydrogen-ion exponent as low as 5.6, the use of sulfur in any quantity exceeding 300 pounds was unnecessary for the control of scab.

Experiment III. The soil on which this experiment was conducted is a Penn Loam that had not been planted in potatoes for a number of years. To

insure the presence of the scab organism in the soil scabby seed was planted. Sulfur applications were made at the rate of 300, 600, 900 and 1200 pounds per acre. The results of this experiment are given in table 3.

On the basis of total yield the plots treated with sulfur at the rate of 600 pounds per acre showed a decrease of 9.9 bushels per acre as compared with the check plots. Each of the other plots showed an increase in yield. This increase was 2.7 bushels, 11.9 bushels and 12.3 bushels per acre for the plots treated with 300, 900 and 1200 pounds of sulfur, respectively. In this experi-

TABLE 3

Influence of sulfur applications on total yield, per cent of scabby tubers and hydrogen-ion concentration

TREATMENT	TOTAL YIELD	YIELD OF PRIMES		YIELD OF SECONDS	pH VALUES OF SOIL EXTRACTS
		Clean	Scabby		
	<i>bushels per acre</i>	<i>bushels per acre</i>	<i>per cent</i>	<i>bushels per acre</i>	
Check*	144.3	128.4	60.0	14.7	6.27
300 pounds sulfur per acre†	147.0	135.4	43.6	11.6	5.90
600 pounds sulfur per acre†	134.4	119.4	26.9	15.0	5.83
900 pounds sulfur per acre†	156.2	141.8	26.3	14.1	5.13
1200 pounds sulfur per acre†	156.6	142.5	15.7	14.1	5.10

* Average of 8 plots.

† Average of 3 plots.

TABLE 4

Influence of sulfur applications on hydrogen-ion concentration of soil extracts

TREATMENT	DATE OF SAMPLING								AVERAGE
	5/19	5/29	6/14	6/24	7/18	7/24	8/2	8/16	
	pH	pH	pH	pH	pH	pH	pH	pH	pH
Check*	6.37	6.43	6.32	6.05	6.23	6.40	6.30	6.27	6.27
300 pounds sulfur per acre†	6.40	6.26	6.00	5.70	6.20	6.00	6.10	5.90	6.07
600 pounds sulfur per acre†	6.13	5.70	5.20	4.93	5.63	5.60	5.53	5.83	5.57
900 pounds sulfur per acre†	5.90	5.16	5.16	4.63	5.90	5.00	5.16	5.13	5.25
1200 pounds sulfur per acre†	5.70	5.43	4.60	4.43	5.10	4.80	4.86	5.10	5.00

* Average of 8 plots.

† Average of 3 plots.

ment no tubers were rendered unsalable by scab. From table 3 it will be observed that the per cent of scabby tubers in the primes decreased with the increased sulfur applications, the plots receiving the highest sulfur application yielding the lowest per cent of scabby tubers.

Soil samples were taken 35 days after the sulfur applications were made and again approximately every 10 days until the crop was harvested. Water extracts of all the soil samples were made and these were tested for the hydrogen-ion concentration. The results of these tests are given in table 4. It will

be seen that there was no marked variation in the hydrogen-ion exponents of the check plots, if the one indicated for June 24 is excepted, this being the lowest of these values. The mean value of all the determinations was 6.3. The exponents of the treated plots at the time when the first observation was made, with the exception of the one indicated for the plots receiving 300 pounds of sulfur, were lower than were those of the check plots. The values of the hydrogen-ion exponents of the soil extracts corresponding to each of the different treatments show a gradual decline, the lowest of these values for each treatment being indicated for June 24, 71 days after the sulfur applications were made. The hydrogen-ion exponents indicated for dates subsequent to June 24 are somewhat variable and all are slightly higher than are those indicated for this date. No explanation is here offered for the sudden interruption (indicated in table 4 for June 24) in the decline of the values of the

FIG. 3. DIAGRAM SHOWING THE RELATION OF SULFUR TREATMENTS TO HYDROGEN-ION CONCENTRATION AND TO THE PER CENT OF CLEAN AND SALABLE SCABBY TUBERS IN THE PRIMES—IRISH COBBLER VARIETY, EXPERIMENT III

hydrogen-ion exponents. It is suggested, however, that oxidation of the sulfur might have been completed at this time (71 days after application), so that further decrease in the values of the hydrogen-ion exponents of the soil extracts from this cause could not be expected. This suggestion is in accord with the work of Lint (15) who has shown that sulfur is practically completely oxidized in the soil in 8 weeks. On the other hand, it must be recalled that Shedd (21) found that only 60 per cent of the sulfur added to the soil was oxidized after four months.

The relation of the hydrogen-ion exponents to the per cent of scabby tubers is shown in figure 3. It will be observed that the 300-pound application of sulfur reduced the quantity of scabby tubers from 60 per cent (indicated for the check plots) to 43.6 per cent. This is somewhat striking since the average of the hydrogen-ion exponents of the plots receiving the 300-pound

treatment is 6.07, and at no time during the growing season did the exponents for these plots show values lower than 5.7, which is considerably above the highest exponent value found by Gillespie (9) to inhibit growth of the scab organism in culture media.

The per cent of scabby tubers among the primes harvested from the plots treated with 600 pounds and those treated with 900 pounds of sulfur per acre was nearly the same, being 26.9 per cent of the total yield of primes for the former and 26.3 per cent for the latter, as compared with 60 per cent for the check plots. The average values of the hydrogen-ion exponents for the plots which had received the 600-pound treatment and for those which had received the 900-pound treatment were 5.57 and 5.25, respectively. It is to be recalled here that the check plots in the preceding experiments showing average hydrogen-ion exponent values of 5.57 and 6.03 yielded a very high percentage of scabby potatoes. The marked decrease in the per cent of diseased tubers among the primes yielded by the plots treated with 600 pounds of sulfur per acre, in spite of the fact that the average hydrogen-ion exponent for these plots was as high as 5.57, may perhaps be explained upon the ground that at one time during the growing season their hydrogen-ion exponent was as low as 4.93.

The plots receiving the 1200-pound treatment showed the lowest hydrogen-ion exponent values and the lowest per cent (15.7) of scabby tubers among the primes, while the total yield, even with this heavy application of sulfur, was considerably increased in comparison with the corresponding yield from the check plots.

Experiments with the American Giant variety

Experiment I. The soil on which this experiment was conducted is a heavy loam that had produced severely scabbed potatoes the preceding year. Sulfur was applied at the rate of 300 and 400 pounds per acre. The results of the experiment are given in table 5 and in the diagrams of figure 4. On the basis of total yield, the treated plots showed an increase over the untreated check plots, this increase amounting to 20.5 bushels per acre for the 300-pound treatments and 5.8 bushels per acre for the 600-pound treatments. From table 5 it will be seen that the per cent of scabby tubers in the primes was greatly reduced by the sulfur treatments. Of the total yield of primes from the untreated plots 82 per cent were diseased while the plots treated with 300 pounds of sulfur per acre and those receiving the 400-pound treatment gave total yields of primes of which only 23.6 per cent and 15.8 per cent, respectively, were scabby.

The relation of the hydrogen-ion exponents of the soil samples from the plots in this experiment to the per cent of scabby tubers is shown in figure 4. Soil samples taken before the sulfur applications were made gave an average hydrogen-ion exponent value of 5.6. At the time of harvesting, the average

FIG. 4. DIAGRAM SHOWING THE RELATION OF SULFUR TREATMENTS TO HYDROGEN-ION CONCENTRATION AND THE PER CENT OF CLEAN AND SALABLE SCABBY TUBERS IN THE PRIMES—AMERICAN GIANT VARIETY, EXPERIMENT I

TABLE 5

Influence of sulfur applications on total yield, per cent of scabby tubers and hydrogen-ion concentration

TREATMENT	TOTAL YIELD	YIELD OF PRIMES		SECONDS	pH VALUES OF SOIL EXTRACTS
		Clean	Scabby		
	<i>bushels per acre</i>	<i>bushels per acre</i>	<i>per cent</i>	<i>bushels per acre</i>	
Check*.....	280.8	240.8	82.0	40.0	5.55
300 pounds sulfur†.....	301.3	247.7	23.6	53.6	5.07
400 pounds sulfur†.....	286.6	247.7	15.8	38.9	4.90

* Average of 6 plots.

† Average of 4 plots.

hydrogen-ion exponent values of soil samples taken from the check plots was 5.55 while the corresponding exponent values for the samples from the plots treated with 300 pounds and from those treated with 400 pounds of sulfur per acre were 5.07 and 4.90, respectively. It will thus be observed from table 5 and from the diagrams of figure 4 that with each decrease in the value of the hydrogen-ion exponents below that of the check plots, a corresponding decrease occurred in the per cent of scabby tubers among the primes.

Experiment II. This experiment was conducted on a light sandy loam soil underlaid at a shallow depth by a greensand marl. In 1918 potatoes grown in the field had been severely scabbed. Sulfur was applied at the rate of 500 and 700 pounds per acre. The results are presented in table 6. The data of this table indicate a reduction of 44.8 bushels per acre for the plots treated with 500 pounds of sulfur in comparison with the corresponding yields from the check plots. It is questionable, however, whether this decrease in yield

TABLE 6
Influence of sulfur applications on total yield, per cent of scabby tubers and hydrogen-ion concentration

TREATMENT	TOTAL YIELD	YIELD OF PRIMES		YIELD OF SECONDS	pH VALUES OF SOIL EXTRACTS
		Clean	Scabby		
	<i>bushels per acre</i>	<i>bushels per acre</i>	<i>per cent</i>	<i>bushels per acre</i>	
Check*.....	247.3	184.4	64.4	62.8	5.6
500 pounds sulfur†.....	202.5	161.2	38.8	41.3	4.8
700 pounds sulfur†.....	250.8	191.6	23.8	59.1	4.8

* Average of 6 plots.

† Average of 4 plots.

can be ascribed to the sulfur treatment, since the plots receiving the 700-pound application gave an increase of 3.5 bushels per acre over the yields from the check plots. A much lower percentage of scabby tubers was obtained from the treated than from the untreated plots. This decrease in the percentage of scabby tubers was much more pronounced than is apparent from the figures given in the table, since the tubers from the treated plots classified as scabby showed fewer lesions than did those from the check plots.

The relation of the hydrogen-ion exponents of the soil samples collected from the treated and untreated plots to the yields of scabby and clean tubers is shown in the diagrams of figure 5. Soil samples taken before the sulfur applications were made gave an average hydrogen-ion exponent value of 5.8. At the time of harvesting, the average hydrogen-ion exponent values of the soil samples from the check plots treated with 700 pounds and from those treated with 500 pounds of sulfur per acre was 4.8 in both cases. Despite this fact the per cent of scabby tubers among the primes harvested from the plots treated with 700 pounds was lower than from those treated with 500

pounds, being 23.8 for the former and 38.8 for the latter, as compared with 64.4 for the check plots.

In this experiment the amount of scab on the tubers from the treated plots was reduced to only a few lesions. It is doubtful whether scab could be entirely eliminated from the crop even by heavier applications of sulfur, since the exponent values resulting from the 400 and 700-pound applications are considerably lower than the exponent shown by Gillespie (7) to inhibit the growth of the scab organism in culture media.

FIG. 5. DIAGRAM SHOWING THE RELATION OF SULFUR TREATMENTS TO HYDROGEN-ION CONCENTRATION AND THE PER CENT OF CLEAN AND SALABLE SCABBY TUBERS IN THE PRIMES—AMERICAN GIANT VARIETY, EXPERIMENT II

The necessity of determining the hydrogen-ion concentration of the soil before making sulfur applications is evident from the experiments here reported. In the case of three of these, soil samples taken before the sulfur applications were made showed an average hydrogen-ion concentration of 5.66. At the time of harvesting the average hydrogen-ion exponent values of the soil samples from plots receiving 300 pounds of sulfur per acre was approximately the same as where larger amounts (400 to 700 pounds) were used, being 4.92 for the former and from 4.8 to 4.9 for the latter. Scab was likewise approximately as well controlled on the plots receiving the 300-pound application as where the heavier applications were made, the percentage of scabby

tubers in the primes being 28.5 for the former and from 15.8 to 38.8 for the latter. In the other two experiments soil samples taken before the sulfur applications were made showed an average exponent value of 6.26, and here the heavier applications of sulfur (400 to 1200 pounds) not only gave a greater decrease in the exponent values than the lighter applications (300 pounds) but with each decrease in the value of the hydrogen-ion exponents below that of the check plots, a corresponding decrease occurred in the per cent of scabby tubers among the primes.

SUMMARY

With due regard for the limitations of the experiments here reported, resulting from the fact that they were conducted for one year only, the following points may be advanced.

1. With the different amounts of sulfur used, all gave substantial gains in the number of clean tubers. With the heaviest application, however, scab was not entirely eliminated.

2. The results would indicate that with those varieties of potatoes known to scab severely the use of sulfur in the proper amount will render a large portion of the crop salable.

3. In all cases, following applications of sulfur there was an increase in soil acidity as measured by the hydrogen-ion concentration of soil extracts. In most instances this increase in acidity, corresponding to a decrease in hydrogen-ion exponent, was in proportion to the amount of sulfur applied.

4. With a decrease in hydrogen-ion concentration there was a decrease in the number of scabby tubers.

5. The necessity of knowing the soil reaction before sulfur applications are made is evident from the fact that where the hydrogen-ion concentration of water extracts of soil samples taken before the sulfur applications were made was 5.8 or less, the lighter applications (300 to 500 pounds) gave approximately as good control of scab as the heavier applications (700 to 1200 pounds). Where the initial exponent was greater than 6.0 the heavier applications gave the best control.

6. The results of the present work would indicate that the limiting exponent for the growth of the scab organism is lower in soil than in culture media.

REFERENCES

- (1) BRIOUX, CH., AND GUERBET, M. 1912 *Mecanisme de l'action fertilisante du soufre. In Compt. Rend. Acad. Sci. (Paris)*, t. 156, no. 19, p. 1476-1479; also in *Ann. Sci. Agron.*, t. 4, ser. 2, no. 4, p. 385-396.
- (2) BROWN, P. E., AND KELLOGG, E. H. 1914 *Sulfocation in soils. Iowa Agr. Exp. Sta. Res. Bul.* 19, p. 49-111.
- (3) BROOKS, W. P. 1897 *Scab of potatoes. Mass. (Hatch) Agr. Exp. Sta. Rpt.* 9, p. 44-45.
- (4) CHANCRIN, E., AND DESRIOT, A. 1911 *Action du soufre comme engrais. In Jour. Agr. Prat.*, n.s., t. 21, no. 14, p. 427-429.

- (5) CLARK, W. A., AND LUBS, H. A. 1917 The colorimetric determination of hydrogen-ion concentration and its application to bacteriology. *In Jour. Bact.*, v. 2, no. 1, p. 1-34; v. 2, no. 1, p. 109-136; v. 2, no. 3, p. 191-235.
- (6) GARMAN, H. 1898 Corrosive sublimate and flour of sulfur for potato scab; experiments made in 1896. *Ky. Agr. Exp. Sta. Bul.* 72, p. 9-18.
- (7) GILLESPIE, LOUIS J. 1918 The growth of the potato scab organism at various hydrogen-ion concentrations as related to the comparative freedom of acid soils from the potato scab. *In Phytopathology*, v. 8, no. 6, p. 257-269.
- (8) GILLESPIE, LOUIS J., AND HURST, LEWIS A. 1917 Hydrogen-ion concentration measurements of soils of two types; Caribou loam and Washburn loam. *In Soil Sci.*, v. 4, no. 4, p. 313-319.
- (9) GILLESPIE, LOUIS J., AND HURST, LEWIS A. 1918 Hydrogen-ion concentration—soil type—common potato scab. *In Soil Sci.*, v. 6, no. 3, p. 219-236.
- (10) HALSTED, B. D. 1895 Field experiments with potatoes. *N. J. Agr. Exp. Sta. Bul.* 112, p. 3-20.
- (11) HALSTED, B. D. 1897 Field experiments with potatoes. *N. J. Agr. Exp. Sta. Bul.* 120, p. 3-19.
- (12) HALSTED, B. D. 1897-1900 Experiments with potatoes. *In N. J. Agr. Exp. Sta. 17th Ann. Rpt.* (1896), p. 309-328; *18th Ann. Rpt.* (1897), p. 276-284; *19th Ann. Rpt.* (1898), p. 299-309.
- (13) HALSTED, B. D. 1900 Soil fungicides for potato and turnip diseases. *In N. J. Agr. Exp. Sta. 20th Ann. Rpt.*, p. 326-345.
- (14) HALSTED, B. D. 1901 Potato Experiments in 1900. *In N. J. Agr. Exp. Sta. 20th Ann. Rpt.* (1899), p. 326-345.
- (16) LINT, H. C. 1914-1916 Report of potato scab experiments. *In N. J. Agr. Exp. Sta. 35th Ann. Rpt.* (1914), p. 477-488; *36th Ann. Rpt.* (1915), p. 375-381; *37th Ann. Rpt.* (1916), p. 618-625.
- (15) LINT, H. C. 1914 The influence of sulfur on soil acidity. *In Jour. Indus. Engin. Chem.*, v. 6, p. 747.
- (17) LIPMAN, J. G., MCLEAN, H. C., AND LINT, H. C. 1916 Sulfur oxidation in soils and its effect on the availability of mineral phosphates. *In Soil Sci.*, v. 2, no. 6, p. 499-538.
- (18) LOUDON, J. C. 1825 *Encyclopedia of Agriculture*. London.
- (19) SHEBRAKOFF, C. C. 1914 Potato scab and sulfur disinfection. *N. Y. (Cornell) Agr. Exp. Sta. Bul.* 350, p. 709-743.
- (20) SHEBRAKOFF, C. D. 1915 The after effect of sulfur treatment on soil. *In Phytopathology*, v. 5, no. 4, p. 219-222.
- (21) SHEDD, O. M. 1914 The relation of sulfur to soil fertility. *Ky. Agr. Exp. Sta. Bul.* 188, p. 595-630.
- (22) WHEELER, H. J., AND ADAMS, G. E. 1898 On the use of flowers of sulfur and sulphate of ammonia as preventive of the potato scab in contaminated soils. *R. I. Agr. Exp. Sta. 10th Ann. Rpt.* (1897), p. 254-268.