

# American Potato Journal

PUBLISHED BY  
THE POTATO ASSOCIATION OF AMERICA  
NEW BRUNSWICK, N. J.

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## THE EFFECT OF SULPHUR AND ACID FERTILIZER ON INCIDENCE OF POTATO SCAB\*

J. H. MUNCIE<sup>3</sup>, H. C. MOORE<sup>4</sup>, J. TYSON<sup>5</sup> AND E. J. WHEELER<sup>6</sup>

*Michigan Agricultural Experiment Station, East Lansing, Mich.*

The relation of soil reaction to incidence of potato scab (*Actinomyces scabiei* (Thaxt) Güssow) has been studied by many investigators. The literature on this subject has been well reviewed by Dippenaar (4) and further brought up to date by Ken Knight (7).

Although in certain areas, decrease of potato scab in alkaline soil has been noted by Goss, (6), Smith, (9), Blodgett and Howe, (1), Blodgett and Cowan, (2), and Larson, Albert and Walker, (8), the general concensus of opinion seems to be that lowering the soil reaction particularly below pH 5.2 also decreases the amount of the disease on the crop when grown in scab-infested soils. This is usually accomplished by the addition of sulphur to the soil or as shown by Cook and Nugent (3) by the use of acid-forming fertilizer.

In many areas of Michigan, it is the custom to grow potatoes on fields where alfalfa has been plowed under to increase humus content of the soil. It is often necessary to make applications of ground limestone, marl or hydrated lime to these soils to bring the soil reaction up to a

<sup>1</sup>The writers are indebted to Mr. A. M. Berridge, Supt. Lake City Experiment Station, Lake City, Michigan, for providing facilities for carrying on this project and his continued interest in the investigation. This investigation represents part of the work done under the cooperative Michigan Experiment Station-Bankhead-Jones Project 1B.

<sup>2</sup>Published by permission of the Director, Michigan Agricultural Experiment Station. Journal Article Number 706 (N.S.).

<sup>3</sup>Research Associate in Plant Pathology.

<sup>4</sup>Associate Professor and Research Associate in Farm Crops.

<sup>5</sup>Associate Professor and Research Assistant in Soils.

<sup>6</sup>Instructor and Research Assistant in Farm Crops.

level suitable for growing the alfalfa crop. On soils so treated although good conditions obtain for growing potatoes, the incidence of potato scab often increases to such extent that serious losses to the crop result. Field experiments were therefore undertaken to find out (1) if by addition of sulphur and acid fertilizer the soil reaction could be lowered to such extent that growth of the scab organism would be inhibited without serious reduction in yield of potatoes and (2) whether after treatments with sulphur and acid-forming fertilizer the later addition of lime to the acid reacting soil would result in renewed activity of the scab parasite.

#### PLOT LOCATION AND TREATMENTS

The plots were laid out on a 2¼ acre field at the Lake City Experiment Station, Lake City, Michigan. The soil was Ottawa sandy loam and typical of that of many fields where potatoes are grown commercially in the northern part of the state. The soil had been uniformly infested with the scab organism in manure cultures and by scattering over it scabby potatoes after harvest in 1937 and 1938. The same plots were used each of the four years 1939-1942 inclusive and were given a heavy coating of manure in the winter between crops of potatoes.

The experiment was set up in series of 12 plots, 50 feet x 24 feet, randomized for treatment and replicated three times, with a 15-foot aisle between each series. Soil tests over the entire tract showed the soil reaction to vary between pH 4.5 and 6.0.

The soil treatments were as follows

1. 400 pounds of sulphur disked into the top 6 inches of soil; 500 pounds of acid 4-16-8 fertilizer applied in bands at planting.
2. 800 pounds of sulphur and 500 pounds of acid 4-16-8 fertilizer applied as in (1).
3. 400 pounds of sulphur plowed under to a depth of approximately 8 inches; 500 pounds of acid 4-16-8 fertilizer in bands at planting.
4. 800 pounds of sulphur and 500 pounds of acid 4-16-8 fertilizer applied as in 3.
5. 400 pounds of sulphur plowed under as in 3 and 400 pounds disked in as in (1); 500 pounds of acid 4-16-8 fertilizer applied in bands at planting.
6. 800 pounds of sulphur plowed under and 800 pounds disked in and 500 pounds of acid 4-16-8 fertilizer applied in bands at planting (5).
7. 200 pounds of sulphur were mixed with 500 pounds of acid 4-16-8 fertilizer and the entire 700 pounds applied per acre in bands at planting.
8. 400 pounds of sulphur mixed with 500 pounds of acid 4-16-8 fertilizer and the entire 900 pounds applied per acre in bands at planting.
9. 500 pounds of acid 4-16-8 fertilizer per acre applied in bands at each side of and level with the seed piece.
10. 500 pounds of commercial 4-16-8 fertilizer applied as in (9).
11. Seed pieces rolled in sulphur and 500 pounds per acre of acid 4-16-8 fertilizer applied in bands at planting.
12. 200 pounds of sulphur mixed with 500 pounds of acid 4-16-8 fertilizer and the entire 700 pounds applied per acre in bands at planting; seed pieces rolled in sulphur.

## MATERIALS AND METHODS

The sulphur used was commercial sulphur flour. The acid fertilizer was made by mixing appropriate amounts of ammonium sulphate, special acid reacting superphosphate and potassium sulphate without lime filler. The sulphur was applied to the soil surface with a grain drill and either disked into the soil or plowed under as required. First sulphur applications were made in April, 1939. A second duplicate series of applications was made in October 1939, after harvest. Soil acidity readings were made in September, 1939, 1941 and 1942, and in July and in August, 1940. Soil samples were taken from the potato hill with no attempt to determine whether the tubers in the hill were scabby.

Untreated potatoes were planted on the plots in early May each year using a two-row mechanical planter. The Chippewa variety was used in these tests because of its susceptibility to scab. They were harvested in late September each year. Records were made of the tubers harvested from 40 feet of the two center rows of the 8-row plots. Tubers were graded into four classes, namely—clean, light, moderate and heavy scab and the weight of each lot tabulated. The degree of scabiness was arbitrarily determined as follows: light scab, 1 to 5 scab lesions; moderate scab, 6 to 10 lesions; heavy scab, more than 10 lesions; and clean, no evidence of scab. Each grade of scabby tubers was weighed and its percentage of total yield taken as the scab index. In each of the four years, the light scab for the most part could have been included with the clean tubers as marketable potatoes. Only a few of the potatoes graded as moderate scab and none of those graded as heavy scab could have been included as marketable. Since the grower is primarily interested in the salable part of his crop, the degree of scab control is expressed as percentage of clean tubers and salable tubers, including both clean and light scab.

## RESULTS OF 1939

The average percentages of clean and salable tubers (clean and light scab) from the three replicated plots of each treatment in 1939 are given in table 1.

Just before harvesting, soil samples were taken from each plot and pH readings made. These data are presented in the table as an average for the three plots of each treatment. From the data in table 1, it is seen that with the exception of plots with treatment 9, the soil reaction was more acid than is usually considered as suitable for scab development. Also, it was considered too acid for optimum growth of the potato plant.

TABLE I—Soil treatment and reaction (pH) of plots in 1939 and percentage and yield per acre of clean and salable tubers, and total yield per acre. Average of three plots. Lake City Experiment Station, Lake City, Michigan.

Treatment	Soil		Clean Tubers		Salable Tubers		Total Yield	
	pH		Per cent	Yield Bu. per Acre	Per cent	Yield Bu. per Acre	Bu. per Acre	
1) * 400 lbs. sulphur disked in	4.5		42.4	53.4	61.9	78.0	126.1	
2) * 800 lbs. sulphur disked in	4.0		32.1	41.2	51.4	66.0	128.4	
3) * 400 lbs. sulphur plowed down	4.0		52.8	53.8	78.6	72.8	102.0	
4) * 800 lbs. sulphur plowed down	4.2		42.5	45.2	63.2	67.2	106.3	
5) * 400 lbs. sulphur disked in	4.6		45.4	62.5	73.1	100.5	137.5	
6) * 800 lbs. sulphur plowed down	4.0		66.6	65.8	80.3	79.3	98.8	
7) 200 lbs. sulphur mixed with 500 lbs. acid 4-16-8 in bands	4.2		49.8	51.3	68.7	70.7	102.9	
8) 400 lbs. sulphur mixed with 500 lbs. acid 4-16-8 in bands	4.0		34.0	32.4	64.9	61.7	95.1	
9) 500 lbs. acid 4-16-8 in bands	5.0		33.7	40.1	50.8	60.4	119.0	
10) 500 lbs. commercial 4-16-8 in bands (Check)	4.5		11.7	11.4	34.9	33.9	97.3	
11) Seed piece rolled in sulphur 500 lbs. acid 4-16-8 in bands	4.3		46.2	46.5	66.0	66.2	100.4	
12) Seed piece rolled in sulphur 200 lbs. sulphur mixed with 500 lbs. acid 4-16-8 in bands	4.2		47.7	50.9	68.1	72.7	106.7	

\*500 pounds per acre acid 4-16-8 applied in bands at planting.

However, potato scab was found in abundance in all treated plots. It is also seen that there was a general increase in percentage and yield of both clean and salable tubers from all treated plots.

Greatest increases in clean and also salable tubers were obtained from plots receiving 800 pounds of sulphur which was turned under to a depth of 6-8 inches followed by an application of 800 pounds, disked into the top 4 inches of soil. Increases in yield of clean tubers on all treated plots, ranged from 21 bushels to 54 bushels compared with the check (treatment 10) in which no sulphur was used and 500 pounds per acre of commercial 4-16-8 fertilizer were applied. There also was an increase in clean and salable potatoes from plots treated with acid reacting fertilizer (treatment 9.) There was no indication that the total yield of potatoes was reduced by additions of sulphur during the first year of the experiment but later, however, sulphur definitely depressed the yield.

#### RESULTS IN 1940-1941 AND 1942

In evaluating the results of soil treatments for the years 1940 to 1942 inclusive, it must be noted that the applications of sulphur in May 1939, were duplicated in October of that year. Thus each treated plot received twice as much sulphur for the season of 1940. No further sulphur applications were made during 1940-1942. The additional sulphur applications were made to find out if the soil acidity could be increased to such an extent that growth of the scab organism would be further inhibited and what effect increased amounts of sulphur would have on growth of the potato plant. The result of the 1940 trials are presented in table 2.

After additional applications of sulphur in treatments 1 to 6 inclusive, the soil pH was higher in 1940 than in 1939. This may have been due to the fact that free sulphur, included in the first year's sample's, affected the reading. The 1939 tests were made with a "Soiltex" outfit and those in 1940 were made using colorimetric indicators.

As in 1939, the percentage of clean tubers was increased over the check by all treatments with greatest increase from treatment 6 which had in two applications received 3200 pounds of sulphur, one-half of which was plowed under and one-half disked into the top 4-6 inches of soil. The smallest percentage increase was obtained from treatment 9 in which no sulphur was added to the soil but acid reacting fertilizer was applied in bands at time of planting. Increases in percentage of clean tubers compared with those of 1939 were obtained from treatments 2 to 7 inclusive but decreases from treatments 1, 8, 9, 11 and 12. Increases in percentage and yield of salable (clean and light scab) tubers

TABLE 2—Soil treatment and reaction (pH) of plots in 1940 and percentage and yield per acre of clean and salable tubers and total yield per acre. Average of three plots. Lake City Experiment Station, Lake City, Michigan.

Treatment	Soil		Clean Tubers		Salable Tubers		Total Yield	
	pH	Per cent	Yield Bu. per Acre	Per cent	Yield Bu. per Acre	Per cent	Yield Bu. per Acre	Bu. per Acre
1) * 800 lbs. sulphur disked in	5.30	39.0	18.6	58.1	28.3	58.1	28.3	48.3
2) * 1600 lbs. sulphur disked in	5.03	45.0	18.5	59.4	24.5	59.4	24.5	42.8
3) * 800 lbs. sulphur plowed down	4.40	58.2	20.9	77.2	27.5	77.2	27.5	35.2
4) * 1600 lbs. sulphur plowed down	4.86	65.1	20.6	78.6	23.9	78.6	23.9	30.3
5) * 800 lbs. sulphur plowed down 800 lbs. sulphur disked in	4.90	59.2	28.9	75.8	39.4	75.8	39.4	52.3
6) * 1600 lbs. sulphur plowed down 1600 lbs. sulphur disked in	4.20	95.7	12.7	100.0	13.7	100.0	13.7	17.3
7) 200 lbs. sulphur mixed with 500 lbs. acid 4-16-8 in bands	5.00	65.8	21.0	72.0	24.1	72.0	24.1	36.9
8) 400 lbs. sulphur mixed with 500 lbs. acid 4-16-8 in bands	4.86	22.7	11.5	41.4	21.0	41.4	21.0	55.0
9) 500 lbs. acid 4-16-8 in bands	5.40	17.1	9.2	24.7	13.1	24.7	13.1	62.0
10) 500 lbs. commercial 4-16-8 in bands (Check)	5.43	3.7	2.1	13.6	8.9	13.6	8.9	60.6
11) Seed piece rolled in sulphur 500 lbs. acid 4-16-8 in bands	5.33	27.0	15.2	43.8	25.7	43.8	25.7	61.3
12) Seed piece rolled in sulphur 200 lbs. sulphur mixed with 500 lbs. acid 4-16-8 in bands	4.56	38.4	17.7	58.1	27.6	58.1	27.6	50.6

\*500 pounds per acre acid 4-16-8 applied in bands at planting.

followed generally those of clean tubers. The highest percentage of clean tubers and the lowest total yields were obtained from treatment 6 receiving the maximum sulphur application. The stand of plants was greatly reduced in 1940 on these plots, the number of plants on the three replicates being 40, 144 and 76 respectively. There also was evidence of sulphur injury on some of the tubers from this treatment.

Although an application of acid 4-16-8 fertilizer alone or mixed with 200 or 400 pounds of sulphur reduced scab, the increases in clean tubers from these treatments were not so great as from the use of heavy application of sulphur worked into the soil before planting.

Rolling the seed pieces in sulphur resulted in increased percentage of clean tubers as compared with applications of acid fertilizer alone.

The results in 1941 were comparable to those of the previous year and are shown in table 3. The percentage of clean tubers was greatest on the treated plots. Treatment 6, again showed the least total yield and highest percentage of clean and salable tubers. The percentage of salable tubers was least from treatment 9 in which only acid reacting fertilizer was applied. The soil reactions showed a change to the more acid for each plot as compared with readings of 1940, the greatest lowering of pH being from treatments 5 and 6 receiving 1600 and 3200 pounds of sulphur respectively in two applications in 1939. It is interesting to note the difference of soil reaction in treatments 2, 3 and 5 showing approximately the same percentage of clean tubers, 48.6 per cent, 52.6 per cent and 53.7 per cent respectively with pH readings of 4.46, 4.28 and 3.44. If soil acidity were the determining factor in scab infection, it would seem that there should be greater variation in percentage of clean tubers between these treatments.

The total yields of tubers were much greater in 1941 than in either previous year because of the favorable growing conditions. There was a reduction in yield probably due to previous heavy applications of sulphur on plots receiving treatment 6. There was also a slight reduction in stand in these replicates.

In October, 1941, applications of hydrated lime were made at the rate of 1500 pounds per acre to the plots of treatment 6, which had previously received additions of 3200 pounds of sulphur per acre. This was done to find out if the scab organism had been killed by the previous sulphur treatment or only inhibited in growth during the previous year. If it had been only inhibited, then increasing the soil pH should furnish better conditions for its growth and scab infection should also increase. Soil reaction in 1942 remained approximately as for 1941 on all plots except those receiving 1500 pounds of hydrated lime on which

TABLE 3—Soil treatment and reaction (pH) of plots in 1941 and percentage and yield per acre of clean and salable tubers and total yield per acre. Average of three plots. Lake City Experiment Station, Lake City, Michigan.

Treatment	Soil		Clean Tubers		Salable Tubers		Total Yield	
	pH	Per cent	Yield Bu. per Acre	Per cent	Yield Bu. per Acre	Per cent	Yield Bu. per Acre	Bu. per Acre
1) * 800 lbs. sulphur disked in	4.60	17.8	30.9	45.3	78.7			173.6
2) * 1600 lbs. sulphur disked in	4.46	48.6	85.8	75.9	134.2			176.7
3) * 800 lbs. sulphur plowed down	4.28	52.6	98.9	78.9	148.3			187.9
4) * 1600 lbs. sulphur plowed down	4.38	61.1	110.7	87.1	157.7			181.1
5) * 800 lbs. sulphur plowed down 800 lbs. sulphur disked in	3.44	53.7	94.4	86.3	151.8			175.9
6) * 1600 lbs. sulphur plowed down 1600 lbs. sulphur disked in	3.79	83.4	93.2	93.4	104.4			111.8
7) 200 lbs. sulphur mixed with 500 lbs. acid 4-16-8 in bands	4.23	35.8	58.7	67.7	110.9			163.8
8) 400 lbs. sulphur mixed with 500 lbs. acid 4-16-8 in bands	4.04	20.7	25.1	47.4	57.4			121.2
9) 500 lbs. acid 4-16-8 in bands	4.95	8.1	12.1	15.6	23.3			149.6
10) 500 lbs. commercial 4-16-8 in bands (Check)	5.41	2.7	4.8	25.3	45.1			178.6
11) Seed piece rolled in sulphur 500 lbs. acid 4-16-8 in bands	4.75	17.2	26.3	51.8	79.1			152.6
12) Seed piece rolled in sulphur 200 lbs. sulphur mixed with 500 lbs. acid 4-16-8 in bands	4.38	31.1	48.1	59.8	92.6			154.9

\* 500 pounds per acre acid 4-16-8 applied in bands at planting.



the reaction was changed from pH 3.79 to 5.38. Results for 1942, (table 4) show that for all treatments except numbers 10, the check and 12, there was a further decrease in percentage of clean and of salable tubers. In contrast with results of 1940 and 1941, the percentage of clean tubers from treatment 6 dropped from 95.2 and 86.9 respectively to 34.1. These results show that the scab organism during previous years of the experiment had not been killed by the treatment and needed only more nearly optimum soil reaction to cause increased infection. Thus in these experiments, applications of sulphur afforded only temporary relief from scab infection while the soil reaction was too low for the best growth of the potato plant. When this level was raised to more nearly optimum for the growth of the crop, then scab increased rapidly on the current crop. Similar results were obtained by Eddins (5) in Florida where limestone was applied after sulphur between potato crops for two years.

It is also indicated that soil acidity is not alone the controlling factor in scab infection, as is shown by percentages of clean tubers in all plots with soil reaction less than pH 5.0. In every case with the exception of treatments 10 and 12 in 1942, the percentage of clean tubers was less than that on the same plots in 1941. It appears that free sulphur in the soil also may have been at least partly responsible for decrease in scab infection. It is also shown that the scab organism may adjust itself to more acid soil conditions and produce infection under these conditions.

#### DISCUSSION

Several interesting facts are shown by the data in considering the results over the four-year period. The special acid fertilizer without sulphur applied in bands slightly increased the acidity of the soil in the region of the hill and increased the percentage of clean tubers, although it apparently had no different effect on the total yield or yield of salable potatoes in comparison with fertilizer of the usual non-acid type.

Applications of sulphur were effective in reducing the soil reaction and in increasing the percentage of clean tubers and yield of salable potatoes, without greatly influencing the total yield per acre, except when applied in a manner that caused direct injury to the plant through contact with free sulphur. This is shown by the plots receiving band applications of 400 pounds of sulphur and 500 pounds of acid fertilizer per acre (treatment 8, 1939).

In 1940 percentage yield of clean tubers was increased when the amount of sulphur applied was sufficient to decrease the soil reaction

TABLE 4—Soil treatment and reaction (pH) of plots in 1942 and percentage and yield per acre of clean and salable tubers and total yield per acre. Average of three plots. Lake City Experiment Station, Lake City, Michigan.

Treatment	Soil-		Clean Tubers		Salable Tubers		Total Yield	
	pH	Per cent	Per cent	Yield Bu. per Acre	Per cent	Yield Bu. per Acre	Per cent	Yield Bu. per Acre
1) * 800 lbs. sulphur disked in	4.60	14.6	37.7	12.6	37.7	32.6	37.7	86.5
2) * 1600 lbs. sulphur disked in	4.70	24.0	52.6	18.3	52.6	40.2	52.6	76.3
3) * 800 lbs. sulphur plowed down	4.80	42.9	67.0	36.0	67.0	53.9	67.0	80.4
4) * 1600 lbs. sulphur plowed down	4.60	34.9	67.8	30.3	67.8	58.0	67.8	86.8
5) * 800 lbs. sulphur plowed down 800 lbs. sulphur disked in	4.53	32.3	60.6	28.1	60.6	53.7	60.6	86.9
6) * 1600 lbs. sulphur plowed down 1600 lbs. sulphur disked in	5.38	34.1	58.5	28.1	58.5	48.2	58.5	82.4
7) 200 lbs. sulphur mixed with 500 lbs. acid 4-16-8 in bands	4.63	32.1	57.2	22.3	57.2	39.7	57.2	69.3
8) 400 lbs. sulphur mixed with 500 lbs. acid 4-16-8 in bands	4.97	17.9	43.5	12.5	43.5	30.4	43.5	69.8
9) 500 lbs. acid 4-16-8 in bands	5.13	3.2	12.7	2.7	12.7	10.8	12.7	84.7
10) 500 lbs. commercial 4-16-8 in bands (Check)	5.41	3.8	22.8	2.8	22.8	16.6	22.8	72.8
11) Seed piece rolled in sulphur 500 lbs. acid 4-16-8 in bands	5.13	12.5	30.1	8.4	30.1	20.2	30.1	67.2
12) Seed piece rolled in sulphur 200 lbs. sulphur mixed with 500 lbs. acid 4-16-8 in bands	4.30	31.8	58.6	20.2	58.6	37.2	58.6	63.5

\*500 pounds per acre acid 4-16-8 applied in bands at planting.

enough to inhibit the growth of potatoes as in the case of the plots receiving respectively 1600 and 3200 pounds per acre (treatments 5 and 6). The soil reaction of these plots was too low for good growth, pH 3.4 and 3.8. 800 and 1600 pounds of sulphur per acre plowed under were more effective in reducing scab than the same amounts disked into the surface. Although 1600 pounds of sulphur per acre was more effective in scab control than 800 pounds when disked into the surface, there was no difference when they were plowed under. The maximum benefits on this soil were obtained with treatment 5 (800 pounds plowed under plus 800 pounds disked into surface). This plot as an average for the four years gave the highest total yield and the highest yield of salable potatoes. The plot receiving twice this amount of sulphur, treatment 6 (1600 pounds plowed under plus 1600 pounds disked into soil) yielded the largest percentage of clean potatoes, but since the total yield was much smaller the yield of salable potatoes was also much less.

The application of sulphur in this experiment did not completely control potato scab in any case. The highest percentage of clean potatoes was secured in 1940 on the plots that received 3200 pounds of sulphur per acre, where the soil reaction, pH 4.2, was too low for best growth of potatoes. Only 4.3 per cent of the potatoes on these plots were scabby. However, where sufficient lime was applied in 1942 to bring the soil reaction to approximately pH 5.4 scab increased to 65.9 per cent of the crop.

In all treated plots with the exception of number 2, there was a slight decrease in 1941 in the percentage of clean potatoes as compared with the 1940 crop harvested after the second application of sulphur. In general, the soil reaction for these plots in 1941 showed in most cases lower pH than in 1940. In 1942, the soil pH was slightly higher than those of 1940 in all, with the exception of two plots. The percentage of clean potatoes on all treated plots except the check was much lower in 1942 than in any of the previous years.

#### SUMMARY

1. Applications of acid fertilizer alone and in combination with sulphur in bands or when used with sulphur plowed under or disked into the soil reduced potato scab infection.
2. Greatest reduction of scab resulted from applications of 3200 pounds of sulphur per acre and acid fertilizer but the yield of potatoes was seriously reduced.
3. The least amount of scab occurred in plots showing soil reactions of approximately pH 3.5-3.8.

4. It is shown that growth of the potato scab organism was only partially inhibited in soils of low pH and that it gradually adapted itself to these conditions.
5. When lime was added to raise the soil reaction to approximately 5.4, scab became more severe.
6. In comparison with the crop of 1939 there was a noticeable decrease in percentage of clean potatoes in the two crops following the second application of sulphur in 1940, although the soil pH in most plots remained lower, except where lime had been applied.

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