Reduction of Powdery Mildew and Other Diseases by Over-the-Trellis Applications of Lime Sulfur to Dormant Grapevines

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ABSTRACT

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From 72 to 96% of the ascospores within cleistothecia of *Uncinula necator* were killed in the spring when exposed to lime sulfur (calcium polysulfide), copper sulfate, copper hydroxide, or copper oxychloride for 5 min in laboratory assays. Dinocap reduced viability in the same assay when the exposure time was more than 1 hr. Neither sulfur nor triadimefon significantly reduced viability. Cleistothecia collected in fall were not affected by the above fungicidal compounds in a 5-min exposure. One hour of exposure to lime sulfur or 8 hr of exposure to copper sulfate was required before ascospore viability was significantly reduced in the fall. Aqueous solutions of lime sulfur at a concentration of 120 ml/L, applied as over-the-trellis sprays at 2,800 L/ha (336 L/ha of lime sulfur) to dormant grapevines in spring, killed cleistothecia of *Uncinula necator* on the bark of the vines and delayed the development of epidemics of powdery mildew. A lower rate of application was not effective against powdery mildew. The delay of the epidemic ranged from a few days to several weeks, depending upon the rate of toxicant used, the resistance of the host to powdery mildew, and the favorability of environmental conditions for disease development. In vineyard trials, the severity of fruit infection was reduced from 43.1 to 14.1% in 1986, from 4.6 to 0.1% in 1988, and from 41.4 to 27.2% in 1989 by a single eradicant treatment of lime sulfur to the *Vitis* interspecific hybrid cultivar Rosette, which is highly susceptible to powdery mildew. The same rate of lime sulfur reduced the severity of powdery mildew from 30.8 to 0.3% in 1988 on the more resistant cultivar *Vitis labruscana* 'Concord'. The incidence of angular leaf scorch (*Pseudopezicula tetraspora*) and Phomopsis cane and leaf spot (*Phomopsis viticola*) was also decreased by over-the-trellis applications of an aqueous solution of lime sulfur at a concentration of 40 ml/L and 120 ml/L. The incidence and severity of black rot of grapes (*Guignardia bidwellii*) was reduced by 120 ml/L of lime sulfur in 1991, but not in 1992.

Additional keywords: Oïdium, eradication, sanitation

Sanitation is an often mentioned (8) but less often used means of control for the most common fungal diseases of grapevine. Disease control tactics such as seasonal fungicide applications or the use of cultivar resistance often predominate in viticulture for reasons of efficacy. Sanitation measures designed to reduce the supply of overwintering inoculum of the major fungal pathogens of grapevines are frequently recommended to augment chemical control, but alone they have rarely resulted in a degree of disease control comparable to that provided by fungicides. The labor-intensive or disruptive nature of some forms of sanitation, such as collection of mummified fruit (8), tillage to bury inoculum (8), or selective pruning of diseased tissue (1,8), often makes such actions difficult to justify when excellent disease control can be obtained relatively inexpensively through the use of fungicides alone. Treatment of dormant vines with fungicidal compounds to eradicate overwintering pathogens was reported in several earlier studies (2,10,11). However, the failure of these treatments to provide the degree of disease suppression obtainable through the use of modern fungicides is the major reason why such treatments are not currently recommended or employed.

There has recently emerged a clear need for alternatives to seasonal fungicide applications for control of grapevine diseases. This need has arisen out of the combined impact of the loss of fungicide registrations, development of fungicide resistance (6), the refusal of processors to buy crops treated with certain fungicides, and the phytotoxicity of some of the remaining fungicides to a number of important grape cultivars grown in the northeastern United States (7). Our objective was to investigate the feasibility of using broad-spectrum biocidal compounds in over-the-trellis applications to dormant grapevines to eradicate the primary inoculum of fungal pathogens. A preliminary account of portions of this work has been published (4).

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MATERIALS AND METHODS

Laboratory screening of compounds for eradicant activity. A number of fungicides registered for use on grapevine in the United States were evaluated for eradicant activity towards cleistothecia of *Uncinula necator* (Schwein.) Burrill (Table 1). Funnel-shaped traps made of filter paper (3) were attached to the trunks of unsprayed grapevines in August 1988 to collect mature cleistothecia of *U. necator* as they dispersed during rain. On 22 September, several traps were collected and cut into 1-cm squares. Squares not bearing abundant cleistothecia were discarded, and the remaining squares were randomly assigned to treatments. The experimental unit consisted of the cleistothecia on a single square of filter paper. Treatments were replicated three times. Candidate fungicides were agitated in distilled water for 5 min prior to treatment. Cleistothecia were exposed to fungicides by flooding a petri dish containing a filter paper square bearing cleistothecia with 2 ml of a fungicide suspension or solution. Negative control dishes were flooded with distilled water. Positive control dishes were flooded with 0.5% formaldehyde. At 5 min, and 1, 4, and 8 hr after flooding, a filter paper square was removed from a petri dish, blotted, and allowed to dry. Single squares were then transferred to petri dishes and incubated dry at 19 C, without light, for 14 days. A subsample of 10 cleistothecia was removed from each square and crushed on a glass microscope slide in an aqueous solution containing 5 μg/ml of fluorescein diacetate, a fluorescent vital stain (13). After 5 min, the slide was observed under fluorescence microscopy. Ascospores which did not show a bright green fluorescence were assumed to be dead (13). The percentage of dead ascospores contained in 10 cleistothecia was recorded. The experiment was repeated on 14 October. To determine if overwintering affected the sensitivity of cleistothecia to the compounds tested, the experiment was also performed twice in April 1989.

Vineyard tests for efficacy. Replicated plots with an area of 0.2–2 ha were established in large commercial vineyards of *Vitis vinifera* L. 'Chardonnay', the *Vitis* interspecific hybrid cultivars Rosette and Seyval, and *V. labruscana* L.H.

Bailey 'Concord'. Chardonnay, Rosette, and Seyval are highly susceptible to powdery mildew (7) and moderately susceptible to angular leaf scorch (9). Concord is moderately resistant to powdery mildew and highly susceptible to Phomopsis cane and leaf spot and fruit rot (8). The plots were treated with an aqueous solution containing 120 ml of lime sulfur (calcium polysulfide, formulated as 29% lime sulfur solution) per liter of water, in a total volume of 2,800 L/ha in 1986 (Rosette only), 1988 (all four cultivars), 1989 (Concord and Rosette), and 1991 (Seyval only). The concentration of lime sulfur was reduced to 40 ml/L of water in 1987, and the spray was applied in 2,800 L/ha to Rosette, Concord, and Seyval. A hydraulic, hooded-boom sprayer operated at a pressure of 2,069 kPa was used to apply the lime sulfur as an over-the-trellis drench at bud swell. Untreated sections of comparable size in the same vineyard were used as controls. Within each of three replicated plots, a six-row-wide subplot containing 72–96 vines was also established, in which no fungicides were applied subsequently. Growers made from five to 10 regularly scheduled fungicide applications to the remainder of the vineyard.

Once the lime sulfur spray had dried, canes were collected within the experimental vineyards from Rosette vines in 1987 and Concord vines in 1989 and brought into the laboratory. Only canes which bore numerous pycnidia of *Phomopsis viticola* (Sacc.) Sacc. were selected. Canes collected from untreated vines served as controls. Approximately three canes from 10 vines were collected from each plot representing a replication of a treatment, for a total of 90 canes. A single section approximately 2 cm long surrounding a node was cut from each cane, split longitudinally, and incubated at 20–25 C at 100% RH for 7 days to encourage production of cirrhi. The numbers of cirrhi per node and per square centimeter of cane were then recorded.

Incidence and severity of powdery mildew and Phomopsis cane and leaf spot and fruit rot, and incidence only of angular leaf scorch, were assessed on 10 vines per replicate beginning at 15 cm of shoot growth. Assessments were repeated at 14–21 day intervals until harvest. From five to 10 shoots and 10 fruit clusters on each vine were examined. Severity of powdery mildew and black rot on fruit was estimated from keys depicting grape clusters with percentages of diseased tissue ranging from 0 to 100%. Similar keys were used to estimate the percentage of leaf area affected by powdery mildew and to estimate the number of Phomopsis lesions per leaf or internode. The stage of growth of the vines was noted at each assessment; and once fruit had formed, a single cluster from each of 20 randomly selected vines was collected. Five berries from each cluster were pooled as a single sample and crushed, and the soluble solids level of the juice was measured with a refractometer.

To assess the direct impact of vineyard applications of lime sulfur on survival of cleistothecia, bark samples were collected from treated and untreated Rosette grapevines on 21 April 1986, approximately 2 wk before bud break. The cleistothecia borne on four 30-g samples of bark were removed as described by Gadoury and Pearson (3) and transferred to moist filter paper in petri dishes. The cleistothecia were kept moist at 20 C for 24 hr, assessed for dehiscence at 50× magnification, and then allowed to dry. The cleistothecia were rewet for 24 hr at 20 C on 4, 11, and 20 May. Four samples of 10 cleistothecia were also placed on wet filter paper in petri dishes over glass slides at 20 C for 24 hr. After 24 hr, the slides were removed and examined at 200×. The percentage of germinated ascospores on each slide was recorded. An ascospore was considered germinated if the germ tube was greater than one-half the length of the ascospore.

Efficacy of over-the-trellis applications of lime sulfur to control black rot of grape were conducted in a 4-ha vineyard of the *Vitis* interspecific hybrid cultivar Delaware in 1991 and 1992. Severe losses due to infection of the fruit by *Guignardia bidwellii* (Ellis) Viala & Ravaz occurred in this vineyard in 1990, and clusters bearing overwintered mummified berries were abundant in the canopy in spring 1991. Vines in one-half of the vineyard were treated prior to shoot emergence with a solution containing 120 ml of lime sulfur per liter of water, with a total volume of 2,800 L/ha, on 26 April 1991 and 7 May 1992. Three 0.2-ha subplots within each half of the vineyard received no seasonal fungicide applications. Incidence and severity of black rot were assessed on 10 vines within each replicated subplot at harvest. Ten to 20 fruit clusters were examined on each vine. Severity of disease was estimated from pictorial keys, as described above. Treatment means in laboratory and vineyard experiments were compared by Student's *t* tests between lime sulfur–treated and untreated controls.

RESULTS AND DISCUSSION

Screening compounds for eradicant activity. Ascospores within cleistothecia

Table 1. Effects of various fungicides applied in either the fall or spring on viability of ascospores contained in cleistothecia of *Uncinula necator*

Compound[y] and rate (a.i./L)	Fluorescent ascospores per cleistothecium[z]: Fall 5 min	Fall 1 hr	Fall 4 hr	Fall 8 hr	Spring 5 min	Spring 1 hr	Spring 4 hr	Spring 8 hr
Calcium polysulfide 120 ml	17.7 ± 2.7	1.6 ± 1.8	0.0 ± 0	0.0 ± 0	3.8 ± 3.6	1.0 ± 0.5	0.2 ± 0.4	0.0 ± 0
Copper sulfate 4.8 g	18.6 ± 2.7	18.6 ± 3.6	22.0 ± 3.2	11.2 ± 2.7	6.8 ± 6.3	2.0 ± 3.6	1.6 ± 1.8	3.6 ± 1.4
Copper sulfate 9.6 g	20.0 ± 6.3	23.0 ± 4.5	16.2 ± 5.4	10.2 ± 2.3	5.8 ± 2.3	0.8 ± 0.6	0.6 ± 0.8	0.4 ± 0.4
Copper hydroxide 2.4 g	25.2 ± 3.6	25.6 ± 5.0	23.2 ± 4.9	26.4 ± 4.1	6.4 ± 3.0	3.2 ± 1.6	0.4 ± 0.3	0.4 ± 0.3
Copper oxychloride sulfate 2.4 g	26.6 ± 1.4	25.2 ± 2.3	27.2 ± 5.0	24.2 ± 4.1	8.2 ± 2.3	4.6 ± 2.1	0.2 ± 0.2	0.4 ± 0.2
Dinocap 0.234 ml	16.3 ± 3.5	25.6 ± 7.2	21.0 ± 5.9	20.2 ± 4.1	21.6 ± 4.1	12.4 ± 3.7	11.8 ± 4.1	4.4 ± 3.2
Sulfur 1.48 g	18.1 ± 5.4	23.0 ± 6.3	21.0 ± 3.2	24.8 ± 3.3	20.2 ± 3.0	23.6 ± 4.7	18.0 ± 4.6	22.2 ± 7.1
Triadimefon 0.05 g	23.4 ± 3.6	25.0 ± 4.1	24.6 ± 3.1	26.4 ± 4.5	26.0 ± 5.9	21.8 ± 8.5	19.0 ± 5.3	23.4 ± 4.2
Formaldehyde 5.0 ml	1.0 ± 1.4	0.0 ± 0	0.0 ± 0	0.0 ± 0	0.0 ± 0	0.0 ± 0	0.0 ± 0	0.0 ± 0
Distilled water	20.3 ± 1.5	19.6 ± 8.1	23.6 ± 1.8	21.2 ± 6.8	29.8 ± 2.7	25.6 ± 3.6	28.0 ± 5.9	28.8 ± 3.2

[y] Cleistothecia collected in fall and spring were exposed to candidate compounds for the indicated times, then incubated dry at 19 C for 14 days. Viability was assessed with fluorescein diacetate and epifluorescence microscopy.

[z] Treatment mean and 95% confidence interval for three replications consisting of 10 cleistothecia and two repetitions of the experiment.

collected in the fall were not affected in a 5-min exposure except by formaldehyde, and an exposure time of 1 hr to lime sulfur or 8 hr to copper sulfate was required before ascospore viability was significantly reduced (Table 1). In contrast, from 72 to 100% of the ascospores within cleistothecia of *U. necator* collected in the spring were killed when exposed in laboratory assays for 5 min to lime sulfur, copper sulfate, copper hydroxide, copper oxychloride, or formaldehyde (Table 1). Dinocap reduced ascospore viability in the same assay when the exposure time was more than 1 hr (Table 1). Neither sulfur nor triadimefon significantly reduced viability. Gadoury and Pearson (5) reported that the strength of the ascocarp wall decreases during overwintering, that the ascocarp wall becomes thinner, and that the water potential of cytoplasm within the ascocarp decreases. One or all of these developments may make cleistothecia more susceptible to penetration by broad-spectrum biocides such as lime sulfur in spring.

Lime sulfur applied to dormant Concord grapevines reduced the production of cirrhi by *P. viticola* from overwintered pycnidia in infected canes by approximately 85% in 1989 (Table 2) and reduced the number of sporulating pycnidia per infected node on Rosette grapevines from 3.5 to 0.5 in 1987 (Table 3).

Vineyard tests for efficacy. A solution containing 120 ml of lime sulfur per liter of water, with a total volume of 2,800 L/ha, applied as an over-the-trellis spray to dormant grapevines, reduced the proportion of cleistothecia of *U. necator* that dehisced, thereby reducing ascospore release and subsequent germination of released ascospores (Table 4). The cumulative percentage of cleistothecia that dehisced from field-treated bark samples in 1986 was reduced to 10% of the level observed on control vines, while the quantity of ascospores released and the germination of ascospores were reduced to 27 and 24%, respectively, of the levels observed on control vines (Table 4). The combined reduction of ascospore release and ascospore germination would yield a reduction of primary inoculum of nearly 94% $[1.0 - (0.27 \times 0.24)]$. Linearized disease progress curves ($\log_{10}$ transformed) for foliar incidence of powdery mildew on lime sulfur treated and control vines were parallel (Fig. 1) and were shifted on the y-axis by approximately one order of magnitude (Fig. 1). Assuming a constant infection rate over the span of the observations, this shift would be expected from a sanitation ratio, sensu Vanderplank (12), of 10^2, or an eradication of 90% of the overwintering inoculum. Disease progress curves for severity of powdery mildew on fruit of untreated vines typically plateaued (Fig. 2) as fruit became resistant to infection during the period of sugar accumulation (7). In the case of fruit infection, therefore, there is an opportunity for the host to escape infection, if by use of an eradicant treatment, the epidemic is delayed until after the fruit become resistant to infection.

A solution containing 120 ml/L of lime sulfur delayed the development of epidemics of powdery mildew (Figs. 1 and 2). The delay of the epidemic ranged from a few days to several weeks depending upon the resistance of the host to powdery mildew and the favorability of environmental conditions for disease development during the year of the trial. In 3 yr of vineyard trials on the *Vitis* interspecific hybrid cultivar Rosette, which is highly susceptible to powdery mildew, the severity of fruit infection was reduced from levels of 43.1 to 14.1% in 1986, from 4.6 to 0.1% in 1988, and from 41.4 to 27.2% in 1989 by 120 ml/L of lime sulfur (Table 5). In 1988, the severity of powdery mildew on fruit of the more resistant *V. labruscana* 'Concord' was reduced from 30.8 to 0.3% (Table 5), while in 1989 the incidence of fruit infection was reduced from 13.3 to 5.3% by a single lime sulfur application. In 1988, the above treatment also improved the control of powdery mildew in Chardonnay, Rosette, Seyval, and Concord vineyards that received additional fungicide applications during the growing season (Table 5). In fact, the level of powdery mildew that occurred in 1988 on Seyval vines

Table 2. Effects of dormant season over-the-trellis application of lime sulfur on sporulation of *Phomopsis viticola* and on incidence and severity of Phomopsis cane and leaf spot on Concord grapevines

Treatment[y]	Sporulating pycnidia per cm[2 z]	Infected internodes per shoot[z]	Rachis surface infected (%)[z]	Infected leaves per shoot[z]	Leaves per shoot[z]: 100 Lesions per leaf	Leaves per shoot[z]: 200 Lesions per leaf
Lime sulfur	9.1 a	5.14 a	1.49 a	2.26 a	0.16 a	0.06 a
Control	61.5 b	6.60 b	3.24 b	3.64 b	1.14 b	0.28 b

[y] Lime sulfur was applied as an aqueous solution at a concentration of 120 ml/L in a total volume of 2,800 L/ha on 20 April 1989. No other fungicides were applied during the growing season.

[z] Sporulation from excised infected nodes was measured on 26 May, leaf infection was assessed on 28 June, and internode and rachis infection was assessed on 27 September 1989. There were 5.2 leaves/shoot on 28 June. Numbers within columns were compared by Student's *t* test. Those followed by the same letter are not significantly different at $P = 0.10$.

Table 3. Effects of dormant season over-the-trellis application of lime sulfur on sporulation of *Phomopsis viticola* and on incidence and severity of Phomopsis cane and leaf spot on Rosette grapevines

Treatment[y]	Sporulating pycnidia per node[z]	Infected internodes per shoot[z]	Infected leaves per shoot[z]	Total lesions per shoot[z]: Leaves	Total lesions per shoot[z]: Internodes
Lime sulfur	0.5 a[z]	1.18 a	2.68 a	19.5 a	11.4 a
Control	3.5 b	3.87 b	5.22 b	250.1 b	67.0 b

[y] Lime sulfur was applied as an aqueous solution at a concentration of 40 ml/L in a total volume of 2,800 L/ha on 14 April 1987. No other fungicides were applied during the growing season.

[z] Sporulation from excised infected nodes, internode infection, and leaf infection was assessed on 9 June 1987. There were 10.1 leaves/shoot on 9 June. Numbers within columns were compared by Student's *t* test. Those followed by the same letter are not significantly different at $P = 0.05$.

Table 4. Effects of dormant over-the-trellis applications of lime sulfur upon survival and dehiscence of cleistothecia of *Uncinula necator* from the bark of Rosette grapevines in 1986

Treatment[x]	Cumulative dehiscent cleistothecia (%)[y]: 22 April	5 May	12 May	21 May	Ascospores released per 10 cleistothecia[z]	Ascospores germinated (%)[z]
Lime sulfur	0	0	10	10	9.3 ±4.1	19.7 ±11.2
Control	0	39	92	100	35.0 ±12.7	81.3 ±3.8

[x] Lime sulfur was applied as an over-the-trellis drench to dormant vines on 14 April 1986 at the rate of 120 ml of lime sulfur per liter in an aqueous solution of 2,800 L/ha.

[y] The cleistothecia borne on 30 g of bark were removed in water on 21 April and transferred to moist filter paper in a petri dish at 20 C. The cleistothecia were kept moist for 24 hr, dehiscence was assessed, and they were allowed to dry. The cleistothecia were rewet for 24 hr on 4, 11, and 20 May.

[z] Ten cleistothecia were placed on wet filter paper in a petri dish over glass slides at 20 C for 24 hr. Means reported are of four replications. Numbers in parentheses are limits of the 95% confidence interval for the mean.

that received only a seasonal spray program was sufficient to result in rejection of the crop by most wineries; whereas the combination of a dormant application of lime sulfur plus the same seasonal spray program resulted in commercially acceptable disease control (Table 5).

When the rate of lime sulfur application was reduced to 40 ml/L in 1987, there was a commensurate decrease in the control of powdery mildew on Seyval and Concord grapevines, and no significant reduction of powdery mildew on Rosette grapevines (Table 5); and this rate was not evaluated further.

On high-quality wine grapes, slight levels of powdery mildew are sufficient to cause rejection of a crop. As little as 3% berry infection can be detected as off-flavors in wine (7). Thus, the levels of powdery mildew that occurred on *V. vinifera* and *Vitis* interspecific hybrid cultivars that received only a treatment of lime sulfur would not be acceptable in commercial viticulture. However, on the more mildew-resistant *V. labruscana* 'Concord', powdery mildew was reduced to trace levels by a single dormant eradicant treatment of lime sulfur at 336 L/ha (Table 5). On more mildew-susceptible cultivars, eradicant treatments can increase the efficacy of the seasonal spray program (Table 5). Acceptable control of powdery mildew was obtained through the combined use of lime sulfur and seasonal fungicide applications on the cultivars Chardonnay, Rosette, and Seyval in 1988, but not with seasonal fungicide applications alone (Table 5).

The incidence of angular leaf scorch (*Pseudopezicula tetraspora* Korf, R.C. Pearson, & Zhuang) was also significantly ($P = 0.05$) decreased by dormant over-the-trellis applications of lime sulfur. This disease is of relatively recent occurrence in the United States (9). The efficacy of lime sulfur is likely due to the eradication of primary inoculum (apothecia) formed on fallen overwintered leaves (9), which presumably are drenched by the high-volume application. In 1986, lime sulfur at 120 ml/L reduced the percentage of infected leaves on Rosette grapevines from 11.2 to 0.8%, whereas application of 40 ml/L in 1987 to Seyval grapevines reduced foliar infection from 5.7 to 1.2%. Thus, while the lower rate of lime sulfur provided mediocre control of powdery mildew, it may be adequate for control of angular leaf scorch.

The incidence and severity of the leaf and rachis phase of Phomopsis cane and leaf spot were also decreased by dormant over-the-trellis applications of lime sulfur (Tables 2 and 3) at both 40 ml/L in 1987 and 120 ml/L in 1989 in 2,800 L/ha of water. In both 1987 and 1989, lime sulfur reduced sporulation of pycnidia by approximately 85%. Observed decreases in disease incidence, measured as the number of infected internodes per shoot and infected leaves per shoot were of lesser magnitude, but commensurate decreases were observed in the severity of foliar infection in both years of the study (Tables 2 and 3). The effects of lime sulfur upon fruit infection could not be determined, since in both years of the study no fruit infection was observed on control vines.

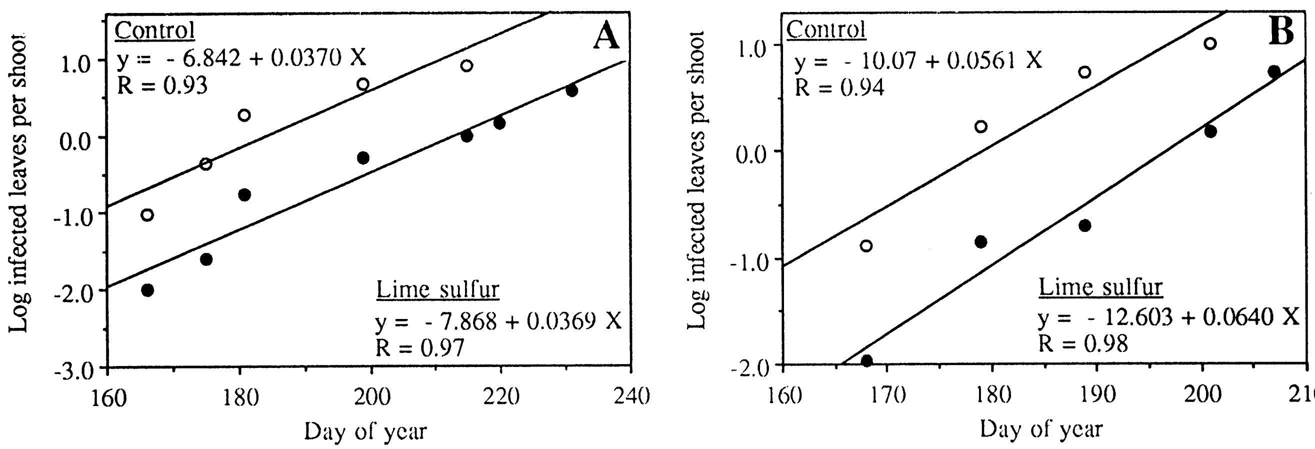

Fig. 1. Incidence of powdery mildew infection on foliage of **(A)** Seyval and **(B)** Rosette grapevines, with or without dormant over-the-trellis applications of lime sulfur at a concentration of 120 ml/L in 2,800 L/ha of water in 1988. Within cultivars, intercepts of simple linear regressions are significantly different and slopes are equivalent at $P = 0.05$.

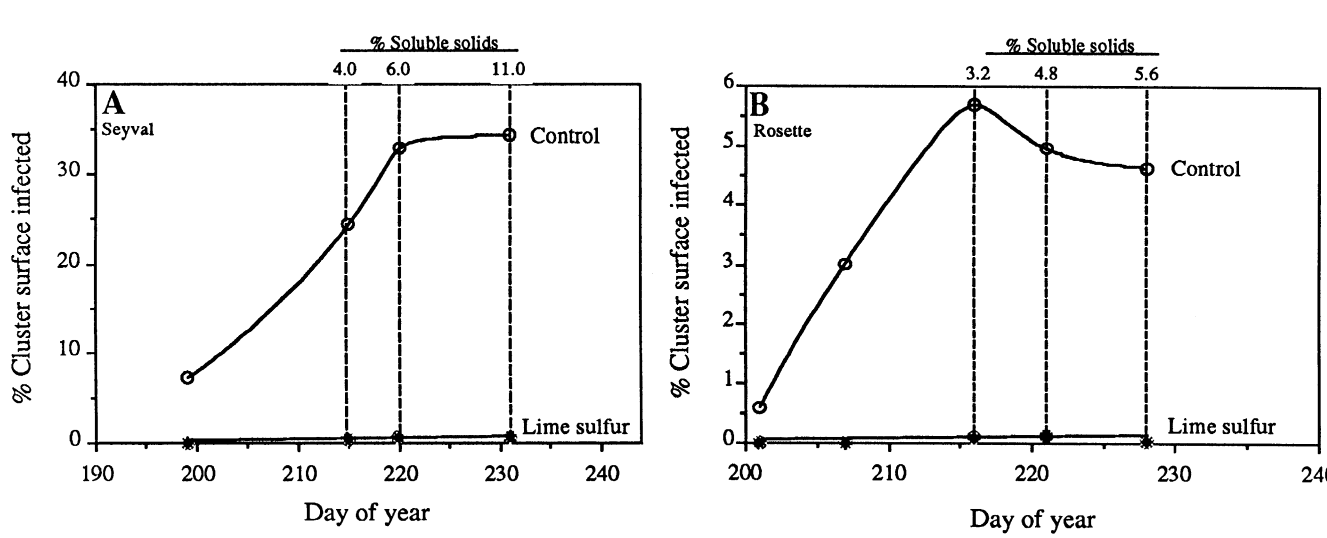

Fig. 2. Severity of powdery mildew infection on fruit of **(A)** Seyval and **(B)** Rosette grapevines, with and without dormant over-the-trellis applications of lime sulfur at a concentration of 120 ml/L in 2,800 L/ha of water in 1988. Dashed vertical lines indicate the mean soluble solid levels of juice from crushed fruit.

Table 5. Effects of dormant over-the-trellis applications of lime sulfur on incidence and severity of fruit infection by *Uncinula necator*

			Without seasonal sprays[z]		With seasonal sprays[z]	
Year	Cultivar	Concentration of lime sulfur (ml/L)[y]	Clusters with berry infection (%)	Cluster surface infected (%)	Clusters with berry infection (%)	Cluster surface infected (%)
1986	Rosette	120	12.0*	14.1*	ND	ND
		0	58.0	43.1	ND	ND
1987	Rosette	40	62.0	5.8	ND	ND
		0	34.0	1.1	ND	ND
	Concord	40	4.6*	0.1*	ND	ND
		0	8.6	0.5	ND	ND
	Seyval	40	6.0*	0.1*	ND	ND
		0	14.0	0.3	ND	ND
1988	Chardonnay	120	100.0	49.4*	23.0*	0.5*
		0	100.0	84.6	74.0	2.3
	Rosette	120	1.1*	0.1*	0.0*	0.0*
		0	100.0	4.6	29.4	0.9
	Seyval	120	24.0*	0.6*	5.0*	0.1*
		0	99.0	34.4	83.0	10.6
	Concord	120	16.0*	0.3*	4.0*	0.1*
		0	99.0	30.8	21.0	0.7
1989	Concord	120	5.3*	0.1*	2.0*	0.1*
		0	13.3	0.5	12.0	0.8
	Rosette	120	74.0*	27.2*	ND	ND
		0	88.6	41.4	ND	ND
1991	Seyval	120	2.7*	0.4*	ND	ND
		0	23.3	2.9	ND	ND

[y] Lime sulfur was applied as an aqueous solution at the indicated concentration in a total volume of 2,800 L/ha (120 ml/L = 336 L/ha of lime sulfur, 40 ml/L = 112 L/ha of lime sulfur).

[z] Means of lime sulfur treatments within columns followed by an asterisk differ significantly from the mean of the subtending untreated control at $P = 0.10$ according to Student's t test. Disease incidence and severity values reported above were assessed approximately 3–4 wk before harvest in each year of the study. ND indicates no data collected.

Table 6. Effects of dormant over-the-trellis applications of lime sulfur to the *Vitis* interspecific hybrid cultivar Delaware on incidence and severity of fruit infection by *Guignardia bidwellii*

			Without seasonal sprays[z]		With seasonal sprays[z]	
Year	Concentration of lime sulfur[y] (ml/L)	Ascospores released per mummified berry ($\times 10^3$)	Clusters with berry infection (%)	Cluster surface infected (%)	Clusters with berry infection (%)	Cluster surface infected (%)
1991	120	338	98.7	20.3*	5.3*	0.2
	0	407	100.0	40.4	24.0	1.1
1992	120	166	100.0	81.4	8.7*	0.6
	0	326	100.0	76.5	19.3	1.8

[y] Lime sulfur was applied as an aqueous solution at the indicated concentration in a total volume of 2,800 L/ha (336 L/ha of lime sulfur).

[z] Disease was assessed on 29 July 1991 and on 11 September 1992. An asterisk indicates that lime sulfur treatment effects within column are significant at $P = 0.05$ compared to untreated vines for that year according to Student's t test.

The incidence and severity of black rot of grapes were also reduced by an application of lime sulfur at 120 ml/L in 2,800 L/ha of water in 1991 (Table 6). Disease incidence, but not severity, was reduced by a similar application in 1992 (Table 6).

Lime sulfur at 336 L/ha reduced the incidence and severity of several grape diseases. In the case of *V. labruscana* 'Concord', the dormant eradicant treatment alone may provide adequate control of powdery mildew. Our dormant eradicant treatments also improved the efficacy of seasonal fungicide sprays on powdery mildew–susceptible cultivars, which is significant because of the low tolerance for mildew infection on high-quality wine grapes. Symptoms of phytotoxicity due to lime sulfur applications were not observed in any of our research plots. Despite these results, the extremely high rates of application required and the volume of water delivered in over-the-trellis drenches weigh against the adoption of lime sulfur eradicant treatments in commercial viticulture. At a current material cost of more than $250/ha, these treatments are not competitive with the best modern fungicides in either efficacy or total seasonal cost. However, the continuing loss of fungicides through regulatory action, development of pathogen resistance, and the refusal of processors to accept crops treated with certain non grata fungicides may make these dormant treatments necessary, simply through the loss of alternative methods of control. Our results demonstrate the potential of a single eradicant treatment to reduce primary inoculum of a number of pathogens and contribute to disease control, and may serve as a stimulus to identify compounds more effective and economical than lime sulfur for this purpose.

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