EFFECTS OF GYPSUM, SULFUR, TERRACLOR AND TERRACLOR SUPER-X FOR POTATO SCAB CONTROL[1]

J. R. DAVIS, J. G. GARNER, AND R. H. CALLIHAN[2]

ABSTRACT

An investigation was made to determine possible effects of gypsum and sulfur for control of common scab of potato [*Streptomyces scabies* (Thaxt.) Waksman and Henrici] in a highly buffered calcareous soil. This investigation included a comparison of the effectiveness of gypsum and sulfur with Terraclor and Terraclor Super-X. Both gypsum and sulfur reduced potato scab and measurements indicate that change of soil pH was slight (0.1-0.4 pH reduction). Band applications of sulfur in the sulfate (gypsum) or elemental form were effective at 600 lbs/A (672.5 Kg/ha) but not at lower rates. The weight of tubers thrown out of grade with scab was reduced by 53% with the effective sulfur rate. Treatment effects of gypsum (600 lb S/A-672.5 Kg/ha) were not significantly different from sulfur dust (600 lb/A-672.5 Kg/ha), Terraclor or Terraclor Super-X (both at 25.0 lb PCNB/A-28.0 Kg/ha). Tissue analyses of tuber peelings showed a significant reduction in calcium from treatments involving sulfur and gypsum, indicating that calcium levels in tuber peelings were positively correlated with scab susceptibility.

INTRODUCTION

In certain areas of Idaho, potato scab [*Streptomyces scabies* (Thaxt.) Waksman and Henrici] is a serious problem.

Sulfur has traditionally been used to control potato scab when the pH can be appreciably reduced (12). The general consensus is that the disease is decreased by lowering the pH below 5.2.

If pH reduction is the only reason for the sulfur effect, then much of the Idaho desert soil is too highly buffered to permit a suitable means for control with sulfur (unpublished data from University of Idaho Dept. of Biochemistry and Soils). However, Duff and Welch (2) suggest that the effect of sulfur may not necessarily be a direct effect of pH on the pathogen. They observed that scab was reduced by applications of sulfur with little change to pH. The work of Vlitos and Hooker (16) also suggests that scab control from sulfur treatment may be a result of factors other than change in soil pH. In peat soil they found actinomycete populations reduced before an appreciable change in soil pH levels became apparent. While actinomycete populations were reduced, the populations of true bacteria were increased in sulfur-treated peat soil. This effect was presumably not a fungicidal effect since elemental sulfur on agar was not toxic to *S. scabies*.

Menzies (10) reported that while calcium sulfate was not effective on soils below pH 8.0, it reduced potato scab in soils of higher pH. Since Idaho desert soils commonly range in pH from 7.5-8.2, the possible effectiveness of gypsum seemed feasible.

On the other hand, Horsfall, Hollis and Jacobson (6) present an opposite possibility. They indicated that increased soil calcium resulted in increased tuber calcium, which was positively correlated with disease severity. Barnes and McAllister (1) observed a significant reduction of calcium and of Ca/K ratios in tuber peelings following scab reduction with sulfur treatments. However, they were unable to determine

[1]Published with the approval of the Director of the Idaho Agri. Expt. Sta. as Research Paper No. 946. Received for publication Aug 9, 1973.

[2]Associate Professor of Plant Pathology, Extension Specialist, and Assistant Professor of Agronomy, Aberdeen Branch Experiment Station, Aberdeen, Idaho 83210, respectively.

whether this relationship was the result of increased infection or a predisposing factor to the disease. Schroeder and Albrecht (15) did not consider that a liberal supply of calcium would increase potato scab. Also, Houghland and Cash (8) suggested that increased calcium in tuber periderm was the result of infection and not a predisposing factor.

Pentachloronitrobenzene (PCNB) treatment has resulted in scab reduction (3, 4, 7, 11, 13, 14); however, most of these reports describe effects of PCNB at excessive rates. Herve', Crosnier, Betancourt and Portier (5) found that a mixture of PCNB and 5-ethoxy-3-trichloromethyl-1, 2, 4-thiadiazole (Terrazole) gave better control than PCNB alone.

This report describes an investigation of effects of gypsum and sulfur for control of potato scab on a highly buffered calcareous soil. Comparisons were also made with treatments involving Terraclor (PCNB) and Terraclor Super-X (mixture of PCNB and Terrazole) for potato scab control.

The soil used in this research was so highly buffered that significant pH reduction was not feasible for any practical means. Therefore, it was believed that in addition to testing possible control measures for potato scab, perhaps some further understanding of the effectiveness of sulfur might evolve.

Materials and Methods

A greenhouse experiment was conducted to test effects of gypsum and sulfur on potato scab. Soil (silt loam) was randomly collected from several sites in a field where potato scab is a serious problem. Before using, soil from all sites was blended. The pH of this soil was 7.7. The experiment was arranged in a randomized block design with six replications. Sulfur concentrations were determined to approximate the concentration of sulfur (flake sulfur 99.5% pure) as provided by band application in the field with 300, 600 and 1200 lb/A (9.2, 24.6 and 36.8 g S/1000 g soil respectively). Gypsum as a sulfur source (United States Gypsum Co. - 88% $CaSO_4.2H_2o$) was applied on the basis of sulfur content. Sulfur and gypsum treatments were hand mixed with the soil before planting seed-pieces of Russet Burbank variety.

Plants were grown in the greenhouse in No. 10 cans for approximately 2 months from emergence date and then harvested. Core samples were randomly collected with given treatments for soil pH determination at respective intervals of 3 weeks and 3 months from the planting date.

Tuber radii lesions per tuber and lesion area were measured. Surface areas of tubers were estimated by the formula for a sphere ($A=4\ r^2$). Although tubers grown under greenhouse conditions were not true spheres, they approached this shape. Radius (r) was obtained by $\frac{\text{length + width}}{4} = r$. Data were then expressed as mm^2 of infected area per 100 cm^2 of tuber surface area.

A field experiment was conducted in 1969 to compare effects of gypsum and flake sulfur. This experiment was comprised of a 5- replicate split-plot randomized block. Main plot treatments were source of sulfur (gypsum vs. flake sulfur). Sub-plot treatments were rates of sulfur application with either gypsum or flake sulfur at 0, 200, 400, and 600 lb/A (O, 224.2, 448.4, and 672.5 kg/ha). The same source of gypsum and sulfur was provided as used in the greenhouse experiment. All plots received $(NH_4)_2SO_4$ (180 lb N/A-201.8 kg N/ha) and P_20_5 (199.0 lb/A-223.1 kg/ha). Di-syston was applied (3.0 lb/A-3.4 kg/ha) for insect control. Dimensions of plots used for all field investigations were 12 x 25 ft (3.7 x 7.6 m). They consisted of 4 rows with 3 ft (0.9 m) spacing.

To test effects on soil pH, sulfur and gypsum were added to soil from this field in greenhouse pots at rates extending from no sulfur to 36,800 ppm of sulfur. Russet Burbank potatoes were grown in this soil for several months and soil from several pots were examined for pH change.

All fertilizers, as well as the gypsum and sulfur treatments, were banded 2 inches (5.1 cm) to the side of the seedpiece at time of planting with an endless belt fertilizer distributor. Russet Burbank seed was planted on May 17. Throughout the growing season, water was applied by sprinkler irrigation. The plots were harvested in mid-September. Following the grading of potatoes, smooth tubers over 4 oz (113 g) were evaluated for scab. Percentages of tubers with 0-trace scab (trace=1-2 lesions totaling less than 1 cm^2) and with less than 5% surface coverage were determined. Tubers with 0-trace scab were essentially free of potato scab. Previous experience has shown this category to provide the most objective and precise criterion for evaluation of treatment effects. Tubers with less than 5% surface coverage provided a criterion of economical significance. For statistical analysis, percentage values were transformed to arcsin percentage.

To test for a possible inhibitory effect of extraneous components in commercial gypsum, the gypsum used in this experiment was compared with reagent grade $CaSO_4.2H_20$ in a laboratory test. Pathogenic *Streptomyces* was seeded on plates of soil extract agar and evenly distributed with a turntable sprayer. Saturated solutions of gypsum were prepared and autoclaved. Sterile bioassay disks (12.7 mm diameter) were then dipped into the respective solutions and placed on seeded plates. Plates (seven plates per treatment) were incubated at 70 F (21 C) for several days.

In 1970, a test was conducted in a field beside the 1969 test area to compare gypsum, sulfur and fungicide treatments for potato scab control. Soil from this field had been used for the previously described greenhouse test to evaluate effect of sulfur and gypsum on potato scab. The soil was a highly buffered silt loam with a pH ranging from 7.5-7.8. The residual sulfate (at 0-18 inches, 0-45.7 cm) was 47 ppm.

The experiment was designed to compare effects of gypsum and sulfur with Terraclor (PCNB) and Terraclor Super-X (mixture of PCNB and Terrazole). Additionally, sulfur and gypsum were applied with Terraclor Super-X to test for additive effects.

Plot dimension, spacing, insecticide and nitrogen application remained the same as 1969. Phosphate was applied at 120 lb P_20_5/A (135 kg/ha).

Treatments and rates consisted of the following as listed in table 5: untreated; Terraclor Super-X at 12.5, 17.5, 25.0, and 35.0 lb/A PCNB; Terraclor at 25.0 lb/A PCNB; sulfur at 600.0 lb/A; Terraclor Super-X at 25.0 lb/A PCNB with sulfur at 600.0 lb/A; Terraclor Super-X at 35.0 lb/A PCNB with sulfur at 600.0 lb/A; gypsum at 600.0 lb/A sulfur; Terraclor Super-X at 25.0 lb/A PCNB with gypsum at 600.0 lb/A; and Terraclor Super-X at 35.0 lb/A PCNB with gypsum at 600.0 lb/A sulfur.

Treatments of Terraclor Super-X involving rates of 12.5-17.5 lb/A PCNB were applied in 18-inch (46.0 cm) band applications; whereas, treatments involving rates of 25.0-35.0 lb/A PCNB were applied as broadcast applications. Prior to planting, furrows were prepared in the plots where either gypsum or sulfur was to be applied. Pre-weighed amounts of gypsum (Wilson Inc.) and sulfur were then applied by hand in each furrow. Terraclor and Terraclor Super-X were applied with a bicycle sprayer within ± 1.0 lb (0.45 kg) of the desired concentration. These materials were incorporated 5 inches deep (12.7 cm) with a tractor-powered rototiller with a simultaneous blanket application of Treflan (0.50 lb/A-0.56 kg/ha) for weed control.

The plots were planted on May 15 with Russet Burbank and harvested on September 30 by digging 20 ft (6.1 m) from each of two center rows. The same procedure used in 1969 was used to evaluate scab severity.

After grading potatoes for size and malformation, smooth tubers over 4 oz (113 g) were evaluated for scab. Each sample was separated into classes by weight as follows:

0 = no evidence of scab.
1 = trace scab (1-2 lesions totaling less than 1 cm^2).
2 = less than 5% surface area with scab, but greater than 2 lesions or 1 cm^2.
3 = greater than 5% and less than 50% of tuber surface covered with scab.
4 = general coverage of scab over entire tuber surface (greater than 50% of tuber with scab).

From this, an index was computed as follows:

$$\text{Index} = \frac{\Sigma\,(\text{class}^2 \times \text{tuber wt in classes})}{\text{total tuber wt}}$$

For chemical analyses, 12 tubers were randomly collected from each plot, washed, rinsed in .05 N HCl, then in distilled water. Periderm samples were collected by shallow peeling. Tuber flesh was collected by taking 1 mm slices as longitudinal sections through the potato.

Samples were oven dried and ground in a Wiley mill with a 600 mesh screen. Determination of Zn, Mn, Fe, Mg and Ca was accomplished via atomic absorption. Potassium was determined with an Eppendorf flame photometer. Phosphorous was determined colorimetrically from a 2% acetic acid extract.

Results

Greenhouse treatments with gypsum were particularly effective in reducing scab (Table 1). A significant reduction in potato scab was evident following treatment with gypsum at the two highest rates. The change in soil pH was negligible (0.1 decrease) and would not account for these differences. Although data from the medium and high rates of sulfur are not significantly different from comparable gypsum rates, scab was not significantly reduced with these treatments. Since sulfur treatments showed the greatest pH reduction, the gypsum results could not be accounted for by a lowering of pH. The effect with gypsum and lack of effect with sulfur may have been due in part to better mixing in soil with gypsum owing to greater volume of material and finer particle size.

There was no difference in scab control between gypsum and sulfur in the 1969 field tests (Tables 2 and 3). Interaction effects between form of sulfur (sulfate vs. elemental) and rate of sulfur were not significant. Potato scab was significantly reduced when sulfur was applied at 600 lb/A (672.5 kg/ha) but not at 200 or 400 lb/A (224.2-448.4 kg/ha), (Table 4).

Petri plate bioassay examination of the gypsum employed in these tests showed no inhibition of *S. scabies*.

Since the maximum pH reduction in soil from this field was slight (0.4), results did not suggest a direct influence on the pathogen by a lowering of pH.

Sulfur and gypsum treatments did not influence total yield, size or tuber smoothness.

Table 5 shows results of the 1970 field experiment. Both gypsum and sulfur reduced potato scab but again did not differ from one another. There was no difference between the forms of sulfur and PCNB at the 25 lb/A (28.0 kg/ha) rate. Addition of Terraclor Super-X to sulfur or gypsum showed no additive effect for scab reduction. PCNB was significantly more effective than a mixture of PCNB with Terrazole.

Table 6 shows yield data from the 1970 field study. Differences in total yield or yield of smooth tubers over 4 oz (113 g) were not significant. Both PCNB and sulfur treatments showed an increase of U.S. 1's due to scab control. When gypsum was applied alone, the results suggest a trend for increased yield of U.S. 1's but differences were not significant. Terraclor Super-X did not significantly increase U.S.

TABLE 1.—*Greenhouse comparison of sulfur and gypsum for potato scab reduction*

Treatment	Gram equivalents of[1] S added/1000 grams of soil	Total pH change	Mean Values mm² of lesion area per 100 cm² of calculated surface area	1%[2]
Untreated	0.0	0.00	149.6	xy
Gypsum	9.2	0.10	39.6	yz
Gypsum	24.6	0.10	21.7	z
Gypsum	36.8	0.10	7.6	z
Sulfur	9.2	0.40	179.0	x
Sulfur	24.6	0.35	93.8	x-z
Sulfur	36.8	0.35	119.5	x-z

[1] Sulfur equivalents were calculated to simulate amount of sulfur in band when applied at 300, 800, and 1200 lb/A (336.3, 896.7, 1345.1 kg/ha).

[2] Level of significance for Duncan's multiple range. Means with the same letter are not significant to level indicated.

TABLE 2.—*Comparison of main plot sources of sulfur*[1] *1969 field experiment*

	Mean Values			
			Arcsin % Transformations	
Sulfur Source	% Tubers with 0-trace scab[2]	% Tubers <5% surface scab	Tubers with 0-trace scab	Tubers with <5% surface scab
Gypsum	38.9	74.0	37.76[3]	62.40[3]
Sulfur	31.4	69.9	33.14	57.76

[1] Gypsum vs flake sulfur compared at equal sulfur concentrations (0, 200.0, 400.0, 600.0 lb/A-0, 224.2, 448.4, 672.5 kg/ha).

[2] Trace scab is maximum of two lesions with less than 1 cm surface area.

[3] Differences not significant.

TABLE 3.—*Comparison of sulfur rates by sulfur source*[1] *1969 field experiment*

	Mean values			
Sulfur	Flake sulfur		Gypsum	
Rates lbs/acre	% Tubers with 0-trace scab	% Tubers with <5% surface scab	% Tubers with 0-trace scab	% Tubers with <5% surface scab
0	29.5	74.2	32.1	69.3
200	22.4	60.5	35.7	67.6
400	27.4	59.3	34.4	71.2
600	46.2	85.5	53.4	88.0

[1] Interaction effects between source of sulfur and rate of sulfur were not significant.

TABLE 4.—*Comparison of sub-plot sulfur rates 1969 experiment*

Equivalent Sulfur Rates lbs/acre	Mean values % Tubers with 0-trace scab	% Tubers with <5% surface scab	Arcsin % Transformations Tubers with 0-trace scab	Tubers with <5% surface scab
			1% level[1]	1% level[1]
0	30.8	71.8	32.82 x	59.25 x
200	29.1	64.1	31.35 x	54.35 x
400	30.9	65.3	32.60 x	55.46 x
600	49.8	86.8	45.03 y	71.25 y

[1] Duncan's Multiple Range Test for 1% level

TABLE 5.—*Comparison of gypsum, sulfur and fungicide treatments for potato scab reduction 1970 field experiment*

Treatment	Mean values % 0-trace scab	% <5% scab	Index
	1%[8]	1%[8]	1%[8]
Untreated	2.2 x	27.4 x	7.84 w
Terraclor Super-X band[1 2]	4.8 xy	35.2 xy	7.26 wx
Terraclor Super-X broadcast[3]	8.9 x-z	48.6 x-z	6.47 w-y
Terraclor Super-X broadcast[4]	9.9 x-z	59.0 yz	5.80 x-z
Terraclor Super-X band[5]	6.8 xy	51.3 yz	6.35 w-z
Terraclor broadcast[3]	21.5 z	72.8 z	4.66 z
Sulfur[6 7]	15.0 yz	53.6 yz	5.90 x-z
Terraclor Super-X broadcast[3] & Sulfur[6]	4.4 xy	55.1 yz	6.12 x-z
Terraclor Super-X broadcast[4] & Sulfur[6]	12.4 yz	57.4 yz	5.77 x-z
Gypsum[6]	15.9 yz	61.2 yz	5.44 yz
Terraclor Super-X broadcast[3] & Gypsum[6]	16.8 yz	60.6 yz	5.46 yz
Terraclor Super-X broadcast[4] & Gypsum[6]	20.7 z	65.5 z	5.15 yz

[1] Band applications were applies in 18-inch (45.7 cm) bands
[2] 12.5 lb/A - 14.0 kg/ha rate of PCNB
[3] 25.0 lb/A - 28.0 kg/ha rate of PCNB
[4] 35.0 lb/A - 39.2 kg/ha rate of PCNB
[5] 17.5 lb/A - 19.6 kg/ha rate of PCNB
[6] 600.0 lb/A - 672.5 kg/ha of sulfur
[7] Sulfur and gypsum applied in planting furrow
[8] Level of significance for Duncan's Multiple Range Test

1's; however, gypsum together with Terraclor Super-X (35.0 lb/A-39.2 kg/ha PCNB) resulted in more U.S. 1's than either the untreated plots or treatment with Terraclor Super-X alone.

Analysis of periderm samples revealed no differences in concentrations of Zn, Mn, P and Mg between potatoes from sulfur, gypsum and untreated check plots (Table 7). The only consistent significant differences between gypsum and sulfur

TABLE 6.—*Comparison of gypsum, sulfur and fungicide treatments for potato yield*
1970 field experiment

Treatment*	Mean values		
	Total cwt/A	cwt/A smooth tubers>4 oz	cwt/A U.S. 1's
			5%[8]
Untreated	199.1[9]	150.4[9]	49.5 a
Terraclor Super-X band[1 2]	252.5	192.5	69.7 ab
Terraclor Super-X broadcast[3]	241.3	179.1	84.4 ab
Terraclor Super-X broadcast[4]	224.4	167.3	100.8 ab
Terraclor Super-X band[5]	231.7	181.6	95.5 ab
Terraclor broadcast[3]	233.2	168.3	124.8 bc
Sulfur[6 7]	283.7	214.0	114.7 bc
Terraclor Super-X broadcast[3] & Sulfur[6]	255.8	205.4	114.6 bc
Terraclor Super-X broadcast[4] & Sulfur[6]	240.0	183.0	104.4 a-c
Gypsum[6]	251.4	177.9	104.1 a-c
Terraclor Super-X broadcast[3] & Gypsum[6]	255.2	198.6	120.8 bc
Terraclor Super-X broadcast[4] & Gypsum[6]	295.0	240.7	161.7 c

* For explanation of treatments see Table 5.
[9] Differences not significant

TABLE 7.—*Tissue analyses from tuber peelings*

Treatment	Mean values							
	Zn ppm	Mn ppm	Fe ppm	P %	Mg %	K %	Ca %	Ca/K ratios
Untreated	29.5[1]	41.0[1]	972.5a[2]	0.360[1]	0.230[1]	3.990 a[2]	0.240 a[2]	0.0601 a[2]
Sulfur (600 lb/acre)	28.0	75.0	1140.0 b	0.390	0.219	4.380 b	0.195 b	0.0454 b
Gypsum (600 lb/acre)	27.3	60.5	1080.0 ab	0.380	0.208	4.108 a	0.203 b	0.0494 b

[1] Differences not significant
[2] Significant at 5% level via Duncan's Multiple Range Test

TABLE 8.—*Tissue analyses from tuber flesh*

Treatment	Mean values							
	Zn ppm	Mn ppm	Fe ppm	P %	Mg %	K %	Ca %	Ca/K ratios
Untreated	18.5[1]	11.5[1]	35.0[1]	0.224[1]	0.130[1]	1.92[1]	0.043[1]	0.0225[1]
Sulfur (600 lb/acre)	12.8	12.5	30.0	0.238	0.119	1.84	0.041	0.0223
Gypsum (600 lb/acre)	12.8	13.5	28.8	0.260	0.125	1.94	0.047	0.0245

[1] Differences not significant

plots were with Ca and Ca/K ratios. Both treatments showed significantly lower values than untreated plots.

No differences in chemical constituents were observed in flesh samples (Table 8).

Discussion

Under 1970 field test conditions, results did not approximate commercial control with any treatment. The presence of malformed potatoes and relatively low yields suggested improper irrigation. In view of work by Lapwood (9) and others, this may have contributed to the extreme scab severity that existed. Nevertheless, under conditions of extreme disease severity, both sulfur and gypsum at equivalent sulfur levels (600 lb/A-672.5 kg/ha) reduced potato scab significantly and to a degree equivalent to that achieved by Terraclor or Terraclor Super-X at 25.0 lb/A (28.0 kg/ha) PCNB.

Results from field investigations suggest that both forms of sulfur (sulfate and elemental) were equally effective. Neither form resulted in control when applied at the lower rates but both forms were effective at 600 lb/A (672.5 kg/ha). Field comparisons at equivalent sulfur levels showed no suggestion for an additive effect of one form compared with the other and results suggest the effect from gypsum to be a result of the sulfur content.

After addition of sulfur at 36,800 ppm and after several months of greenhouse growing conditions, soils obtained from field test areas showed only slight pH reductions of 0.1-0.4. Therefore, results suggest that more is involved for mode of action for sulfur than pH effect on the causal organism.

Vlitos and Hooker (16) observed that when sulfur was applied to the soil, the actinomycete population decreased but the bacterial counts increased before the change of pH was demonstrated. They were unable to demonstrate a direct toxic effect to *S. scabies* in plate culture. Therefore, their results strongly imply the possible influence by sulfur on biological control.

In this report, no evidence for a direct toxic or inhibitory effect for gypsum was observed. The possibility exists that control with gypsum was due to a change of host physiology, surrounding microflora, or both.

Chemical analyses from tubers grown in sulfur and gypsum plots showed slight but significant decreases of Ca and Ca/K ratios as observed with sulfur by Barnes and McAllister (1). There may be a relationship between Ca in tuber peelings to scab susceptibility as shown by Horsfall *et al.* (6). However, the possibility exists that the reduction of Ca and Ca/K ratios observed with sulfur and gypsum may have been coincidental with scab reduction. Elucidation of the meaning of the relationship between Ca and Ca/K ratios to potato scab requires further investigation.

Acknowledgments

This work was supported by the Idaho Potato Commission, and assistance by C. E. Dallimore, Mike Groskopp and Mary Leisy is gratefully acknowledged.

Literature Cited

1. Barnes, E. D., and J. S. V. McAllister. 1972. The effects of irrigation, manganese sulfate and sulfur treatments for common scab of the potato on the mineral composition of plant material and soil extracts. North Ireland Minist. Agric. Rec. Agric. Res. 20:53-58.
2. Duff, G. H., and Catherine G. Welch. 1927. Sulphur as a control agent for common scab of potato. Phytopathology. 17:297-314.
3. Erickson, H. T. 1960. Potato scab control on organic soils. I. Initial response to PCNB. Amer. Potato. J. 37:18-22.
4. Fink, Harry C. 1956. Vapam and PCNB soil treatments for potato scab control. Plant Dis. Reptr. 40:190-192.

5. Herve', J. J., J. C. Crosnier, A. Betancourt, and J. C. Portier. 1968. Preliminary tests for chemical control of common scab of potato (*S. scabies*). Phytiat. Phytopharm. 17(1):5-10.
6. Horsfall, James S., John B. Hollis, and H. G. M. Jacobson. 1954. Calcium and potato scab. Phytopathology. 44:19-24.
7. Houghland, G. V. C., and L. C. Cash. 1954. Effectiveness of certain soil fungicides in the control of potato scab. Plant Dis. Reptr. 38:777-780.
8. Houghland, G. V. C., and Lillian C. Cash. 1956. Some physiological aspects of the potato scab problem. II. Calcium and calcium-potassium ratio. Amer. Potato J. 33:235-241.
9. Lapwood, D. H., and T. F. Hering. 1970. Soil moisture and the infection of young potato tubers by *Streptomyces scabies* (common scab). Potato Res. 13:296-304.
10. Menzies, J. D. 1950. Potato scab control with calcium compounds. Phytopathology. 40:968 (Abstr).
11. Menzies, J. D. 1957. Dosage rates and application methods with PCNB for control of potato scab and rhizoctonia. Amer. Potato J. 34:219-226.
12. Muncie, J. H., H. C. Moore, J. Tyson, and E. J. Wheeler. 1944. The effect of sulphur and acid fertilizer on incidence of potato scab. Amer. Potato J. 21:293-304.
13. Nugent, T. J. 1956. Soil treatments with PCNB (Terraclor) for control of potato scab. Plant Dis. Reptr. 40(5):428.
14. Potter, H. S., W. J. Hooker, W. Cargo, and G. T. Stachwick. 1959. Pentachloronitrobenzene and urea-formaldehyde for potato scab control in Michigan. Plant Dis. Reptr. 43:633-637.
15. Schroeder, R. A., and W. A. Albrecht. 1952. Plant nutrition and the hydrogen-ion. II. Potato scab. Soil Sci. 53:481-488.
16. Vlitos, A. J., and W. J. Hooker. 1951. The influence of sulfur on populations of *Streptomyces scabies* and other Streptomycetes in peat soil. Amer. Potato J. 38:678-683.