Humidity-temperature recorder in Napa Valley Cabernet Sauvignon vineyard.

Temperature-based sulfur applications to control grape powdery mildew

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Powdery mildew *(Uncinula necator)* has been a consistent disease problem in California vineyards for over a century. For nearly that long, elemental sulfur has been applied for its control. Agricultural bulletins dating to the 1890s describe the treatment schedule still in use today: regular applications of sulfur at 7- to 14-day intervals during the period of vine susceptibility. The interval may be adjusted for local conditions and grape variety, but no systematic method for determining the best timing has been previously presented. The past recommendations have led to under- or over-use of sulfur in years when environmental conditions are more or less favorable for epidemic spread.

Germination, infection, and colony development by the powdery mildew fungus are known to be closely related to temperature, indeed more closely than to available moisture. These relationships to temperature were the basis of a mathematical model of powdery mildew development that demonstrated the consequences of various weather patterns on epidemic spread and predicted the course of epidemics in several areas of California. The success of this model led to the idea that temperature might be the key to a more efficient sulfur application schedule.

Environmental conditions, particularly temperature, also are closely related to the effectiveness of sulfur as a fungicide and to the growth rate of the vine. Two principal reasons for repeating applications of sulfur are its weathering and subsequent decline in effectiveness, and the growth of new and, hence, unprotected host tissue.

We have formulated a systematic method for timing sulfur application based on temperature monitoring. Our goal has been adequate suppression of grape powdery mildew with minimal but optimally timed applications.

Derivation of timing scheme

The timing method rests on the assumption that temperature is the most important factor controlling the development rate of the pathogen, growth of susceptible tissue, and weathering of the sulfur dust. We assume that the organism, either the vine or the fungus, reacts instantaneously to changes in temperature and that past temperatures do not influence future growth reactions. The assumption is not strictly true, but it is a necessary simplification.

In a method similar to use of physiological time to follow insect maturation, we have used the length of the latent period of the fungus to plot its development. The latent period is the time from spore deposition until sporulation of the resultant colony. Optimum temperature for development is 80°F (27°C), and thermal inactivation occurs at 84.5°F (35°C). By combining this relationship with the daily temperature pattern and integrating over 24 hours, one can mathematically estimate the amount of progress the fungus makes in one day when temperatures are not constant.

Published results on the influence of

Heavy powdery mildew infection on cluster of young Thompson Seedless grapes.

Overwintering powdery mildew bud infection.

temperature on grapevines demonstrate that the relation of temperature to the growth of susceptible tissue closely parallels that for vine photosynthesis. Maximum rates occur at about 86°F (30°C), and at 103°F (45°C) growth ceases. The differences between the temperature reaction pattern for vine growth and for fungal development imply that below 80°F (27°C) the fungus is growing faster than the vine relative to its optimum, and that above 80°F (27°C) the opposite occurs.

Numerous studies indicate that the radius of effectiveness of sulfur particles is drastically reduced below 68°F (20°C). Thus, at low temperatures, sulfur coverage must be very dense to control powdery mildew spread. Weathering rates over a range of temperatures and the interaction of these rates with various sulfur densities are under further investigation.

Taking into consideration the reaction to temperature of the fungus, vine, and sulfur, we devised a table of intervals between sulfur applications (table 1). These intervals determine a mildew treatment schedule that adjusts for changing conditions. When temperatures are most favorable for vine growth, the fungicide is applied most frequently. When mildew development is limited by high termperatures, the interval lengthens. When the effectiveness of sulfur is reduced, regular applications are made to ensure adequate coverage.

Use of timing scheme

In using the table, growers check the daily high and low temperatures at least every 5 days. The first dust is applied either 12 days after the first leaves appear from the buds or at 6 inches (15 cm) of shoot growth, whichever comes first. However, if early shoot infections (usually arising from infected buds) are found, the block should be treated with sulfur spray (wettable, micronized, or flowable) for mildew eradication.

Subsequent sulfur dust treatments are timed by temperature, at intervals as indicated in table 1. Sulfur is reapplied if rain, sprinkler irrigation, or sprinkler frost protection exceeds 0.10 inch (2.5 mm). Also, when temperatures exceed 100°F (38°C), the amount of sulfur applied must be reduced to avoid burning. This application schedule is maintained until grapes reach an average of 12 to 15 percent sugar.

This scheduling method is not used for fruit destined for fresh market. It provides adequate control of the damage to yield and quality desired for wine or raisin fruit, but the control level may not be sufficient to prevent some cosmetic damage.

Results of field trials

In 1981, the temperature-based timing method was field-tested in 44 vineyards throughout California. At each site, growers were asked to use the timing chart to schedule sulfur dustings in a large block and to treat an adjacent area on their standard schedule. Most growers were able to follow the temperature-based schedule.

Of the 36 vineyards where the test was completed, fewer applications were made using the temperature-timed sulfur schedule in 10 cases (1 to 6 fewer; mean = 2.4), the same number of applications were made in 15 cases, and more applications were made using the temperature-timed schedule in 11 cases (1 to 5 more, mean = 2.0). Table 2 summarizes the results by grape growing area. The greatest reduction in the number of sulfur applications occurred in the San Joaquin Valley, where actual temperature patterns more closely approximate the smooth curve used to devise table 1.

Excessive numbers of applications related to the temperature-timing scheme occur mainly at the beginning of the growing season when the scheme usually requires a 12-day sulfuring interval. Under low temperatures, such as those common early in the growing season, the schedule is based on the influence of temperature on the effectiveness of sulfur as a fungicide. Our knowledge in this area is incomplete, so this is the weakest link in the timing scheme. More information is needed to refine the schedule for use in cool weather.

In nearly all cases, the powdery mildew levels in the standard-schedule and the temperature-timed blocks were identical. However, in three cases, substantially greater levels (14 to 48 percent) of mildew were found in the temperature-timed blocks. In these cases, there were some inaccuracies in timing the applications, and in one location, wettable sulfur was used to eradicate infections in the standard schedule block but not in the temperature-timed block.

We conclude that the temperature-based schedule can assist grape growers in making fewer, but more effectively timed, sulfur applications in their vineyards, while not substantially elevating levels of grape powdery mildew. The method is more effective in eliminating unnecessary applications in the San Joaquin Valley than in the coastal areas. In years with normal weather patterns, sulfur applications would be made at nearly the same time using either the temperature-timing method or the standard control schedule. It is in the years when conditions are particularly conducive or suppressive to mildew growth that this system can be of most value in helping to prevent severe disease outbreaks or to eliminate unnecessary treatments.

TABLE 1. Number of days between sulfur dust applications according to various temperature regimes.

Daily low temperature	Daily high temperatures (°F)								
	60-65	65-70	70-75	75-80	80-85	85-90	90-95	95-100	100-105
40-45	12	12	12	12	13	15	15	18	20
45-50	12	12	12	11	12	13	15	17	19
50-55	12	12	12	10	11	12	13	16	17
55-60	12	12	11	9	10	11	12	13	16
60-65	12	12	9	9	9	10	11	13	14
65-70	—	10	7	7	8	8	10	11	13
70-75	—	—	7	6	7	8	9	11	13
75-80	—	—	—	7	8	11	12	15	18
80-85	—	—	—	—	11	13	17	*	*
85-90	—	—	—	—	—	17	17	*	*

* Weekly averages in these ranges are not likely to occur. Sulfur applications under these conditions may result in phytotoxicity.

TABLE 2. Results of field trials conducted in 1981

Location	No. of vineyards examined	Mean no. sulfur applications		Mean percent clusters infected	
		Standard schedule	Temperature-timed	Standard schedule	Temperature timed
North Coast	7	7.0	7.7	0	0
Central Coast	7	9.9	10.5	11	13
South Coast	13	8.5	8.3	1	1
San Joaquin Valley	9	11.3	10.5	61	63

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