

Application of Crop Modeling for Sustainable Grape Production

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Summary

Alternatives to a calendar-based spray program for the control of grape powdery mildew (*Uncinula necator*) were investigated in Western Colorado vineyards over five seasons (2002-2006). Participating growers used a calendar-based program on approximately half of a vineyard block while using an integrated disease management program on the other half. Weather stations installed in those vineyard blocks provided the climatic data used to guide spray recommendations. Conclusions are as follows. First, powdery mildew does not appear to overwinter in infected buds under the growing conditions of western Colorado. Second, the establishment of powdery mildew requires a primary infection originating from overwintering cleistothecia. The weather conditions required for a successful primary infection are thought to be a minimum of 0.1" of precipitation, a minimum temperature of 50 °F, and at least 8 hours of continuous leaf wetness. Weather conditions inside grape canopies can easily be monitored, and the information can be used in the decision-making process regarding mildew control. Third, spray recommendations from established regions like California with very different climatic conditions are inappropriate for Western Colorado locations. Due to the absence of bud perennation and hence the lack of early-season inoculum, fungicide applications shortly after bud break are not needed unless weather conditions are conducive for a primary infection. Finally, grape powdery mildew can be effectively controlled with a spray program that is reactive (treating only infection hotspots plus a buffer) rather than preventative in nature. Using such a program can lead to significant reductions in both spray applications and the costs for spray materials. Combining weather monitoring with field observations of powdery mildew infections can greatly reduce, if not entirely eliminate, powdery mildew sprays within a season. Survey data from 2004-2006 indicate that many Colorado growers have adopted a response-type approach to powdery mildew control.

Introduction and Objectives

Grape powdery mildew is the primary disease of *Vitis vinifera* grapes in Colorado. Historically, the typical grape powdery mildew control program in western Colorado vineyards has been preventative in nature. Growers began applying prophylactic sprays when shoots were about 4-6 inches long and continued through veraison at intervals determined by the spray longevity of the materials used. This approach has historically resulted in four to as many as eight sprays applied each season.

Our previous studies examined the combined use of weather monitoring, computer modeling for grape powdery mildew risk based on the collected weather data, crop development stage, field scouting, and prescribed fungicide sprays when powdery mildew infection is found. We have shown that it is possible to substantially reduce the number of pesticide applications to control grape powdery mildew by basing the applications on model assessment of mildew infection risk and observed infection confirmation (Caspari and Larsen, 2005). As a result, much of the wine grape industry in western Colorado has adopted our recommendations and reduced the number of mildewicide sprays by applying them only when needed, not simply on a calendar basis. For example, survey data from 2004 indicate that growers used on average only 2.3 fungicide sprays to control powdery mildew, while data for 2005, a year with a higher disease pressure, show an average of 3.1 sprays. Data from this

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year (2006), again a year with low powdery mildew pressure, show an average of 2.6 sprays.

In the studies conducted from 2002-2004 it was observed that powdery mildew infections within the study vineyards might arise seasonally from vineyard "hot spots." The infection then spreads to other parts of the vineyard if not controlled by fungicide sprays. Once an infection is noticed, growers then typically apply fungicide sprays to the entire vineyard to protect developing fruit from infection. This vineyard-wide application results in spray materials being applied to substantial portions of the vineyard that have no observable infection. The current study investigates if the amount of fungicides applied can be further reduced by use of closer field monitoring, identification of "infection hot spots" within the plots by fine discrimination GPS coordinates, and prompt application of effective fungicides to these "hot spots." Results from the 2005 season showed that it is indeed possible to effectively control powdery mildew when applying sprays to "hot spots" and a buffer zone as long as the infected areas are correctly identified (Caspari and Larsen, 2006). But they also showed that

incorrect identification of the "hot spots" and/or mistakes when applying sprays to the target areas can lead to re-infection from the "hot spots", and rapid spread of powdery mildew. Further, restricting spray applications to "hot spots" plus buffer is not feasible when powdery mildew infection is widespread throughout the vineyard. Under those circumstances the whole block needs to be treated.

Materials and Methods

Two cooperator vineyards were identified with a minimum 2 acres of Chardonnay. The blocks are the same as used continuously since 2002 for our previous study. Grower cooperators were to use their choice of control programs (grower's standard control program) for grape powdery mildew control on one half of the block (minimum of 1 acre) and to use the control program designated by the researchers for the other half of the block (minimum of 1 acre, which included the site of a remote weather station described below). The two different blocks/treatments will be referred to as "grower" and "model" (Fig. 1). In addition, Colorado State University's entire research vineyard was

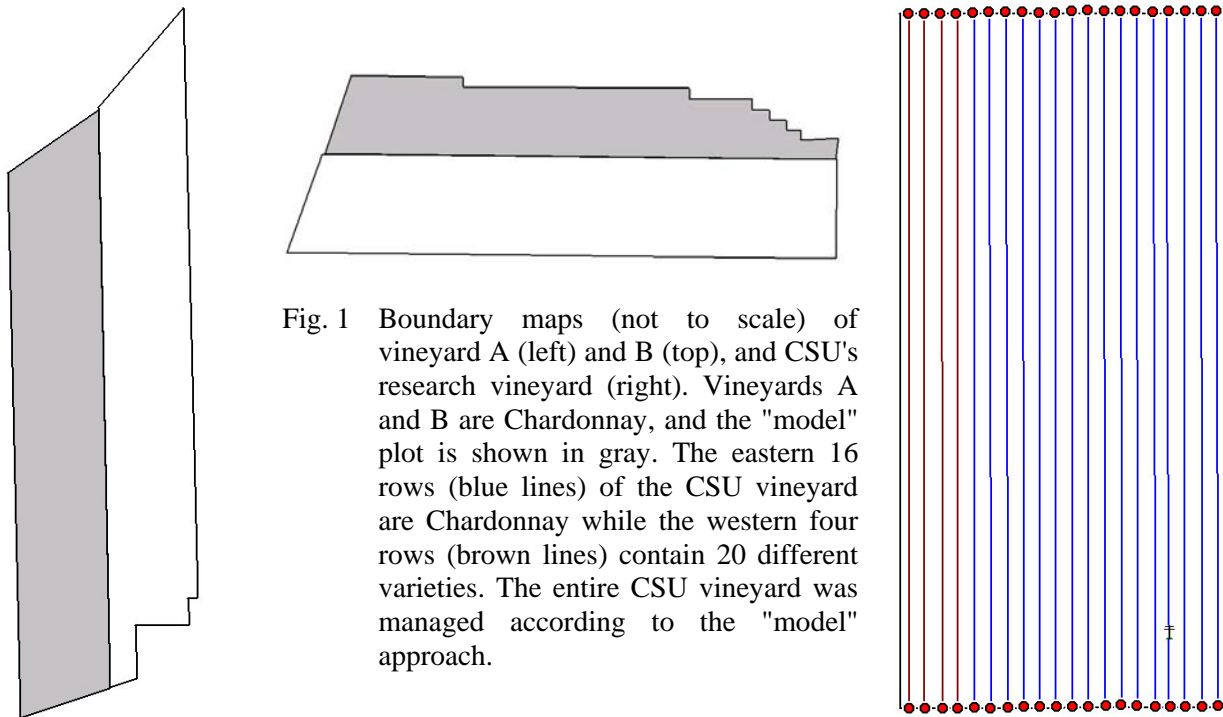


Table 1. Powdery mildew spray programs used at cooperator vineyard A during the 2006 season.

Grower's Standard Mildew Program			Integrated Disease Management Program		
Date	Materials & rates used	Cost ^z	Date	Materials & rates used	Cost ^z
5/8	Sulfur 6 @ 0.5 gal/a	\$2.50	5/8	Sulfur 6 @ 0.5 gal/a	\$2.50
5/26	Sulfur 6 @ 0.5 gal/a	\$2.50			
7/14	Nova 40W @ 4 oz./a + Stylet-Oil @ 1.25 gal/a	\$33.50	7/14	Nova 40W @ 4 oz./a + Stylet-Oil @ 1.25 gal/a	\$33.50
7/29	Sovran @ 4 oz./a + Stylet-Oil @ 1 %	\$39.75	7/29	Sovran @ 4 oz./a + Stylet-Oil @ 1 %	\$39.75
Total Spray Program Cost		\$78.25	Total Spray Program Cost		\$75.75

^z Costs per acre for spray material only.

Table 2. Powdery mildew spray programs used at cooperator vineyard B during the 2006 season.

Grower's Standard Mildew Program			Integrated Disease Management Program		
Date	Materials & rates used	Cost ^z	Date	Materials & rates used	Cost ^z
5/9	Microthiol @ 4 lbs/a	\$3.40	5/9	Microthiol @ 4 lbs/a	\$3.40
5/24	Nova 40W @ 3.75 oz./a	\$15.00			
6/20	Sovran @ 4 oz./a	\$27.29			
7/14	Sovran @ 4.8 oz./a + Stylet-Oil @ 1.5 %	\$57.15	7/14	Sovran @ 4.8 oz./a + Stylet-Oil @ 1.5 %	\$57.15
8/3	Stylet-Oil @ 1 %	\$17.50	8/3	Stylet-Oil @ 1 %	\$17.50
Total Spray Program Cost		\$120.34	Total Spray Program Cost		\$78.05

^z Costs per acre for spray material only.

Table 3. Powdery mildew spray programs used at the CSU vineyard during the 2006 season.

Date	Materials & rates used	Cost ^z	Area treated (%)
6/15	Pristine 38WDG @ 8 oz./a	\$18.75	7
7/14	Nova 40W @ 5 oz./a + Stylet-Oil @ 1.5 %	\$62.00	100
Total Spray Program Cost		\$80.75	

^z Costs per acre for spray material only.

managed as a "model" block according to the researchers' protocol. The spray programs varied from two to five sprays per season between sites (Table 1-3).

Automated Adcon weather stations were installed at the three sites in 2002. Each station is equipped with sensors to measure air temperature, humidity, leaf wetness, precipitation, wind speed and direction, and solar radiation. Data was relayed back to a base station at CSU's Western Colorado Research Center via radio telemetry on 15-minute intervals. The base station database was then accessed using the Thomas-Gubler powdery mildew disease model to assess mildew infection risk.

As in previous years, field scouts assessed powdery mildew infection incidence and severity on variable intervals, typically once a week. Incidence and severity of powdery mildew infections on leaves were recorded from late May to early August 2006 (about veraison). Samples included both basal (near the fruit zone) and more apical leaves at each sampling time. Sampling was at random although an effort was made to sample all areas of the blocks. At each sampling date, the incidence and severity of powdery mildew was determined on two leaves per vine on a total of 50 vines per plot (i.e. 100 samples per plot, and 200 samples per site). Field scouts were equipped with a Global Position System receiver (Trimble AgGPS 114

receiver connected to HP iPAQ handheld computer). The AgGPS 114 receiver uses Differential GPS to achieve high, submeter accuracy. The use of this system allowed the calculation of a 3D position (latitude and longitude, altitude, and time) of the disease data. After downloading the field data to a desktop PC, the sample locations as well as the disease incidence could then be visualized using a dedicated software program (FarmGIS, Red Hen Farming Systems, Fort Collins, CO), and maps showing the distribution of powdery mildew (if present) by severity were created using MapCalc software (Red Hen Farming Systems, Fort Collins, CO). This information on distribution and severity was then used to determine if a fungicide application should be applied, and to what areas of the "model" plot. Although we provided information about powdery mildew severity and distribution to the cooperating growers, any fungicide application in the "grower" plot was always to the entire plot.

Results

Results from the 2002-2005 seasons have been reported previously (Caspari and Larsen, 2003, 2006; Larsen and Caspari, 2004, 2005). Here we

concentrate on the results from the final year of this project. Weather conditions in May 2006 were dry and warm, and only two days had measurable rainfall. However, rainfall amounts were too small and leaf wetness duration too short to cause a primary infection. The first significant rainfall and leaf wetness period occurred on June 9, 2006. Although rainfall amounts and leaf wetness durations at all three sites appeared sufficient for primary infections, no mildew was found at the grower vineyards until after a second significant rainfall event on July 9, 2006. In contrast, some powdery mildew was found in a small area of CSU's research vineyard (Fig. 2). In response to the mildew observation, this area and a buffer zone was treated on June 15, 2006. The treated area was only 7 % of the total vineyard area. It is worth noting that the vines in this area are the most vigorous within the entire vineyard, and although not quantified, had the highest canopy density within the vines in the block. This denser canopy might indeed be the reason why the mildew infection got established in this area as the dense canopy might have caused a longer leaf wetness period. However, the fungicide

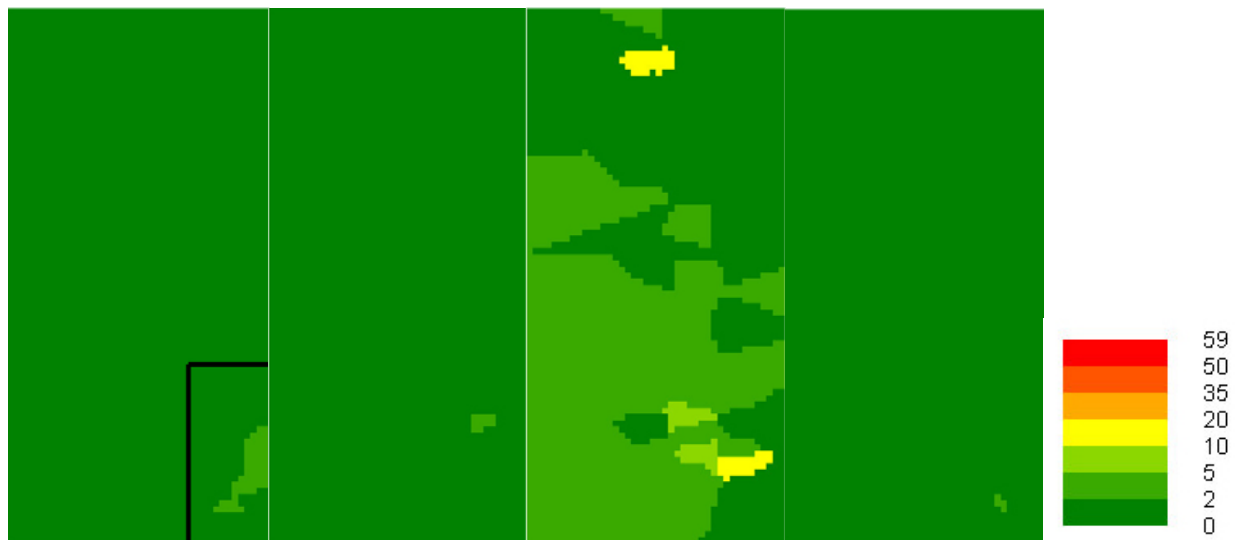


Fig. 2: Distribution and severity of grape powdery mildew at the CSU research vineyard on 13 and 22 June, 13 and 27 July, 2006 (left to right). Different colors represent different severities. The black line in the map for 13 June shows the approximate boundary for the southeastern edge of the vineyard that was treated on 15 June, 2006. Note that no mildew was found at any other date between 23 May and 3 August, 2006.

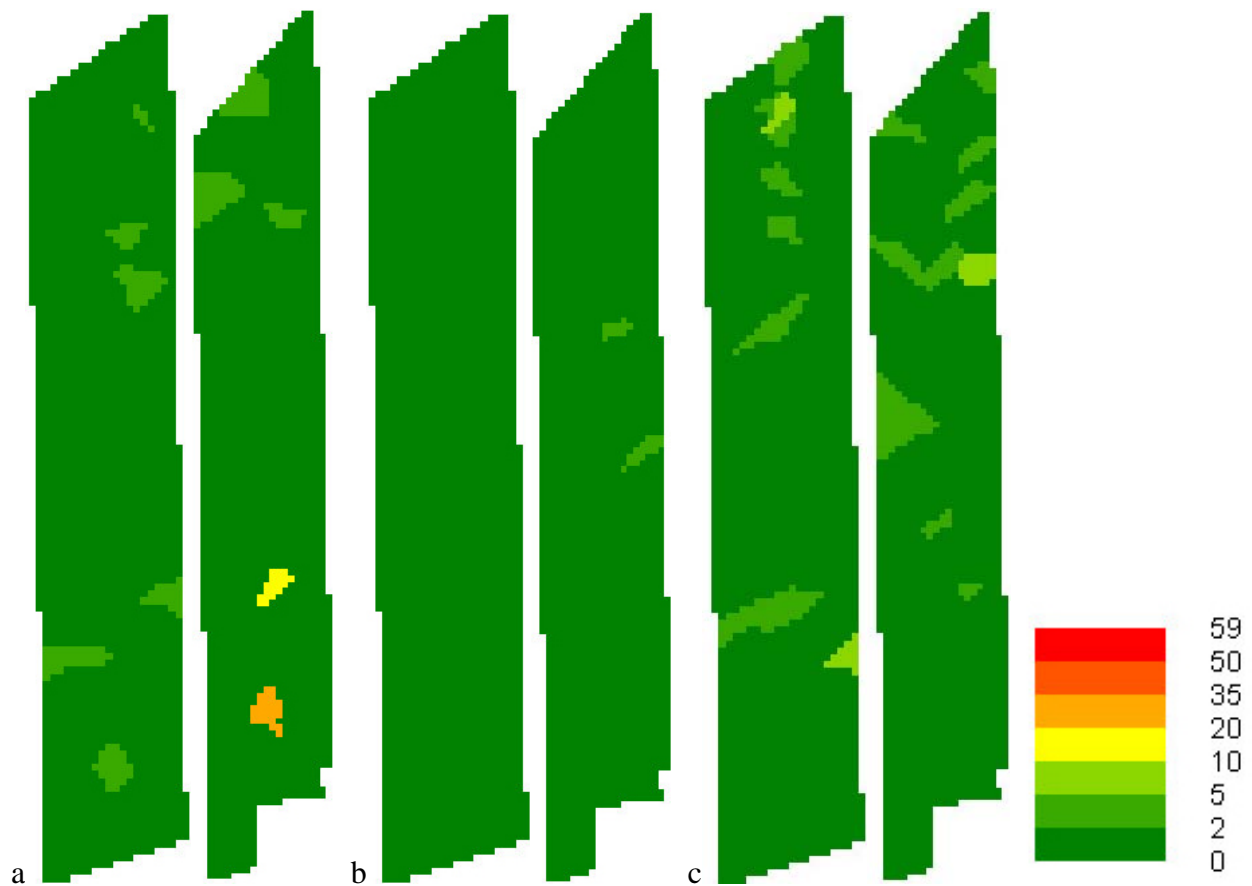


Fig. 3: Distribution and severity of powdery mildew on Chardonnay grape leaves at vineyard A. From left to right: 12, 21 & 28 July. For each date, the model block is on the left, the grower block on the right. Note that no mildew was found at any other date between 31 May and 3 August, 2006.

application to this area provided good mildew control for the remainder of June, although some mildew was found within the area treated on June 22 (Fig. 2).

No mildew was observed on the cooperator vineyards until 12 July (vineyard A; Fig. 3a) or 13 July, 2006 (vineyard B "model" block only; Fig. 4). The occurrence of powdery mildew at the cooperator vineyards, as well as at CSU's research vineyard at the same time (Fig. 2), is likely the result of an extended rainy period from 7-10 July, 2006. At vineyard A, powdery mildew was found in several areas of both blocks, and the entire vineyard was treated on 14 July, 2006 (Table 1). Scouts did not observe any mildew in the "model" block on the next visit 6 days after the fungicide application, but there were two small infection spots within the "grower" block (Fig. 3b). On 28 July, 2006, i.e.

14 days after the fungicide application, powdery mildew was again evident in several areas in both blocks (Fig. 3c). The final spray for the season was applied on 29 July, 2006 (around veraison and before applying bird netting) and no mildew was found on the final observation on 3 August, 2006.

At vineyard B, powdery mildew infections were spread throughout the "model" block on 13 July, 2006 (Fig. 4, top), but no mildew was found in the "grower" block. It appears that the fungicide application in the "grower" block on 20 June, 2006 (Table 2) still provided protection during the extended wetness period. However, both blocks were treated on 14 July, 2006 (Table 2). This spray provided good protection as no mildew was observed on the next two visits (20 and 27 July) in the "model" block with only a



Fig. 4: Distribution and severity of powdery mildew on Chardonnay grape leaves at vineyard B. Top: 13 July, 2006 (model). Bottom: 20 July, 2006 (grower). Note that no mildew was found at any other date between 26 May and 27 July, 2006.

very small area showing infection in the grower block on 20 July, 2006 (Fig. 4, bottom). The cooperater applied a final fungicide to both blocks at the time of veraison just prior to the application of bird netting (Table 2). Powdery mildew pressure was low to moderate during late summer and fall of 2006, and no fruit infection was found at any of the monitored vineyards.

Discussion

Alternatives to a calendar-based spray program for the control of grape powdery mildew (*Uncinula necator*) were investigated in Western Colorado vineyards over five seasons (2002-2006). Participating growers used a calendar-based program on approximately half of a vineyard block while using an integrated disease management program on the other half. Weather stations were installed in those vineyard blocks and the climatic data received from the stations were used to guide spray recommendations. Under favorable weather conditions, i.e. dry spring and early summer, it was feasible to control powdery mildew with as little as 1-2 spray applications per year compared to up to 8 applications in a calendar-based program. In most vineyards, powdery mildew was not observed until early-mid July in 3 out of 5 years, irrespective of the early-season spray program. As a result, a control strategy that is reactive, rather than preventative, in

nature has the potential to substantially reduce both the number of spray applications and application costs compared to a calendar-based spray program while providing the same level of control.

Over the five years of this project we have never found "flag shoots" - shoots arising from overwintering buds that are infected with powdery mildew. At vineyard B, powdery mildew was never detected prior to July - irrespective of the control strategy used during the early part of the season. Likewise, mildew wasn't found at vineyard A until July during 2002, 2004 and 2006, while it was late June in 2003. Only in 2005 did we observe the first mildew of the season in early June at vineyard A. During 2003 and 2004 we also monitored powdery mildew infections in three other vineyards, and mildew was generally not observed until July (Larsen and Caspari, 2004, 2005). In almost all cases the first mildew infections of a season were found after a rainy period.

Based on observations in the first three years (2002-2004) that powdery mildew infections within study vineyards might arise from "hot spots", we investigated the potential to use GPS technology to a) identify and delineate infected versus non-infected areas, and b) target spray applications to the infected areas only (plus a buffer zone) during the 2005 and 2006 season. This alternative control strategy was evaluated

on two commercial vineyards as well as Colorado State University's research vineyard. On the commercial vineyards, approximately half of a mature Chardonnay block received the grower's standard spray program ("grower") while the other half was managed according to powdery mildew modeling and the results of weekly, GPS-referenced disease assessments ("model"). At the CSU vineyard, the entire block was managed according to the "model" approach.

Powdery mildew incidence varied greatly between the three Chardonnay blocks as well as between years. In 2005, mildew was present and widespread in early June on one site and required a season-long spray program. At the second site, a localized powdery mildew infection was found in the "model" block in early July and controlled by treating the "model" block only. Similar control of powdery mildew was achieved with three fungicide applications in the "model" block compared to five applications in the "grower" block. At the CSU vineyard, the first (mid June) and second (early July) application was restricted to infected areas, treating 56 and 37 % of the vineyard area, respectively, while the final application in late July was to the entire vineyard. In 2006, no mildew was observed in the two commercial vineyards until mid July. Excellent powdery mildew control was achieved with either control strategy, yet with a reduction in the number of spray applications and application costs in the "model" blocks. At the CSU vineyard, only 7 % of the vineyard block was treated in response to a very localized powdery mildew infection in mid June, which provided good control until a rainy period during 7-10 July. A final spray was applied to the entire vineyard area following this infection period.

The results from all seasons illustrate both the potential and limitations of this alternative control strategy. Early, widespread disease pressure found at one site in one year required a continuous spray program with no advantage of the "model" over the "grower" standard. However, excellent control of powdery mildew was achieved with a reduced ("model") spray program during other times, and at other sites. In addition, targeted fungicide applications at the CSU vineyard resulted in the elimination of the

equivalent of one spray in 2005, and only 7 % of the vineyard area was treated with the first spray in 2006. Timely analysis of GPS data and proper identification of spray target areas are required to reduce the risk of re-infection from non-treated "hot spots". Further, wetness periods appear to be required to cause powdery mildew infections, and spray applications early in the season prior to a primary infection are not needed. The number of spray applications and application costs can be reduced when combining weather monitoring with field observations. Survey data from 2004-2006 indicate that many Colorado growers have adopted a response-type approach to powdery mildew control.

A number of conclusions can be drawn from our results. First, powdery mildew does not appear to overwinter in infected buds under the growing conditions of Western Colorado. Second, the establishment of powdery mildew requires a primary infection originating from overwintering cleistothecia. The weather conditions required for a successful primary infection are thought to be a minimum of 0.1" of precipitation, a minimum temperature of 50 °F, and at least 8 hours of continuous leaf wetness. Weather conditions inside grape canopies can easily be monitored, and the information can be used in the decision-making process regarding mildew control. Third, spray recommendations from established regions like California with very different climatic conditions are inappropriate for Western Colorado locations. Due to the absence of bud perennation and hence the lack of early-season inoculum, fungicide applications shortly after bud break are not needed unless weather conditions are conducive for a primary infection. Finally, this project has shown that grape powdery mildew can be effectively controlled with a spray program that is reactive rather than preventative in nature. Using such a program can lead to significant reductions in both spray applications and the costs for spray materials. When combining weather monitoring with field observations of powdery mildew infections it is possible to greatly reduce, if not entirely eliminate, powdery mildew sprays.

A noteworthy, if somewhat unexpected outcome of our research on powdery mildew

management has been a better grower understanding about fungicide choices and rotations to minimise the risk of resistance development. During the past five years we conducted several workshops on pest and disease management and have presented the results from this study at several meetings. We also had numerous one-on-one discussions with the collaborating growers. Prior to this study many growers mistakenly thought that they were minimising the risk of resistance development by alternating fungicides. For example, an actual spray program used by a Colorado grape grower in 2001 was a rotation of Bayleton, Nova, and Rubigan. All three of those products are

DMI fungicides, i.e. they share the same mode of action; so rather than reducing the risk of resistance development, this spray program increases it. Changing fungicide product and not the mode of action was indeed a common mistake among Colorado growers. As a result of our workshops and seminars as well as the online publication of the Grape Pest Management Options for Colorado (where fungicides are listed by class) growers today are more aware of the various products that are available, and the correct procedure to rotate the mode of action.

Acknowledgments

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