# Influence of Soil Moisture and Fungicide Treatments on Common Scab and Mineral Content of Potatoes

J. R. Davis, G. M. McMaster, R. H. Callihan, F. H. Nissley, and J. J. Pavek

Associate Professor of Plant Pathology, Professor of Agricultural Engineering, Assistant Professor of Agronomy, and Scientific Aide, University of Idaho; and Research Geneticist, Agricultural Research Service, U.S. Dept. of Agriculture, Research and Extension Center, Aberdeen, Idaho 83210.

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ABSTRACT

Irrigation and fungicide treatments were tested for their effect on common scab (caused by *Streptomyces scabies*) on two potato clones (Russet Burbank and A6371-2).

Significantly less scab resulted with irrigation throughout the growing season at either −0.45 or −0.65 bars of soil moisture tension than with irrigation at −0.96 or −1.60 bars. Irrigation at −0.65 bars appeared suitable for maximum potato production. Lesions on tubers irrigated at −1.60 bars were significantly deeper than lesions on tubers irrigated at either −0.96 or −0.65 bars.

Treatments with pentachloronitrobenzene (PCNB) at 17, 22, or 28 kg/hectare (ha) and treatments with sulfur at 450, 670, or 900 kg/ha reduced scab. However, when soil moisture was allowed to drop to −1.60 bars, the percentage of scab-free potatoes in fungicide-treated plots was not significantly different from untreated plots.

Nutrient analyses of petioles collected in July showed that scab severity was positively correlated with calcium and negatively correlated with potassium, phosphate, and manganese. Tubers grown with moisture depletion to −1.60 bars showed more calcium in the peel than tubers grown with lower moisture tensions, but no significant effect was observed on potassium, phosphate, or manganese.

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*Additional key word:* nutrition.

Most of the work involving moisture and common scab [*Streptomyces scabies* (Thaxt.) Waksman and Henrici] of potato (*Solanum tuberosum* L.) has been directed toward maintaining the soil at high moisture levels during the initial stages of tuber formation (3, 11, 15, 16, 17, 18, 19). From this work, it is generally accepted that most infection occurs during the first month after tuber initiation. Results of work in Idaho (7) indicate that most scab infection occurred between 2-5 weeks after tuber initiation. Previous studies in Idaho involved holding the soil moisture level above 90% available soil moisture (−0.46 bars) for 3, 6, and 9 weeks respectively, starting at tuber initiation. For purposes of investigating the relation of high moisture to scab control, this was satisfactory. However, irrigation at 90% available soil moisture is not practical under most farming conditions. Lapwood and Adams (14) indicate that water potentials which will limit infection have not been precisely measured, but Lapwood et al. (16) indicated that common scab could be effectively controlled when water was applied to the field after 40-50% loss of available soil moisture on a field with a water-holding capacity of 38 mm in the top 30 cm. However, with different soil types and gross environmental differences between England and the desert region of southern Idaho, it seemed feasible that differences of moisture requirement might occur. To more closely bracket the moisture level required for control, the primary objective of this study was to grow the Russet Burbank cultivar and A6371-2 selection under our conditions with several moisture regimes.

It was previously observed (7) that a high degree of scab reduction could be achieved with 6 weeks of high moisture (−0.46 bars to field capacity) following tuber initiation. However, the degree of reduction was still not enough to meet standards required for U.S. No. 1 potatoes. Tubers with scab coverage greater than 5.0% are not acceptable for U.S. No. 1 grade, and if more than 5.0% of tubers in a lot are out of grade with scab, the entire lot of potatoes may be rejected for U.S. No. 1 grade (1). The desired level of control was achieved with applications of either pentachloronitrobenzene (PCNB) or sulfur, and additive effects were observed between irrigation and chemical treatments. Results suggested that with the proper moisture level, lower fungicide rates might be successfully used for scab control.

The most commonly suggested mechanism for scab control with increased moisture is by bacterial antagonism to *S. scabies* (11, 13, 14), and the preponderance of evidence suggests that this is an important factor. Results of other work suggest the possibility that moisture treatments may influence host susceptibility. High moisture levels have been associated with a decrease of calcium in tuber tissue (4), and several workers have implicated increased calcium with increased scab susceptibility (9, 10). Lapwood and Adams (14) indicated that the release of manganese may be greater in wet soils. McGregor and Wilson (20, 21) observed that manganese sulfate controlled scab when applied to a neutral soil with low water-soluble manganese content. They suggested that low scab incidence on acid soils might be partially attributed to the concentration of soluble manganese released.

The purpose of this investigation was to investigate effects of moisture levels on common scab severity,

**TABLE 1. Irrigation treatments and their effects on common scab and yield of Russet Burbank potatoes**

| Mean soil moisture[a] tension at irrigation (bars) | Total[b] irrigations per season (no.) | Total water per season (cm) | Scab-free[c] potatoes (%) | Mean scab[c] lesion depths (μm) | Yield[c,d] (quintals/ha) | |
|---|---|---|---|---|---|---|
| | | | | | U.S. No. 1 | Total |
| −0.45 | 26 | 35.8 | 37.7 A | 516.0 AB | 219.6 AB | 356.9A |
| −0.65 | 14 | 33.8 | 35.7 A | 406.7 A | 262.6 A | 396.2 A |
| −0.96 | 10 | 32.3 | 16.0 B | 449.5 A | 235.7 A | 361.6 A |
| −1.60 | 6 | 29.7 | 21.1 B | 633.3 B | 189.2 B | 331.7 A |

[a]Based on calcium carbide moisture determinations and calculations from consumptive use data.
[b]Initial irrigation on 15 June and last irrigation on 25 August.
[c]Unlike letters denote differences $P = 0.05$ with Duncan's multiple range test.
[d]Quintal = 100 kg.

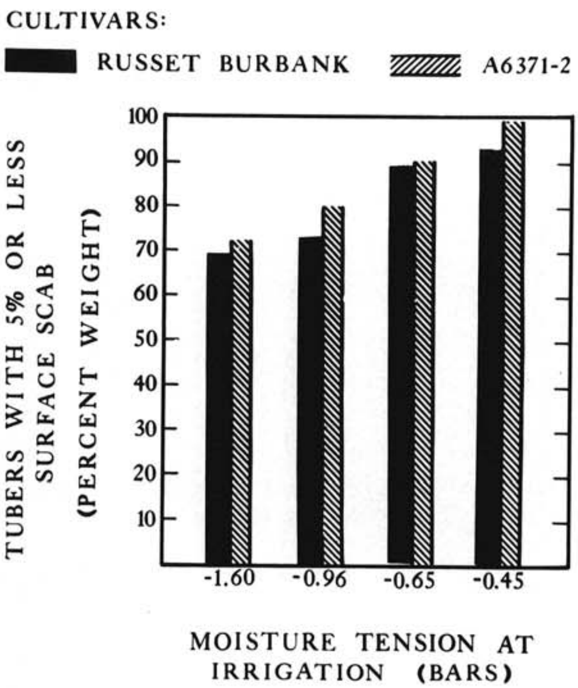


**Fig. 1.** Effect of irrigation treatments for scab control on two potato cultivars.

potato production, and the relationship of moisture levels to fungicide treatments. Since plant nutrients have previously been associated with soil moisture and common scab, treatment effects on mineral content of petioles and peelings were also determined. Two abstracts (6, 8) have been published describing a portion of this work.

MATERIALS AND METHODS.—The site selected for field investigation was located near Blackfoot, Idaho. The soil at the site is a Pancheri silt loam, and the soil characteristics of this area previously have been described (2). The pH ranges from 7.5 to 7.8. The noncalcareous surface has a high percentage of exchangeable calcium and overlies a highly to very highly calcareous (20-30% calcium carbonate equivalent) subsoil at a depth of about 30 cm. The field had been cropped several times with potato, and was unsuited for commercial potato production because of common scab. The water-holding capacity of this soil was 13.3 cm/m. Field capacity (water remaining at 0.33 bar of tension) was 19.6%. Permanent wilting point (water remaining at 15.0 bars of tension) was 9.8%.

This experiment was designed as a split-plot latin square with four replications. Main plots were of different soil-moisture treatments. Subplots consisted of the Russet Burbank cultivar, A6371-2 clone, and several chemical treatments applied to Russet Burbank. Chemical treatments consisted of PCNB applied at 28, 22, and 17 kg/ha and sulfur applied at 900, 670, and 450 kg/ha. Dimensions of subplots were 3.7 × 9.1 m.

Irrigation of each soil-moisture treatment was accomplished with a separate solid-set irrigation system. Sprinkler heads were spaced 12.2 × 12.2 m with 0.306 cm diameter nozzles and operated under a pressure of 3.51 $kg/cm^2$. To minimize any treatment overlap, main plots were separated by a 24-m buffer.

Moisture was monitored daily with a calcium carbide moisture tester and readings from a U.S. Weather Bureau class A land pan. Additionally, tensiometers (two per plot) were positioned at 23- and 53-cm depths in each main plot in replications 3 and 4. Evaporation pan determinations were correlated with historical consumptive-use based on 10 years of data, and used to predict water depletion each day. In order to accurately calculate the available soil moisture (ASM), due consideration was given to depth of root zone throughout this experiment. Tensiometer and calcium carbide readings were used to provide a constant base on predicted soil moisture for irrigation scheduling. Available soil moisture on a percentage basis was correlated with soil-moisture tension by the pressure plate extraction method (25).

All irrigation treatments were initiated on 15 June (1 week after potato emergence), and all plots were simultaneously brought to field capacity (FC). After emergence, daily inspections were made for evidence of tuberization (swelling of stolon tips to double the stolon diameter). The first evidence of tuberization was detected on 20 June.

Table 1 shows irrigation treatments applied, total irrigations per season, and the total depth of irrigation water applied when calculated for 75% efficiency of application. The total water applied to all of the irrigation treatments was similar. The differences among irrigation treatments were in total irrigations, length of irrigation period and moisture level at time of application.

Irrigation treatments were continued until 25 August, and vines were killed several weeks prior to the September harvest.

TABLE 2. Chemical effects on common scab and yield of Russet Burbank potatoes[a]

| Treatments and rate | Percent by weight of tuber sample[b] Scab-free | With >5% Scab coverage | Yield in quintals/ha[c] U.S. No. 1 | Total |
|---|---|---|---|---|
| Untreated | 27.6 A | 18.4 A | 190.2 A | 337.4 A |
| PCNB (28 kg/ha) | 62.0 E | 2.6 B | 242.8 B | 379.2 A |
| (22 kg/ha) | 58.0 DE | 3.4 B | 221.1 B | 355.0 A |
| (17 kg/ha) | 46.8 BCD | 3.4 B | 234.3 B | 361.4 A |
| Sulfur (900 kg/ha) | 51.7 CDE | 4.7 B | 238.1 B | 371.1 A |
| (670 kg/ha) | 44.7 BC | 7.5 B | 230.6 B | 365.2 A |
| (450 kg/ha) | 40.9 BC | 6.4 B | 230.1 B | 362.0 A |

[a]Mean values from all irrigation treatments.
[b]Unlike letters denote differences $P = 0.01$ with Duncan's multiple range test.
[c]Unlike letters denote differences $P = 0.05$ with Duncan's multiple range test.

TABLE 3. Effects of chemical treatments within irrigation treatments for Russet Burbank potatoes

| | | Percent by weight of tuber sample with given irrigation treatments[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | −0.45 bars | | −0.65 bars | | −0.96 bars | | −1.60 bars | |
| Treatments | rate | >5% scab | Scab-free | >5% scab | Scab-free | >5% scab | Scab-free | >5% scab | Scab-free |
| Untreated | | 6.6 | 37.7 A | 11.4 | 35.7 A | 26.1 | 16.0 A | 29.7 | 21.1 A |
| PCNB | (28 kg/ha) | 1.2 | 73.0 C | 1.1 | 77.4 C | 2.2 | 62.9 D | 6.2 | 34.7 A |
| | (22 kg/ha) | 0.0 | 77.9 C | 0.3 | 73.8 C | 4.1 | 47.4 CD | 9.4 | 32.9 A |
| | (17 kg/ha) | 0.8 | 68.5 C | 1.9 | 50.2 AB | 5.3 | 32.9 BC | 5.6 | 35.4 A |
| Sulfur | (900 kg/ha) | 1.9 | 61.7 C | 0.5 | 67.2 BC | 4.0 | 49.7 CD | 12.3 | 28.3 A |
| | (670 kg/ha) | 1.0 | 58.1 BC | 1.0 | 55.2 AB | 3.0 | 47.1 CD | 25.1 | 18.3 A |
| | (450 kg/ha) | 4.0 | 40.1 AB | 2.6 | 51.5 AB | 8.2 | 38.6 BC | 10.9 | 33.4 A |

[a]Unlike letters denote differences ($P = 0.05$) between chemical treatments by Duncan's multiple range test for scab-free potatoes. Interaction effects for tubers with greater than 5.0% scab were not significant.

For the first 7 weeks after tuberization, natural rainfall from several showers was negligible (3.3 cm), and several showers from 12 August to the season-end provided an additional 3.3 cm of precipitation.

PCNB treatments were broadcast with a bicycle sprayer within an accuracy of 5.0%, and incorporated to a depth of 13 cm by a tractor-powered rototiller. Immediately ahead of planting, sulfur treatments were applied by spreading flowers of sulfur (preweighed to respective concentration) to the center and sides of precut furrows 15-cm deep and 19-cm wide. Seedpieces were planted in these furrows with a potato planter.

Standard cultural practices involving fertilizer application, insecticide, and herbicides were applied as previously described (7).

On 29 June, plants from 1.5 m of row were dug from the ends of plot rows from all plots treated with PCNB and from untreated controls. These plants were evaluated for Rhizoctonia disease severity (caused by *Rhizoctonia solani* Kühn), percentage of tuber initiation and tuber weight. Rhizoctonia severity was determined by a previously described method (5).

For early evaluations of common scab, Russet Burbank tubers from 1.5 m of row were dug from ends of the two center rows from Russet Burbank plots on 23 August.

On 26 September, tubers from 11.6 m of row were dug from each plot. These tubers were graded and evaluated for scab as previously described (7). Indices of scab severity were determined by first grouping tubers into the following classes: 1 = 0-trace (trace = 1-2 lesions totaling less than 1 $cm^2$); 2 = >trace-5.0%; and 3 = >5.0% scab coverage. Indices of scab severity were then calculated with the following formula:

$$\text{Scab severity index} = \frac{\Sigma\ (\text{class}^2 \times \text{tuber weight in classes})}{\text{total tuber weight}}.$$

Tubers with 0 to a trace of scab were, for practical purposes, considered to be scab-free.

Petioles were collected from plots on 13 July by selecting the first mature petiole from 40 plants per plot. Samples of potato peelings were obtained after harvest. Twelve tubers were randomly collected from each plot after final harvest, washed, rinsed in 50 mM HCl, and then in distilled water. Samples for chemical analysis were collected by shallow peeling.

Samples were oven-dried and ground through a 250-$\mu$m (60-mesh) screen in a Wiley mill. Nutrient evaluations were made by Analytical Services, Department of Plant and Soil Sciences, University of Idaho, Moscow, using standard colorimetric, atomic absorption, and

Eppendorf flame photometer procedures.

For histological evaluation of scab lesions, nine Russet Burbank tubers were randomly collected from untreated subplots and subplots treated with PCNB (28 kg/ha) and sulfur (670 kg/ha) within each main-plot irrigation treatment. From tubers in each plot, 50 scab lesions were randomly selected within 2.5 cm from the tuber stem-ends. A slice about 1.0-mm wide and 5.0-mm deep was removed from the center of each scab lesion and placed in formalin-acetic acid (FAA) until stained. Scab lesions were stained and examined using the method of Nielsen (24).

RESULTS.—Moisture tension held between FC and −0.65 bars approaches the minimum moisture condition required for common scab control as shown in Table 1. Irrigation treatments involving either of the two lowest moisture tensions (−0.65 and −0.45 bars) showed significantly less scab than potatoes irrigated at either of the two highest (−0.96 and −1.60 bars). There were no differences in effectiveness between the two lowest moisture tensions (−0.65 and −0.45 bars). These results in Table 1 were corroborated by data from potatoes harvested at two different dates (August and September) and by two additional evaluation methods (indices and percent tubers with >5% scab). Regardless of harvest date (early or late) or method of evaluation, results indicate that the two lowest moisture tensions (−0.65 and −0.45 bars) reduced scab over the highest moisture tension (−1.60 bars). Main-plot effects of the Russet Burbank cultivar, involving combined values of subplot treatments, showed significantly less scab with irrigation at −0.96 bars when compared with irrigation at −1.60 bars, but this difference was not observed when chemically untreated plots were considered separately.

No significant benefit was observed following irrigation at −0.45 bars when compared with irrigation at −0.65 bars. Comparisons between clones (Fig. 1) indicated that the relation of soil moisture to scab severity is at least common to more than one clone.

Histological evaluations to determine irrigation-treatment effects on lesion depth (Table 1) further show the influence of soil moisture on common scab. Results show a significant lesion-depth reduction with irrigation at lower moisture tensions (−0.96 and −0.65 bars) compared with irrigation at a higher moisture tension (−1.60 bars). In contrast to irrigation treatments, chemical treatments involving either PCNB (28 kg/ha) or sulfur (670 kg/ha) showed no significant effect on lesion depth. Yield data indicated a significant negative correlation (−0.35) between lesion depth and yield.

PCNB and sulfur treatments significantly reduced scab and increased yield of U.S. No. 1 potatoes. Differences in disease and yield between high and low rates of either PCNB or sulfur were slight (Table 2).

Early in the season, treatment with PCNB at the lowest rate (17 kg/ha) significantly increased the percentage of stolons initiating tubers. Higher PCNB-application rates (22-28 kg/ha) resulted in a trend for more rapid tuber initiation, but differences were not significant. In contrast, irrigation treatments showed no significant influence on tuber initiation.

When PCNB-treated plots were compared with untreated plots for Rhizoctonia disease severity, all three rates significantly reduced Rhizoctonia symptoms on stems and stolons. There were no differences among PCNB rates, and Rhizoctonia disease severity was not significantly influenced by irrigation treatments.

When judged by percentages of scab-free potatoes, interactions between chemical and irrigation treatments were found (Table 3). There were no significant differences in scab-free potatoes among PCNB treatments, sulfur treatments, and untreated plots in the highest moisture-tension treatment, but irrigation at lower moisture tensions did show differences with these treatments.

Inorganic nutrient-levels in petioles collected during the growing season were highly correlated with common scab severity. A highly significant positive linear correlation was observed with calcium (+0.564), whereas negative correlations were observed with potassium (−0.481), phosphate (−0.560), and manganese (−0.471). In contrast, levels of nitrate and iron showed no correlation with common scab severity.

Irrigation at the highest moisture tension (−1.60 bars) resulted in significantly more calcium in tuber peelings than irrigation at lower moisture tensions (−0.96, −0.65, and −0.45 bars). In contrast, irrigation treatments showed no significant effect on manganese, phosphate, or potassium in tuber peelings. Irrigation at the highest moisture tension also showed a significant decrease of potassium in petioles when compared with lower moisture tensions, but differences of calcium, manganese, or phosphate were not significant.

Chemical treatments also influenced the nutrient content of potato tissue. Calcium from petioles was lower in treatments with either PCNB or sulfur, and there was significantly less calcium from sulfur treatments than with other treatments. In tuber peelings, PCNB resulted in significantly less calcium, but sulfur treatments did not. The high sulfur rate (900 kg/ha) significantly increased phosphate level in tuber peelings when compared with all other treatments, whereas the lower sulfur rate (670 kg/ha) did not influence phosphate in tissue from either peelings or petioles. Sulfur did not influence tissue manganese, but PCNB significantly reduced manganese in tuber peelings. Chemical treatments showed no effect on potassium levels.

DISCUSSION.—Results of this investigation (corroborated by the same reaction with two clones) suggest that a mean moisture depletion to −0.65 bars approximates the minimum soil moisture required for scab control. Since the highest yields occurred with irrigation at −0.65 bars, results also suggest that this irrigation treatment is suitable for maximum yield production.

Lapwood and Adams (14) indicate that moisture levels limiting infection have not been measured precisely, but work of Labruyère (11), Langton (12), and Lapwood et al. (16) suggests that the disease is likely to occur in soils at −0.4 bar or drier, and unlikely to occur in wetter soils.

When irrigated at −0.65 bars, our results showed no significant difference in scab reduction than when irrigated at a lower moisture tension (−0.45 bars).

Potatoes are rejected from the U.S. No. 1 grade if more than 5.0% of the tubers have more than 5.0% surface scab (1). Even when moisture was maintained at −0.65 to −0.33 bars (FC) throughout the growing season, commercially acceptable control was not achieved by irrigation treatment alone. Since moisture maintenance above −0.65 bars approaches the limit of practical management in many field situations and since elevation differences exist in many fields, making uniform moisture application difficult, chemical treatments are also needed.

Additive effects were observed between irrigation and chemical treatments. Treatment with sulfur provided the best example of this. Commercially acceptable control with 670-900 kg/ha sulfur was obtained on our highly buffered alkaline soil when the moisture level was maintained above −0.96 bars. When moisture was allowed to deplete to −1.60 bars, the level of control was not acceptable. Acceptable control was also achieved with the lower sulfur rate (450 kg/ha); however, a lower moisture tension was required with this treatment (−0.65 bars). These results are supported by previous work (7) involving effects of irrigation timing on soil treatments.

The cost of effective PCNB and sulfur treatments are currently similar. However, the relative ease of application of PCNB, combined with the fact that flowers of sulfur can be a serious fire hazard, suggest certain advantages for the use of PCNB. PCNB has the added advantage of controlling *R. solani.* In this study, it controlled common scab and *R. solani* with equal effectiveness at all three rates.

The cost of PCNB application might be considerably reduced by improved application techniques. This report describes the use of PCNB as a broadcast application. However, when PCNB was applied in 45-cm bands with 90-cm row spacing at 14 kg/ha, it has been shown to provide equal Rhizoctonia control and yield increase as when applied broadcast at 28 kg/ha (5).

Irrigation treatments showed significant effects on scab-lesion depth, with the deepest lesions occurring at the lowest moisture level. This, combined with the fact that lesion depth was negatively correlated with yield (the greater the yield, the shallower the lesions), suggests relationships among host susceptibility, plant vigor, and soil moisture.

Although scab control with increased moisture is commonly explained by bacterial antagonism (11, 13, 14), our results suggest the additional possibility of factors leading to increased resistance with increased moisture.

With nutritional changes, differences of host susceptibility also appear plausible. Nutrient analyses of petioles collected early in the season showed a highly significant positive linear correlation between calcium and scab severity and negative correlations with potassium, phosphate, and manganese.

It has been previously suggested that soil moisture may influence manganese availability (14, 21), and several workers (20, 21, 22, 23) have reported common scab reduction with manganese treatments. Changes in soil moisture that alter soil aeration may affect the release of manganese, which is greater in wet soils (14). McGregor and Wilson (21) suggested that decreased scab associated with acid soils and high moisture may be related to manganese absorption. Although our study showed significant linear correlations with manganese in potato tissue and scab severity, significant effects of irrigation treatment on manganese were not observed.

Calcium was highly correlated with scab and treatments showed significant effects on calcium level. Tubers grown with the lowest moisture level (moisture depletion to −1.60 bars) showed significantly more calcium in the peel than all other treatments. The correlation of calcium with common scab was consistently supported by correlations of calcium from either petioles collected at mid-season, or from potato peelings collected after final harvest, with data involving either degree of scab coverage or scab-lesion depth.

Chemical treatments also produced changes in calcium level, and results suggest that differences of calcium level were the result of treatments, and not the indirect result of infection. Both PCNB (17 kg/ha) and sulfur (670 kg/ha) treatments reduced calcium in potato petioles. PCNB reduced calcium in tuber peelings, but sulfur did not. Since there was no significant difference in scab severity with either treatment, results suggest that differences of calcium level were the causal effect of treatments, and not the result of different degrees of infection.

The possible significance of calcium was first introduced by Horsfall et al. (10) who showed that increased calcium in the soil resulted in increased tuber calcium, and that this was positively correlated with scab severity. Eichinger (9) further indicated that calcium ion deposits drastically altered periderm cells of the peel, making the areas with high calcium deposits highly susceptible to *Streptomyces* spp., and he hypothesized that phosphate may influence scab by neutralizing the calcium ion.

The concept of Eichinger may at least partially explain scab reduction with sulfur. Although our investigation did not show reduction of calcium in tuber peelings with sulfur, the highest rate (900 kg/ha) did increase phosphate. Thus, even though no direct effect on calcium in tuber peelings was observed with sulfur, the adverse effect of calcium may have been counteracted with increased phosphate. Indirectly, sulfur may have still influenced scab by the effect on calcium.

Among elements considered, the possible influence of calcium on scab severity appeared most plausible, and the effect of soil moisture on common scab control may, at least partially, be related to calcium.

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