The Relationship of Irrigation Timing and Soil Treatments to Control Potato Scab

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ABSTRACT

Control of common scab (*Streptomyces scabies*) on the potato cultivar 'Russet Burbank' was related to high soil-moisture periods started five days before tuber initiation. No scab reduction resulted with 3 wk of high moisture, but disease was significantly reduced when moisture was held for either 6 or 9 wk above 90% available soil moisture (0.46 bar). Differences of scab severity were not significant between the 6- and 9-wk high-moisture periods, indicating that greatest scab susceptibility occurred between 2 and 5 wk after tuber initiation. Additive effects occurred between irrigation and chemical treatments; e.g., sulfur (897 kg/ha) controlled scab with 3 wk of high moisture, but showed no significant effect when available soil moisture was allowed to deplete to 45% (1.8 bars) throughout the season. Sulfur and irrigation treatments interacted to influence calcium in tuber peelings. The 6-wk high-moisture period appeared to encompass the time of greatest susceptibility, and there was significantly lower calcium in tuber peelings from the 6-wk high-moisture treatment than from the low-moisture treatment.

Scab reduction was positively correlated with factors that reduced periderm russeting; e.g., high moisture and soil compaction. However, results indicate that scab reduction with high moisture involved more than influence to periderm russeting.

Scab was controlled with either pentachloronitrobenzene [PCNB (28 kg/ha)] or a mixture of PCNB (28 kg/ha) and 5-ethoxy-3-trichloromethyl-1,2,4-thiadiazole [Terrazole (7 kg/ha)]; however, the effectiveness of PCNB was reduced by Terrazole. The nitrogen stabilizer, N-Serve [2-chloro-6-(trichlormethyl)-pyridine], increased disease severity and reduced manganese in tuber peelings.

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Additional key words: soil compaction, soil moisture.

In some areas of southeastern Idaho, common scab [*Streptomyces scabies* (Thaxt.) Waksman and Henrici] of potato (*Solanum tuberosum* L.) is a serious problem. Fields with a scab problem commonly have highly buffered silt loam soils with a pH ranging from 7.5 to 8.2. Although these soils have a highly calcareous subsoil (below 30 cm), the surface is noncalcareous. Even with high applications of sulfur (36,800 ppm) to this soil, reduction of pH has been slight (0.1 - 0.4 pH units). Natural rainfall is commonly low during the growing season and many farmers utilize sprinkler irrigation.

TABLE 1. Effect of soil moisture on periderm russeting[a] and common scab of potatoes (Aug. harvest)

	Percent by weight of tuber sample[b]		
Wks of 90% ASM-FC[c]	With >75% net coverage[a]	Scab-free[d]	With >5% surface scab coverage
0	72.0 A	45.4 A	17.7 A
3	67.2 A	48.9 A	13.7 A
6	49.8 B	73.0 AB	2.5 B
9	49.6 B	85.3 B	1.6 B

[a]Tuber surface covered with russeted periderm (net coverage).
[b]Level of significance for Duncan's multiple range test. Treatment means with uncommon letters are significantly different, $P = 0.01$.
[c]Weeks of 90% available soil moisture (ASM) to field capacity (FC).
[d]Scab-free tubers had a maximum of two scab lesions with a total surface area less than 1 cm^2.

TABLE 2. Effect of soil compaction on periderm russeting[a] and common scab of potatoes (Aug. harvest)

	Percent by weight of tuber sample[b]		
Treatment	With >75% net coverage[a]	Scab-free	With >5% surface scab coverage
Not compacted	74.8 A	59.3 A	10.1 A
Compacted	44.5 B	67.0 B	7.6 A

[a]Tuber surface covered with russeted periderm (net coverage).
[b]Level of significance for Duncan's multiple range test. Treatment means with uncommon letters are significantly different, $P = 0.05$.

TABLE 3. Irrigation effects on common scab of potatoes (October harvest)

	Percent by weight of tuber sample[a]	
Wks of 90% ASM-FC[b]	Scab-free	With >5% surface scab coverage
0	20.8 A	22.6 A
3	26.4 A	17.0 AB
6	34.7 AB	5.3 BC
9	53.7 B	0.7 C

[a]Level of significance for Duncan's multiple range test. Treatment means with uncommon letters are significantly different, $P = 0.01$.
[b]Weeks of 90% available soil moisture (ASM) to field capacity (FC).

Normally the potential exists for precise management of soil moisture.

Numerous workers have reported scab reduction with increased moisture, pentachloronitrobenzene (PCNB), and with sulfur (16).

Prior to this study, previous work in Idaho (6) showed reduction of common scab following broadcast application of PCNB at 28 kg/ha or by sulfur application of 673 kg/ha. However, the degree of reduction was not sufficient to meet U.S. grade 1 standards (1).

Much of the work involving moisture and common scab has been directed towards maintaining the soil at high moisture levels during the initial stages of tuber formation (2, 16, 17, 18, 19, 20, 21). From this work, it is generally accepted that the first month from the time of tuber initiation is the most susceptible period for infection.

Use of the ammonium stabilizer, N-Serve [2-chloro-6-(trichlormethyl)-pyridine], has also been reported to reduce potato scab (14, 15, 28). For disease reduction, these reports indicate that high ammonium and low nitrate levels in the soil are important.

Some workers (23, 24, 26, 27) have reported reduction of common scab with treatments of manganese. McGregor and Wilson (24) suggested that decreased scab associated with acid soils and high moisture may be related to manganese absorption. However, Barnes and McAllister (3) were unable to show a relationship between scab control and manganese. Their work involving irrigation treatments showed no increase of manganese in plant tissue with increased irrigation. However, their data does show reduced calcium with increased irrigation.

Horsfall et al. (13) reported that increased soil calcium resulted in increased tuber calcium, and that this calcium increase was positively correlated with disease severity. In view of this work, a question was raised about the effect of irrigation on calcium accumulation in tuber periderm.

Under south Idaho growing conditions, it seemed highly feasible that practical scab control might be obtained with good soil-moisture management. The possibility was also considered that additive effects might occur between irrigation treatments and chemical treatments used for scab control.

Menzies (25) considered temp and aeration in addition to soil moisture to be the three most important natural factors for pathogen survival. The possibility for temp manipulation in the field is extremely limited. However, with soil compaction, decreased aeration would be anticipated (29), and quite frequently effects of aeration and soil moisture are related.

Therefore, this investigation was designed to investigate effects of irrigation timing and soil compaction on chemical treatments for control of common scab. To help answer previous questions concerning calcium and manganese, determinations of these elements were made in tuber tissue.

MATERIALS AND METHODS.—The site selected for field investigation was located near Blackfoot, Idaho. The soil at the site is a Pancheri silt loam (coarse-silty, mixed, frigid family of Xerollic calciorthids). This highly buffered soil contains 70-80% silts and 8-10% clays. It has an organic matter content of 1.5% and a pH ranging 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. These soil characteristics are relatively uniform throughout the study site. The field selected 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 1/3 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-split randomized block with five replications. Main plots were of different soil-moisture treatments. Subplots were compaction and no compaction treatments. Sub-subplot treatments consisted of the following chemical treatments: untreated, N-Serve at 1.7 kg/ha, sulfur at 896.7 kg/ha, mixture of 28.0 kg/ha PCNB and 7.0 kg/ha Terrazole (5-ethoxy-3-trichloromethyl-1,2,4-thiadiazole), and PCNB at 28.0 kg/ha. Dimensions of sub-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 on each plot to provide acceptable uniformity of water application (22). To minimize any treatment overlap, main plots were separated by a 24 m buffer.

Moisture was monitored daily. Tensiometers (2 per plot) were positioned at 23 and 53 cm depths in each irrigation main plot treatment in replications 3 and 4. Field inspections of other replications indicated uniformity within treatments. Tensiometer readings were calibrated with oven-dry determinations of moisture content. Throughout the course of this experiment, moisture levels were frequently checked within plot areas with either oven-dry or calcium carbide determinations.

All irrigation treatments were initiated on 15 June (1 wk after emergence of potato), when all plots were brought to field capacity (FC). After emergence, daily inspections were made for evidence of tuberization (when stolon tips swell to double their original diam). The first evidence of tuberization was detected on 20 June.

For the following irrigation treatments, plots were irrigated to the nearest day with given moisture levels:

Irrigation treatment 1.—Soil in the upper 23 cm was allowed to deplete to 45% available soil moisture (1.80 bars) and then irrigated to field capacity (45% ASM-FC).

Irrigation treatment 2.—Plots were maintained between 90% available soil moisture (0.46 bar) and field capacity (90% ASM-FC) for first 3 wk and then returned to same cycle as irrigation treatment 1.

Irrigation treatment 3.—Plots were maintained between 90% ASM-FC for first 6 wk and then returned to same cycle as irrigation treatment 1.

Irrigation treatment 4.—Plots were maintained between 90% ASM-FC for first 9 wk and then returned to same cycle as irrigation treatment 1.

Irrigation was continued until 20 August and vines were killed 3 wk prior to the October harvest.

From the date when tuberization was first observed,

TABLE 4. Chemical effects on common scab of potatoes (October harvest)

	Percent by weight of tuber sample[a]	
Treatments and rate	Scab-free	With >5% surface scab coverage
Untreated	27.3 B	16.8 B
N-Serve (1.7 kg/ha)	8.4 A	29.0 A
Sulfur (896.7 kg/ha)	39.2 C	6.0 C
PCNB (28.0 kg/ha) + Terrazole (7.0 kg/ha)	39.1 C	3.0 C
PCNB (28.0 kg/ha)	55.5 D	2.3 C

[a]Level of significance for Duncan's multiple range test. Treatment means with uncommon letters are significantly different, $P = 0.01$.

TABLE 5. Comparisons between effects of chemical treatments within irrigation treatments on potato scab (October harvest)

	Percent by weight of tubers having greater than 5% surface coverage with scab[a]			
Chemical treatments	0 wk[b]	3 wk	6 wk	9 wk
Untreated	27.0 B	28.6 B	10.3 AB	1.3 A
N-Serve	58.4 A	46.2 A	9.5 A	1.8 A
Sulfur	13.9 BC	5.3 C	4.4 ABC	0.3 A
PCNB + Terrazole	8.7 C	2.0 C	1.3 BC	0.0 A
PCNB	5.0 C	3.0 C	0.8 C	0.2 A

[a]Level of significance for Duncan's multiple range test. Treatment means with uncommon letters are significantly different, $P = 0.05$.

[b]Weeks of 90% available soil moisture (ASM) to field capacity (FC).

TABLE 6. Comparisons between effects of irrigation treatments within chemical treatments on potato scab (October harvest)

	Percent by weight of tubers having greater than 5% surface coverage with scab[a]				
Weeks of 90% ASM-FC[b]	Untreated	N-Serve	Sulfur	PCNB + Terrazole	PCNB
0	27.0 A	58.4 A	13.9 A	8.7 A	5.0 A
3	28.6 A	46.2 A	5.3 AB	2.0 A	3.0 A
6	10.3 B	9.5 B	4.4 AB	1.3 A	0.8 A
9	1.3 B	1.8 B	0.3 B	0.0 A	0.2 A

[a]Level of significance for Duncan's multiple range test. Treatment means with uncommon letters are significantly different, $P = 0.05$.

[b]Weeks of 90% available soil moisture (ASM) to field capacity (FC).

natural rainfall was negligible following several showers in the Blackfoot area (1.29 cm).

Subplot treatments receiving a soil compaction treatment were compacted by running a tractor-operated press wheel over the hills at a pressure of 0.7 kg/cm^2. Soil compaction obtained from this treatment showed no evidence of decreased water penetration. Throughout the season, comparisons of moisture in the compacted and noncompacted soil showed no evidence of moisture differences.

Treatments involving PCNB and a mixture of PCNB with Terrazole were applied as broadcast treatments with a bicycle sprayer within 4.0% of the desired concn. These materials, together with a simultaneous blanket application of Treflan [A,A,A-trifluoro-2,6-dinitro-*N*,*N*-dipropyl-p-toluidine (0.56 kg/ha)] and Eptam [S-ethyl-*N*,*N*-dipropylthiocarbamate (3.4 kg/ha)] for weed control, were incorporated to a depth of 13 cm by a tractor-powered roto-tiller.

Prior to planting, flowers of sulfur were applied by hand to the center of precut furrows. Immediately following, seedpieces were planted in those furrows with a potato planter.

Preweighed amounts of $(NH_4)_2SO_4$ and triple superphosphate were prepared for each plot to provide 202 kg/ha N and 168 kg/ha P_2O_5. For plots involving the N-Serve treatment, N-Serve was applied to preweighed amounts of $(NH_4)_2SO_4$ and thoroughly mixed with the fertilizer immediately prior to application. All fertilizers were applied at time of planting with an endless belt applicator attached to the planter. On 11 May, certified Russet Burbank seed was planted 25 cm apart in rows which were 92 cm apart with a commercial cup-type planter. Di-syston [O-O-diethyl S-(2-(ethylsulfinyl) ethyl) phosphorodithioate (3.4 kg/ha)] was applied for insect control.

TABLE 7. Chemical effects on manganese in tuber peelings

Treatment	Mean values (μg Mn/g in potato tuber peelings)[a]
Untreated	64.1 A
N-Serve	31.7 B
Sulfur	54.4 A
PCNB	55.8 A

[a]Level of significance for Duncan's multiple range test. Treatment means with uncommon letters are significantly different, $P = 0.01$.

TABLE 8. Interaction of chemical and irrigation treatments on Ca in tuber peelings

Weeks of 90% ASM-FC[b]	Mean values (μg Ca/g potato tuber peelings) for chemical treatments[a]			
	Untreated	N-Serve	Sulfur	PCNB
0	616.0 AB	628.0 A	676.0 A	528.0 B
3	666.0 A	560.0 A	580.0 AB	588.0 B
6	464.0 B	558.0 A	502.0 B	464.0 B
9	592.0 AB	535.0 A	668.0 A	800.0 A

[a]Level of significance for Duncan's multiple range test. Treatment means with uncommon letters are significantly different, $P = 0.05$.

[b]Weeks of 90% available soil moisture (ASM) to field capacity (FC).

For early plot evaluations, tubers from 1.5 m of row were dug from ends of the two center rows on 21 August from selected treatments. These potatoes were graded for periderm russeting (net) coverage and for potato scab.

On 11 October, tubers from 11.6 m of row were dug from each plot. These tubers were graded and evaluated for scab. Evaluation for scab was accomplished by rating each tuber into categories of 0 to a trace of scab (trace = 1-2 lesions totaling less than 1 cm^2) and with less than 5% surface coverage. For practical purposes, tubers with 0 to a trace of scab were free of potato scab. Since tubers with greater than 5.0% surface coverage are thrown out of grade, tubers with less than 5.0% surface coverage provided a criterion of economical significance.

For tubers harvested in August, the percentages of tubers with greater than 75% net coverage were visually determined. Prior to statistical analysis, percentage values were transformed to arcsin percentages.

Twelve tubers were randomly collected from each plot of the October harvest, washed, rinsed in 50 mM HCl, and then in distilled water. Peel samples were collected by shallow peeling for chemical analysis.

Samples were oven-dried and ground through a 250-μm (60-mesh) screen in a Wiley mill. Calcium and manganese levels were obtained via atomic absorption by Analytical Services, Department of Plant and Soil Sciences, University of Idaho, Moscow.

RESULTS.—Data from the early-season harvest (August) showed scab reduction when soil moisture was held above 90% available soil moisture (ASM) for either 6 or 9 weeks (Table 1). Soil compaction showed slight but significant scab reduction (Table 2). These treatments were also observed to reduce net coverage (Tables 1 and 2), thereby suggesting a correlation between periderm russeting and scab susceptibility.

The influence of soil compaction on periderm russeting was as great as that observed with high-moisture maintenance for 6 and 9 wk. However, at final harvest in October, the treatment involving soil compaction showed no significant influence on scab development, and interaction effects between soil compaction and other treatments were not significant. In contrast, irrigation treatments continued to show significant scab reduction in October (Table 3), and data were similar to that obtained in the earlier harvest. There was no difference between the 6 or 9-wk high-moisture treatments, and no difference existed between the lowest moisture level and the treatment involving 3 wk above 90% ASM.

Results suggest that most infection occurred between 16-37 days from the first evidence of tuber initiation.

Chemical treatments also showed effects on common scab (Table 4). Treatments with sulfur, PCNB, or a PCNB and Terrazole mixture effectively reduced the disease; whereas treatment with N-Serve significantly increased disease. When scab-free tubers were considered, results show that treatment with PCNB was significantly more effective than treatment with sulfur or a PCNB-Terrazole mixture.

Interaction effects were found between irrigation and chemical treatments (Tables 5 and 6). Table 5 shows comparisons between chemical treatments for the same irrigation treatment.

Under United States standards, potatoes are rejected from the U.S. No. 1 grade if more than 5.0% of the tubers have greater than 5.0% surface scab (1). Under these standards it can be seen that all untreated plots irrigated by any of the three lowest moisture treatments did not provide commercially acceptable scab control. Common scab was adequately reduced in chemically untreated plots maintained at high-moisture level for 9 wk. However, as previously indicated, problems occurred with net development.

The data show that interrelationships can occur between moisture management and effective chemical control. With the lowest moisture treatment, treatment with sulfur did not provide acceptable control and treatment with sulfur was not significantly different from the untreated check. However, with 3 wk of high moisture, treatment with sulfur yielded potatoes that were mostly (95%) acceptable under U.S. grade 1 standards for common scab, and showed significantly lower scab than the untreated check treatment. This irrigation schedule caused no apparent adverse effect. With the treatments involving 6 and 9 wk of high moisture, there existed no significant difference between the sulfur treatment and the untreated plots. Plots which received only the 6-wk high-moisture treatment did not provide commercially acceptable scab reduction, but when the sulfur treatment was added, the disease was adequately reduced to meet U.S. No. 1 standards.

With the two shortest periods of high soil moisture, the mixture of PCNB and Terrazole significantly reduced the disease. However, with 3 wk of high moisture, the PCNB-Terrazole mixture provided acceptable scab reduction; whereas with the lowest moisture treatment, the disease reduction was not sufficient to meet standards required for U.S. No. 1 potatoes.

PCNB provided scab reduction, meeting U.S. No. 1 standards, with all irrigation treatments. For all chemical treatments there was either significant reduction of potato scab with increased periods of high moisture or a trend towards reduction (Table 6).

N-Serve, which increased scab severity, was also influenced by irrigation treatments. With the two lowest moisture treatments N-Serve significantly increased scab severity; whereas with treatments involving 6 and 9 wk of high moisture, N-Serve showed no effect.

Treatment with N-Serve reduced manganese in tuber peelings (Table 7). No other chemical treatment showed this effect. Irrigation treatments showed no significant effect on manganese in tuber peelings.

The residual nitrate level in this soil was too low to support a normal potato crop. The average residual NO_3 in the upper 61 cm of soil was 56 kg/ha, with 18 kg/ha occurring in the upper 15 cm, 17 kg/ha occurring from the 15 cm depth to 31 cm, and with the remainder below this depth. Yield data showed no significant change in yield with application of N-Serve. Thus, there was no suggestion of differences in available nitrogen due to leaching losses of nitrates nor evidence of phytotoxicity with N-Serve.

At final harvest, the effect of soil compaction showed a significant yield reduction of 5.7% and treatment with sulfur reduced total yield by 13%. Other treatments in this investigation did not show a significant effect on either total yield or tuber size.

Results show that irrigation treatments can influence the calcium level in tuber peelings. With this investigation, irrigation or chemical treatments alone showed no significant effect on calcium; however, interactions resulted in significant differences for calcium level (Table 8). The treatment involving sulfur showed a significant reduction of calcium for the 6-wk high-moisture treatment, but this was not observed for the treatment involving 9 wk of high moisture. The 6-wk high-moisture treatment showed a trend towards calcium reduction in tuber peelings from all chemical treatments investigated; whereas the 9-wk high-moisture treatment indicated either no change in calcium level, or a significant increase in calcium, as shown with the PCNB treatment.

DISCUSSION.—By holding soil at high moisture for several time periods from emergence, it was possible to determine that most infection occurred between 2 and 5 wk after tuber initiation. These results are similar in principle to those of other workers (17, 18, 21) who report scab control when suitable moisture is maintained for at least 4 wk after tuber initiation.

Results from the present study in southeastern Idaho show that when irrigation was started 5 days before tuber initiation and moisture was maintained above 90% ASM for a period of 6 wk, significant scab reduction occurred, but the degree of reduction did not meet official grade standards required for commercial control. To achieve the required level of control, additional help in the form of either sulfur or PCNB was necessary.

Data of Labruyére (16) suggests a combined effect with PCNB and soil moisture for scab control. However, he found that PCNB reduced yield. In contrast, there was no evidence of yield reduction from PCNB in this or previous studies (5, 6, 7, 8, 9).

The effectiveness of PCNB was reduced when it was used with Terrazole. The exact reason for this is not understood; however, the possibility exists that Terrazole may have adversely affected competitors of *S. scabies*.

Although other workers have reported scab reduction with N-Serve (14, 15, 28), a significant scab increase was observed in this study. Huber and Watson (14) theorized that residual nitrate nullifies disease-suppressing effects of the ammoniacal form of nitrogen, and must be tied-up or reduced before scab can be reduced by ammoniacal nitrogen. The residual soil nitrate level found in this study (56 kg/ha) would have to be considered low.

Reduced manganese levels in tuber peelings occurring with N-Serve may provide an explanation for scab increase. McGregor and Wilson (24) associated increased manganese with decreased scab and have suggested that factors associated with scab reduction may be related to manganese absorption. The exact explanation for reduced manganese levels with N-Serve is not known, but it is apparent that the effect of N-Serve involves more than nitrogen stabilization. Under conditions of this study, N-Serve was not effective for control of common scab.

Irrigation and chemical treatments interacted to influence calcium in tuber peelings. Results of the 6-wk high-moisture treatment were similar to results of Barnes and McAllister (3) who observed reduced calcium in potato tissue following increased irrigation. The possible significance of calcium was first introduced by Horsfall et al. (13) who showed that increased soil calcium resulted in increased tuber calcium and that calcium increase in tuber tissue was positively correlated with scab severity. In this investigation, scab severity and calcium level were reduced with 6 wk of high soil moisture and the 6-wk high-moisture period apparently encompassed the time of maximum infection. Calcium was not reduced with 9 wk of high moisture. However, since this irrigation treatment involved at least an additional 3 wk beyond the period of maximum infection, it is conceivable that a change of calcium beyond the 6-wk period may have shown no effect.

There was no evidence for interaction between irrigation treatments and soil compaction. However, scab was reduced with soil compaction. A similar relationship has been reported for the "take-all" disease (*Ophiobolus graminis*). Griffiths reported (12) that the take-all disease was more severe in a seed bed with loose soil and less severe when soil was more compact. Garrett (11) later showed that the effect of the more-compact soil was likely to be associated with the inhibitory action of accumulated CO_2.

Soil compaction was also observed to decrease periderm russeting and similarly, irrigation treatments that reduced scab also reduced coverage of periderm russeting. Several workers (4, 10) have suggested a relationship between periderm russeting and common scab. Cooper et al. (4) reported that scab was more severe on tubers with thicker periderm, and suggested that periderm thickness was correlated with scab resistance. Emilsson and Heiken (10) compared potato varieties for scab susceptibility and observed a positive correlation between periderm thickness and scab severity for certain varieties, but not all cultivars. They concluded that periderm thickness may be a factor, but not the only factor, related to scab resistance. With this study the extent of periderm russeting was altered by treatments on a single cultivar, thus eliminating the multigenic variables that can occur with varietal comparisons. Results support the view of Cooper et al. (4) that russet periderm can be related to scab susceptibility.

The possibility exists that the effect of irrigation treatments on periderm russeting may have accounted for part of the results observed with irrigation. However, irrigation treatments continued to show highly significant effects on potato scab throughout the season; whereas the compaction treatment showed a significant effect on scab earlier in the season, but not at final harvest. Since the effect of soil compaction on periderm russeting was as great as that observed by any irrigation treatment, the results indicate that more was involved with soil moisture effects on potato scab than the effect on periderm russeting. Although 6 or 9 wk above 90% ASM produced adverse effects on russeting (a desirable character in cultivar Russet Burbank), it has also been shown that irrigation at 75% ASM is as effective for scab control as 90% ASM (8), without adverse effects on russeting characteristics. Use of this lower moisture level (75% ASM-FC) would appear to be more practical.

Possibly the most significant point of this investigation is the realization that interaction effects can occur between chemical and irrigation treatments. Treatment with sulfur provided the best example for this interaction. When available soil moisture was allowed to deplete to 45% throughout the growing season, treatment with sulfur was not effective for disease control. When soil moisture was maintained above 90% for 3 wk from the emergence date, there was no disease reduction when compared with 45% ASM throughout the season. However, when sulfur was combined with the 3 wk above 90% ASM, it provided good control.

Results show that where moisture management alone is not sufficient for disease control, good moisture management may still provide a powerful tool for effective use of chemical treatments. Sewell (30) indicated that in the future, techniques for altering the physical soil environment may become more important for increasing the effectiveness of chemical sterilants and controlling or guiding subsequent biological events. Soil moisture is one of the paramount physical factors governing the soil environment. Further studies in this area should be encouraged.

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