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The Costs of Powdery Mildew Management in Grapes and the Value of Resistant Varieties: Evidence from California

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ABSTRACT.

Powdery mildew (PM) is a fungal disease that can affect a variety of crops, but it is the most significant disease in terms of expenses for control and losses in quality and yield faced by grape growers worldwide. PM-resistant grape varieties are currently being developed, but the value of such varieties to the growers in different industry segments is yet to be determined. The first step in estimating the potential value of PM-resistant varieties is to establish the costs of PM management that these varieties will serve to mitigate. We utilize Pesticide Use Reports from the California Department of Pesticide Regulation as well as data on pesticide application costs and measures of environmental impact to evaluate annual costs, both pecuniary and non-pecuniary, of powdery mildew management among California grape growers. We estimate the statewide cost of PM management (fungicides and their application) in 2011 to be about $189 million. In addition, we find that PM management accounts for 74 percent of restricted material (pesticide) applications by grape growers and eliminating powdery mildew would significantly reduce the environmental burden from disease management in grapes.

Key Words: Powdery mildew, resistant varieties, California grapes, disease management

JEL Codes: Q12; Q16; Q50

1. Introduction

Powdery mildew (PM) is a fungal disease that can be caused by several species of fungi and can affect a variety of plants. Grape powdery mildew (*Erisiphe necator, syn. Uncinula necator)* affects grape crops all over the world and is the most significant disease in terms of expenses for control and losses in quality and yield faced by grape growers, in California and worldwide (Bettiga et. al., 2013). Efforts are underway to develop PM-resistant grape varieties that can be used by growers of all types of grapes, including wine, table and raisin grapes (e.g., VitisGen http://www.vitisgen.org/). So far, there has been no formal evaluation of the likely value to growers in the different industry segments, and the broader community if PM resistant varieties become available. A first step to answering that question is to establish the costs of PM management, which resistant varieties would serve to mitigate. The total statewide costs of PM management include pecuniary costs such as the costs of purchasing and applying fungicides, and non-pecuniary costs such as environmental and worker health effects, as well as the inconvenience to the grower from having to worry about the appropriate methods of disease control or the potential damage to the crop.

We find that PM management accounts for a very large share of the total pesticide applications (74 percent of total pounds of active ingredient) by California grape growers and a significant share (17 percent) of the total pesticide use in California agriculture. The pecuniary costs vary across industry segments, depending on various factors such as the location of production and the end-use for the grapes, but these costs typically represent a very substantial share of the total costs of production—in the range of 37 percent of the gross value of production in places where PM pressure is significant. Much of the total volume of fungicides is sulfur, which is relatively environmentally benign, but even so in the production of table grapes and raisins, in particular, PM-management may account for well more than 90 percent of the total environmental burden from pesticide applications.

2. Powdery Mildew in Grapes

Grape powdery mildew can survive the winter in California in buds or as spore structures (chasmotheica). Once weather conditions are favorable (warm, moist winter days or during early spring), the release of ascospores begins the reproduction cycle, which continues throughout the season.[1] Initial infection appears as white, powdery spots on leaves, shoots, flowers, or fruit. These spots are the mycelium (fungal tissue) spores, which are the fungi's primary means of dispersal. If untreated, the mycelium can spread over large areas of the leaves and stems and cause reduced yields and lower quality fruit (Davis, et al., 2008).

Grape growers start spraying early in the spring and continue either at preset intervals or using a disease risk-assessment tool such as the Powdery Mildew Index (PMI). Fungicides commonly used for PM treatment can be classified into the categories shown in in Table 1.

[Table 1: *Pesticides Used for Powdery Mildew Control*]

The three most commonly used groups of pesticides are strobilurins, sterol inhibitors, and sulfur. Other types of pesticides such as biological, systemic acquired resistance products, or cell-signaling inhibitors are typically used when disease pressure

[1] Ascospores are reproductive spores specific to fungi such as powdery mildew.

is low to moderate. Contact materials, such as stylet oils, are mainly used for eradication, but can also be used for outbreak prevention and may be used as an alternative to sulfur in areas where buyers discourage the use of sulfur, primarily among wine grape growers.

Powdery mildew populations have shown an ability to develop resistance to fungicides with a single mode of action, such as sterol inhibitors and strobilurins. As a result, growers are recommended to alternate between fungicides from different groups and limit the number of applications of fungicides from a single group of synthetic chemicals per season. A common spraying schedule is to alternate sterol inhibitors, strobilurins and other synthetics with sulfur. Organic growers use only organically certified products that include sulfur, biologicals, and contact chemicals such as stylet oil, neem oil, and potassium bicarbonate and fungicidal soaps (Bentley, et al., 2008).[2]

The cost of PM management to a grape grower includes the cost of the pesticides used, the application costs and any losses from reduced yield and quality. In addition to these pecuniary costs, three categories of non-pecuniary costs are associated with management of crop pests and diseases: human and worker safety, environmental pollution, and the general inconvenience from having to devote time and resources to ensure the adequacy of pest and disease control (Marra and Piggott, 2006). We first take a closer look at the pecuniary costs incurred by growers: specifically, the value of materials applied and the costs of application.

[2] Neem oil is a vegetable oil obtained from the seeds and fruit of the neem tree (*Azadirachta Indica*). It is widely used in organic farming as an insect repellent and for control of fungal diseases such as powdery mildew. Stylet oil is paraffinic oil used for treatment and prevention of powdery mildew and as an insecticide, primarily for mite control. JMS Stylet Oil is the most popular of the stylet oils for use on grapes and is certified for organic farming.

3. Fungicides used for PM Management and their Application Schedule

a) Categories of pesticides

The choice of chemical and application schedule depend to some extent on the location of the vineyard, category of grapes (i.e., wine, table, or raisin) and varieties grown. Location of the vineyard can affect the pesticide application schedule because the timing of the growing season and disease pressure vary among different regions throughout the state (Bettiga, et al., 2013).

b) Grape production regions

California is made up of six major grape growing regions: the North Coast, Central Coast, South Coast, Northern San Joaquin Valley, Southern San Joaquin Valley, and Coachella Valley. Each region has a slightly different growing season for grapes because of differences in climate (Bettiga, et al., 2013).Therefore the timing of the critical disease control season also varies. Grape growing regions can further be classified according to PM disease pressure. Powdery mildew thrives in moderate climates, so at any given time during the growing season, coastal regions and the foothills typically have higher disease pressure than the Central Valley, where temperatures are higher.

Differences in varietal susceptibility and category of grapes create additional differences in PM management programs. Grape varieties also vary in their sensitivity to PM at different points in the season. White grape varieties are more susceptible than red grape varieties, with chardonnay being highly susceptible (W. Douglas Gubler, 2013, personal communication). In some cases fruit quality may also be affected by the amount or timing of a pesticide application (for example, some grapes may be damaged by sulfur or copper). The end-use category of grapes also matters: at 8–12° Brix PM is no longer able to infect the fruit, but can still affect stems and leaves, a quality factor only for table grapes.[3] Therefore, according to the University of California Integrated Pest Management (UC IPM) guidelines, PM management for wine and raisin grapes may be discontinued once the fruit reaches 12° Brix, but should be continued until harvest for table grapes (Bentley, et al., 2008). While many growers still continue spraying wine and raisin grapes up until harvest, the spraying schedule may be more conservative after the grapes reach 12° Brix. Table 2 includes the classification of grape varieties into three groups of susceptibility to PM for each category of production: table, wine or raisin grapes.

[Table 2: *Grape Varietal Susceptibility to Powdery Mildew*]

c) Sample Spraying Programs

Growers who follow a calendar schedule will spray at predetermined intervals as recommended for each group of pesticides. Sample recommended treatment programs for growers in areas with high and moderate disease pressure are presented in Table 3.

[Table 3: *Examples of powdery mildew spraying programs*]

d) PM Forecasting Tools

Growers may adjust the spraying schedule if they feel weather is particularly favorable for PM. Additionally, growers can use forecasting tools to guide their timing of pesticide sprays. The Gubler-Thomas Powdery Mildew Index (PMI) is the leading tool for forecasting PM; it is available to growers either bundled with weather monitoring software, or for free from public sources such as the UC IPM website or pesticide suppliers. The index provides information about disease pressure and recommendations for adjusting the spraying intervals for various groups of pesticides. In field trials,

[3] The Brix scale is used to measure the sugar content of grapes and wine. Each degree Brix is equivalent to 1 gram of sugar per 100 grams of grape juice.

growers using the PMI to guide the timing of their treatment saved 2–4 sprays per year, a significant reduction both in pesticide application costs and the environmental burden from PM control (Thomas, et al., 1994, Weber, et al., 1996).

4. Statewide Pesticide Application Data

We can estimate the quantities of pesticides applied and the approximate costs of PM management to grape growers in California using the Pesticide Use Reports (PUR) published by the California Department of Pesticide Regulation. Pesticides used for PM control are used almost exclusively for that reason. Several other diseases are treated with fungicides, but the choice of product, timing and amount of application allows us to identify PM treatments with a high degree of accuracy. Our analysis includes pesticide totals in pounds of material and active ingredient, as well as estimates of the costs of both the product used and its application. Tables 4 and 5 describe the amounts of pesticides applied by chemical category in pounds of active ingredient. The calculations include only pesticides applied during the "preferred disease management seasons" for each growing region as described in the 2013 University of California Grape Pest Management Handbook (Bettiga, et al., 2013) but these totals account for 89 percent of total fungicide applications. We include only applications made during preferred PM management seasons in order to exclude fungicide applications made for reasons other than PM management, but in doing so we also will have excluded some applications made for PM control.

The quantity of pesticides applied gives some indication of the magnitude of potential savings both in vineyard management costs to the grower and in environmental costs from pesticide applications if the danger of PM infections were significantly reduced by the introduction of resistant grape varieties. Table 4 includes the top ten counties by total pounds of pesticides applied in 2011, which are also the top grape producing counties in California.

[Table 4: *Top Ten Counties by Pounds of Powdery Mildew Pesticides Applied, 2011*]

Pesticide use for PM management varies substantially by geographic location and according to the value of the crop. Geography and grape crop value in California are highly correlated, so it is feasible to analyze the two together. We begin by analyzing the pesticide use trends at the county level, making use of PURs.

We gathered data on county grape acreage, average yield per acre, and harvest value from the annual county crop reports available from the corresponding Agricultural Commissioners' offices. We used the information from these reports to group grape-producing counties into three categories: high-priced grape counties include counties with average grape prices above $1200 per ton in 2011; low-priced grape counties include counties with average grape prices $700 per ton and below in 2011, and medium-priced grape counties include counties not in the previous two groups. The prices used to form these categories are weighted averages for all three categories of grapes: wine, raisin, and table grapes based on reported acreage, production and price per ton for each category, as provided in the annual county crop reports. Production and price per ton for dried raisin grapes were calculated on a fresh equivalent basis.

[Table 5: *Grape Value per Ton, by County, 2011*]

We then used the PUR data to rank the counties according to the amount of pesticides used per acre harvested as well as per ton of grapes produced. The results are presented in Figures 2a and 2b. Figure 2b shoes the amount of pesticides applied per acre. Counties with lower-value grapes are by far the heaviest per acre users of sulfur, while counties with the highest-value grapes lead in the use of biologicals.[4] Sulfur is losing popularity in counties that predominantly grow wine grapes, especially high-value wine grapes. Contact materials such as JMS Stylet Oil and Kaligreen, and biologicals can serve as alternatives for sulfur in a PM spraying program, and we can see that the heaviest users of these types of products are indeed counties with high- and medium-value grapes. Synthetic fungicides such as sterol inhibitors and strobilurins are designed for rotation with other chemical groups to avoid resistance buildup. Growers generally alternate with sulfur or contact materials. Sulfur is by far the cheapest to purchase and apply (in terms of material and application costs per acre), and synthetics, biologicals and contact materials are significantly more expensive.

Figure 2b shows the amount of pesticides applied per ton of output. By this measure, counties with high-value grapes use the most chemicals of any category because the yields per acre are much lower compared to lower value grapes (3.5 to 4.5 tons per acre in North Coast counties versus 12 or more tons/acre in Central Valley counties).

[Figures 2a-b: *Annual Pounds of Pesticides Used per Acre and Per Ton of Output, by Chemical Category, 2011*]

The variation in pesticide choices means that the benefits from adopting varietals resistant to PM will also vary geographically, as well as by type of grower. In particular, counties producing high-priced grapes are in the coastal valleys—mainly Napa and

[4] Biological fungicides are based on microorganisms such as fungi, bacteria or viruses. Biologicals used for PM control include Sonata and Serenade, both of which are based on bacteria (*Bacillus pumilis* and *Bacillus subtilis* respectively) and are approved for organic use.

Sonoma—and produce premium winegrapes. The 2011 average prices per ton for these counties were $3,508 and $1,176 per ton, respectively. Counties producing medium-priced grapes, among which county average prices ranged from $614 to $1,150 per ton in 2011, include some counties producing mid-priced winegrapes (primarily Monterey and San Luis Obispo counties on the Central Coast) and some Central Valley counties producing table grapes (in particular Kern and Tulare counties). Counties producing low-priced grapes, among which county average prices ranged from $390 to $600 per ton in 2011, produce low-priced winegrapes, raisin grapes and table grapes, predominantly in the southern San Joaquin Valley—in particular, Fresno, Madera, and San Joaquin Counties.

5. Pecuniary Costs of Powdery Mildew Management

In this section we focus on the pecuniary costs of PM management such as the dollar value of pesticides applied and the costs of application. University of California (UC) Davis Cost and Return studies indicate that PM management costs—including materials, labor, and costs of running tractors or other equipment involved in the application process—average about 4–6% of revenue for grape growers. Applying these percentages to the crop values reported at the county level, we derive rough estimates of costs at the level of the county. These estimates are presented in Table 6.

[Table 6: *Estimates of County Level Powdery Mildew Management Costs, 2011*]

Several hundred products are registered with the State of California for use on PM and we were not able to collect specific pricing information for all of the products. Consequently, we can estimate only an approximate monetary value of all products applied in a particular year. We grouped the products into categories according to their content of active ingredients, and collected prices for the most-used products in each category. We then calculated an average price per pound of chemical for each category, and used this price to calculate the dollar value of products applied. The results are presented in Table 7.

[*Table 7: Total Dollar Value of Chemical Products Applied, 2011*]

Total expenditure on PM pesticide products in California in 2011 was approximately $70 million. Over fifty percent was spent on synthetic fungicides such as sterol inhibitors and strobilurins. Sulfur accounts for about 25 percent of total expenditure, but over 90 percent of the total pounds of pesticide products applied. The estimated costs in Table 6 include both product and application costs, which range from $180 to $271 million. Based on the total value of pesticide materials alone, the product costs are around $70 million, which leaves the application costs at between $110 to $201 million. We take a closer look at the application costs per acre to arrive at a more precise estimate.

Application Costs

Powdery mildew pesticides can be applied either as dry dust (sulfur dust) or liquid spray (wettable sulfur and all other fungicides). The applications are made with a tractor and appropriate spraying equipment: a duster for dry applications or a large capacity vineyard sprayer (100 gallons and more) for the other fungicides.

We use information from the UC Davis Cost and Return Studies for grape operations in the North Coast, San Joaquin Valley and Sacramento Valley to estimate the average per acre treatment times and the implied costs of labor and equipment. The details of the estimation procedure are described in the Appendix.[5]

Tables 8 and 9 summarize the application costs per acre from the most recent Cost and Return Studies for the North Coast, San Joaquin Valley and the Sacramento Valley. Application costs range between $12 per acre and $67 per acre for North Coast counties and between $9.30 per acre and $23 per acre for the San Joaquin and Sacramento Valleys. Dusting sulfur is the cheapest to apply, with costs ranging from $9 per acre to $16 per acre. Wettable sulfur has the same application costs as other sprayable fungicides, ranging from about $10 per acre to $46 per acre. The differences in costs result from higher prices for labor and equipment for North Coast counties and also higher operation times.[6] Additionally, Napa County wage rates include a payroll overhead of 45%, which is significantly larger than overhead for other counties, which have payroll overhead of 33 or 34%).

[Table 8: *Per Acre Application Costs, North Coast*]

[Table 9: *Per Acre Application Costs, San Joaquin Valley and Sacramento Valley*]

The type of tractor used to operate the sprayers/dusters affects both application times and total cost. Tractors with less power are cheaper to operate per hour, but they also take longer to cover a vineyard acre. Powerful tractors are more expensive to purchase, but they shorten operation time considerably, especially on flat valley terrain.

[5]Assumptions about the types of labor and machinery used for fungicide applications, as well allowances for setup and removal of equipment and payroll overhead are based on the UCCE Cost and Return Studies.

[6] Higher operation times may be because of terrain or applicators taking greater care with a more-highly valued crop.

As a result, liquid spray operation times vary between about 1.0 hours per acre for the North Coast to around 0.5 hours per acre for the Central Valley.

We interviewed UC Extension specialists and industry experts to develop similar Cost and Return budgets for a selection of growers typical to the Central Coast and San Joaquin Valley regions and updated the application costs to reflect current prices and preferred programs for treating PM. Table 10 provides the best estimates of the current labor and machinery costs per acre based on the sample budgets (for additional details, see Fuller et al., 2014).

[Table 10: *Costs per Acre to Treat Powdery Mildew: Sample Budgets*, *2013*]

Extending estimates to other counties

Application times and prices paid for labor and equipment vary significantly among grape growing regions. Analysis of application costs for other counties not included in the Cost and Return Studies requires a set of assumptions about appropriate work rates (hours per acre) for each type of application. We base our estimates of the appropriate work rates and equipment rates for each major grape growing region on the most recent Cost and Return Studies as well as the set of budgets we developed for regionally specific wine, raisin, and table grape growers (Fuller et al., 2014).

San Joaquin and Sacramento Valleys

We assume that a 60HP tractor is used for both dust and liquid spray applications. Drawing on estimates from the available cost studies, the assumed work rate is 0.3 hours per acre for dry dust and 0.5 hours per acre for liquid spray. Tractor use time includes an additional 10 percent allowance and equipment operator time includes an additional 20 percent. We assume that these rates are applicable to all grape growing counties in the San Joaquin and Sacramento Valleys.

North Coast and Central Coast

We assume that a 60HP tractor is used for both dust and liquid spray applications and the work rate is between 0.7 and 1.0 hours per acre for liquid sprays and 0.5 hours per acre for dry dust, plus the allowances for tractor use time and operator time as above. We combine information from Tables 8, 9 and 10, and estimate the current average labor and equipment costs for Coastal and Valley growing regions. Results are in Table 11.

[*Table 11: Costs per Acre to Treat Powdery Mildew: by Region, 2013*]

Mixed Sprays

Liquid sprays are often made with more than one pesticide. Two types of mixed sprays are used: mixed sprays with more than one fungicide (PM control) and mixed sprays that include insecticides or other types of pesticides in addition to the fungicides used for PM control. Mixed sprays of the first type are entirely for PM management, but mixed sprays of the second type are not. In the case of mixed insecticide and fungicide sprays, the question is whether an application would have been made absent a PM threat were absent. It is reasonable to assume that the sprays would have still been made for insect control, so we do not attribute the spraying costs to PM control. In 2011, 13% of all chemical applications related to PM included mixed sprays. Of that 13%, only 2% included insecticides or other chemicals not related to PM. The other 11% of mixed sprays consisted of two or more fungicides used for PM treatment.

Using assumed average application rates for Coastal and Valley regions, the total application costs for chemicals used for PM treatment are summarized in Table 12. The total estimated statewide application cost is about $118 million. The total pecuniary costs of PM management combined from Tables 7 and 12 are $189 million in 2011, which is approximately 4% of revenue as calculated in Table 6.

[Table 12: *Statewide Application Costs for Powdery Mildew Treatment, 2011*]

6. Non-pecuniary Costs of Powdery Mildew Management

The toxicity of each product is evaluated both with respect to both humans and the environment. Common health hazards include skin or eye irritation and inhalation potential. Environmental hazards include ground water contamination: toxicity to fish and aquatic organisms, domestic animals and livestock, and drinking water contamination. According to the United States Environmental Protection Agency (EPA) Pesticide Product Label System (PPLS), most products used for PM management are considered to be of low toxicity, with the exception of some synthetic products in the sterol inhibitor chemical category. The toxicity ratings of the most popular PM products, according to their labels, are summarized in Table 13.[7]

[*Table 13: Most Frequently Used Products for Treating Powdery Mildew, 2011*]

b) Description of EIQ and PURE

The impact of pesticide use on human health and the environment use is a topic of much interest, and multiple measures of pesticide use risk have been developed in recent

[7] The PPLS provides a collection of pesticide product labels with three potential hazard levels: *caution, warning, danger*. The hazard levels are based on the exposure to undiluted chemicals, so they are especially relevant for handling during mixing and preparation for application. Labels are available on the EPA website: http://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1.

years. Pesticide risk indicators typically use a ranking or an index based on toxicological and physiochemical properties of the pesticides, as well as site-specific environmental conditions (Bockstaller, et al., 2009). Many pesticide risk indicators are developed with a specific purpose or user in mind and it is not always possible to apply them outside the intended scope (Labite, et al., 2011). To quantify the environmental effect of PM control on human health and the environment, we use two pesticide risk measures: the Environmental Impact Quotient (EIQ) and the Pesticide Use Risk Evaluation (PURE) systems. We use the EIQ to calculate the environmental impact of PM control programs from our sample farmer budgets and compare the environmental impact profiles of PM management in several regions. The PURE system is specific to California and it calculates environmental risk scores for actual pesticide applications from the PUR database. We use this measure to evaluate the environmental impact of PM control for actual pesticide applications by grape growers in California in 2011.

c) EIQ

The EIQ is an aggregate measure of environmental impact, which combines the pesticide hazard posed to farm workers (applicator and harvester exposure), consumers (consumer exposure and ground water contamination), and the environment (toxicity to aquatic and terrestrial organisms and bees) (Kovach, et al., 2012).

Data on toxicity of individual chemicals is collected from sources such as the Extension Toxicology Network (Cornell University Pesticide Managment Education Program/ExToxNet), CHEM-NEWS (Cornell Cooperative Extension Network), SELCTV database (Oregon State), and other studies by the USDA Economic Research

Service and the Environmental Protection Agency, as well as material safety data sheets from chemical manufacturers. Table 14 describes the elements used to construct the EIQ.

[Table 14: *Elements of the Environmental Impact Quotient*]

The Environmental Impact Quotient is a simple average of three EIQ components: farm worker EIQ, consumer EIQ and ecological EIQ. Each component combines the relevant factors of chemical toxicity described in Table 14. The basic principle behind EIQ is that the impact of the chemical is equal to a measure of toxicity times the potential time of exposure. Factors within each component carry different weights: factors with the highest impact are multiplied by five, factors with medium impact are multiplied by three and factors with low impact are multiplied by one. Therefore, while the total EIQ is a simple average of three components, the elements within each component are weighted based on toxicity and exposure potential.

The farm worker component is a sum of worker exposure $(DT \times 5)$ and picker exposure $(DT \times P)$, multiplied by chronic toxicity C: $C[(DT \times 5)+(DT \times P)]$. The consumer component is the sum of exposure potential (which considers chemical plant and soil half-life, systemicity and chronic toxicity) and groundwater leaching potential: $C\left(\frac{S+P}{2}\right)SY + L$. Finally, the ecological component is a sum of the effects each chemical has on aquatic and terrestrial organisms such as fish, birds, and beneficial arthropods: $F \times R + 3D\left(\frac{S+P}{2}\right) + 3(Z \times P) + 5(B \times P)$.

The total EIQ for each chemical is an average of all three components:

(1) $$EIQ = \left\{ \overbrace{C\left[(DT \times 5) + (DT \times P)\right]}^{\text{Worker Component}} + \ldots \overbrace{\left[C\left(\frac{S+P}{2}\right)SY + L\right]}^{\text{Consumer Component}} + \ldots \overbrace{\left[(F \times R) + 3D\left(\frac{S+P}{2}\right) + 3Z \times P + 5B \times P\right]}^{\text{Ecological Component}} \right\} / 3$$

Since the index is calculated as an average, two pesticides may have similar EIQ values, but one could be a lot more toxic to farm workers and the other one to consumers or the environment. In some cases it may make sense to consider the three EIQ components individually rather than combining them into a single index. EIQ values for all agricultural pesticides range from 6 to about 200. Table 15 summarizes the EIQ values for the chemicals used for PM control.

[Table 15: *Environmental Impact Quotient for Powdery Mildew Chemicals*]

Overall, the toxicity of fungicides used for PM control is relatively low. Most have an EIQ of 40 or less, with the exception of Lime Sulfur. Lime Sulfur has the highest EIQ (67), but it is not widely used. Even though the EIQ values for PM pesticides are relatively low, the application volume is high, and consequently the environmental impact of PM treatments is significant relative to the total environmental impact of grape production.

We calculate the total EIQ of PM management for a selection of representative growers. To do that we consider per acre dosage and the number of applications for each pesticide, and use the EIQ Field Use Rating equation (Equation 2) to determine the total environmental impact of PM management. We include all pesticides applied by growers during a standard growing season, not just the PM pesticides. Doing so allows us to compare the EIQs for traditional grape varieties with PM-resistant varieties.

(2) *EIQ Field Use Rating=EIQ × % active ingredient × Rate of application (lbs per acre)*

We use sample budgets for representative raisin, table and wine grape growers in the San Joaquin Valley and the Central Coast, which describe the standard pesticide application programs, including PM treatment programs, for each type of grower. We collected information about active ingredient content and recommended per-acre dosage rates for each product from the California Department of Pesticide Regulations and the UC IPM website, and calculated the EIQ for each representative grower. Table 16 provides a summary of the results.

[Table 16: *Per Acre Environmental Impact of Powdery Mildew Control*]

Powdery mildew management by table grape growers has by far the largest per-acre environmental impact compared with other types of grape growers. Table grape growers have the longest disease pressure season, and are concerned about the appearance of the entire cluster, so they have to manage PM on stems as well as berries. As a result, table grape growers apply more PM treatments than raisin or wine grape growers. In addition, table grape growers use more sulfur, which raises the EIQ quite a bit because of large volumes applied per acre. The total EIQ of wine grape growers is almost negligible because the synthetic pesticides they use are applied infrequently and at very low application rates per acre. In addition to fungicides required for PM control, Table 16 also includes EIQ calculations for other chemicals applied by grape growers throughout the growing season, such as insecticides, herbicides and fungicides for non-

PM issues. Even though the per-pound EIQ score for sulfur is relatively low, EIQ is calculated per pound of chemical, and sulfur constitutes the majority of chemical weight applied by raisin and table grape growers. PM control accounts for over ninety percent of the total EIQ per acre for table and raisin growers (almost one hundred percent for DOV raisin grapes), and only eight or so percent per acre for Central Coast Chardonnay growers, who do not use any sulfur in our scenario.[8]

Sulfur is by far the biggest contributor to the EIQ for grape growers because of the dosage per acre (10 pounds or more) and the frequency of application. However a review of literature on the environmental and health impacts of sulfur suggests that sulfur is widely considered to be environmentally neutral (Cornell University Pesticide Management Education Program/ExToxNet, 1995) and the main concern with sulfur applications in agriculture are human health effects. Specifically, sulfur has been linked to respiratory illness (McGourty, 2008), although the exact mechanism and type of exposure that causes illness is unknown (Lee, et al., 2006). Because of these findings we treat the extremely high EIQ from sulfur use with caution. We feel that it is appropriate to discount the ecological component of the sulfur EIQ and to consider the human health component in more depth. For example, the exposure potential to the workers is highest during sulfur applications because of the large per acre volume and frequent applications. In this case it make sense to think of the risk as an additive risk because there is potential for exposure during each application. In contrast, some of the other synthetic chemicals are applied at longer intervals (up to 21 days) and in very diluted form (application rate

[8] Over ninety percent may seem unreasonably high, but it is important to note that powdery mildew fungicide applications dominate any other pesticide applications by grape growers. In fact, for many grape growers, PM fungicides are the only restricted materials they report in the PURs and in their case PM accounts for 100% of their environmental imprint from pesticide applications.

for synthetics is less than one pound per acre, versus 10 or more pounds per acre for sulfur). The high total worker EIQ for sulfur demonstrates the total risk over the course of the growing season. Even though appropriate equipment and safety precautions can reduce or eliminate worker exposure, the implementation and management of such equipment and precautions is a cost to the grower. The costs of enforcing the safety rules (e.g., worker training, supervision and any necessary equipment) can be classified as a pecuniary cost (although it is not counted in our budgets), while the general inconvenience of having to implement these rules and the existing potential for unknown negative health effects is a non-pecuniary cost.

Overall, the EIQ values suggest that the environmental benefits from PM-resistant varieties are disproportionately distributed among the three different types of growers. Varietals resistant to PM would almost eliminate the current environmental impact for table and raisin grape growers, but would have very little effect on wine grape growers. Additionally, we can conclude that the environmental benefits from eliminating PM control would mostly accrue to growers, farm workers and the natural environment. According to the EIQ, the effect on the consumers is relatively minor.

d) PURE

An alternative method for evaluating the environmental impact of PM control is Pesticide Use Risk Scores. The Pesticide Use Risk Evaluation system (PURE) system information on pesticide properties (toxicity) with environmental conditions to evaluate the risk from pesticide use on a specific field with respect to five dimensions of the environment: groundwater, surface water, soil, air and bees (Zhan and Zhang, 2012). The model was developed as a decision support system for growers to help with evaluating the potential pesticide-use risk for a specific field. PURE is linked directly to the Pesticide Use Reports and provides a risk score for each pesticide application as well as a total annual risk score for a specific field. The environmental conditions incorporated include soil properties, meteorological conditions, groundwater depth, ground slope and distance to surface water, as well as soil properties specific to the area of the site. Meteorological conditions include precipitation and temperature (Zhan and Zhang, 2012).

The PURE risk values are aggregated additively within each environmental component using the following formula (Zhan and Zhang, 2012):

(3) $$RV_i = \sum_j RV_{ij}$$

where *i* represents the environmental compartment (air, groundwater, soil, surface water or bees) and *j* is the active ingredient (*AI*) of the product applied. The risk levels for each *AI* are calculated as a ratio of the predicted environmental concentration (*PEC*) to the toxicity value (Cornell University Pesticide Managment Education Program/ExToxNet):

(4) $$RV = \frac{PEC}{Tox}$$

The calculated risk values are then transformed to risk scores (*R*) and scaled to fall between 0 and 100:

(5) $$R_i = 25(\log RV_i + 2)$$

Finally, an integrated risk (R_T) score is calculated as the maximum of all the separate risk scores for each environmental component. The integrated risk score therefore reflects the level of environmental risk for the most vulnerable environmental component for a particular pesticide application:

(6) $$R_T = \max(R_i)$$

We obtained a dataset of PURE values for all pesticide applications made on grapes during 1996-2011. We use the unscaled risk values to evaluate the contribution of each PM pesticide category to the share of environmental effects from PM management. Figure 3a details the results.

[Figure 3: Share of Each Chemical Category in Annual PURE Scores from PM Management, 2011]

Strobilurins, sterol inhibitors and sulfur account for most of the environmental risk from PM management. Strobilurins and sterol inhibitors (both synthetic pesticides) are responsible for the largest share of soil, ground water and surface water risk. Sulfur applications have the largest effect on bees and air. The PURE scores are specific to California and so may not be representative of the environmental effects from PM management in other states. However, California accounts for the vast majority of U.S. grape production.

We can use the EIQ or PURE scores to evaluate the environmental impact of PM pesticides relative to other chemicals, and for some general comparison of per-acre applications among growers in different regions and growing grapes for different market segments or end-uses. While the fungicides used for PM treatments are relatively non-toxic compared to some of the other classes of pesticides, large volumes and frequency of application do matter, especially when it comes to safety measures to prevent worker exposure. Although the exact effect on human health is unknown, the implementation of safety measures and the potential for human health effects factor into both pecuniary and non-pecuniary costs for the grower.

Conclusion

Powdery mildew in grapes is responsible for the bulk of pecuniary disease management costs for the entire industry. In addition, the volume of pesticides applied creates an environmental burden that contributes to non-pecuniary costs from PM. We estimate pecuniary PM management costs in California of $189 million in 2011. We do not place a monetary value on environmental costs, but we conclude that, depending on the location, and the type of grapes being grown, PM management can account for over 90 percent of the environmental burden from pesticide applications on grapes. We also show that just a few of the chemicals used on grapes account for the majority of the environmental impact from PM management, and reducing the use of these chemicals would have a beneficial effect on all environmental categories, especially soil, air and bees.

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Appendix A: Details of Application Costs for PM Products

Operation time (hours per acre) depends on the type of application and equipment used. Tractors with more power typically take less time to cover an acre, and dry dust takes less time to apply than liquid spray. Application costs per acre depend on the time it takes to spray or dust an acre using appropriate equipment, plus additional labor to set up and disassemble the equipment.

Labor

Agricultural operations involve two types of labor: non-machine labor and equipment operator labor. Powdery mildew management requires equipment operator labor, which is slightly more expensive than non-machine labor. Hourly wages include an additional 34–45% for payroll overhead, which consists of the employer's share of payroll taxes (state and federal), workers' compensation insurance and other benefits (University of California Cooperative Extension, 2000–2011). Labor time for operations involving machinery is assumed to be 20% higher than the per acre operation time to allow for time spent in setting up, maintenance, moving, field repairs etc. Total labor costs therefore include per acre operation costs plus a 20% time allowance for equipment operations.

Machinery

Tractors used for pesticide application range from 30 to 90 Horsepower. In addition to the tractor, pesticides are applied using either dusters (sulfur dust) or sprayers (micronized wettable sulfur and all other pesticides). Dusters are used only for dusting sulfur, while sprayers apply liquid mixes and can be used for other pesticide applications (University of California Cooperative Extension, 2000–2011). Total hourly operating costs include fuel, lube and repair costs per hour of operation. Tractor time is assumed to be 10% higher than operation time to allow for setup, travel and down time. Total equipment costs therefore include operation costs per acre (costs per hour divided by the hours per acre for the operation), plus the stated time allowance.

Tables and Figures

Table 1: Chemicals Used for Powdery Mildew Control

Chemical Group (Active Ingredient)	Total Pounds Applied (2011)*	Chemical Name	Disease Pressure
Sulfur Compounds	32,500,000	Sulfur Lime-sulfur	All
Contact Materials	2,356,085	Potassium bicarbonate Petroleum distillates Neem oil Cinnamaldehyde	All, eradicant
Copper**	404,669	Copper hydroxide Copper sulfate	Low
Sterol Inhibitors	134,684	Tebuconazole Triflumizole Myclobutanil Fenarimol Triadimefon Difenoconazole	All
Strobilurins	121,701	Azoxystrobin Trifloxystrobin Kresoxim-methyl Pyraclostrobin Boscalid	All
Cell-Signaling Inhibitor	28,488	Quinoxyfen	Low-moderate
Biologicals	14,944	Bacillus Sumilus Bacillus Subtilis Reynoutra Sacalinensis Streptomyces Ludicus	All
Multichemical Formulations***	64,440	Fluopyram+Tebuconazole Difenoconazole+Cyprodinil	All
Benzophenone	37,266	Metrafenone	All
Systemic Acquired Resistance Products	20	Harpin protein L-glutamic acid	Low
Other	111,370	Mancozeb Captan, other related Benomyl	Low-moderate

*Weight of active ingredient only
** Copper is not a part of the official IPM program for PM management. However, some growers apply copper-sulfur mixes for PM control. We exclude copper from further calculations in order to remain consistent with the official IPM guidelines.
***Exclude chemicals accounted for in previous categories, such as Tebuconazole and Difenoconazole.
Source: Pesticide Use Reports 2011, Department of Pesticide Regulation, UC IPM

Table 2: Grape Varietal Susceptibility to Powdery Mildew

Susceptibility	Wine	Table	Raisin
High	Carignane	Christmas Rose	Fiesta
	Chardonnay	Chrimson seedless	Zante Currante (Black Corinth)
	Chenin blanc	Flame seedless	DOVine
	Muscat blanc (Muscat Canelli)	Marroo seedless	
	Roussane	Perlette	
		Redglobe	
		Ruby Seedless	
		Tokay	
Moderate	Barbera	Autumn Royal	Black Monukka
	Burger	Beauty Seedless	Thompson seedless
	Cabernet franc	Calmeria	Muscat of Alexandria
	Cabernet Sauvignon	Cardinal	Selma Pete
	Gamey Beaujolais	Emperor	
	Grenache	Fantasy seedless	
	Malbec	Italia	
	Melon	Princess	
	Mission	Ribier	
	Muscat Noir (Black Hamburg)		
	Nebbiolo		
	Pinot noir (Pinot family)		
	Ruby Cabernet		
	Saubignon blanc		
	Semillon		
	Syrah		
	Tempranillo (Valdepenas)		
	Viognier		
	Zinfandel		
Low	Alicante Bouschet	Queen	
	Dolcetto (Charbono)		
	Folle blanc		
	French Colombard		
	Gewurtzraminer		
	Malvasia Bianca		
	Merlot		
	Mourvedre		
	Palomino		
	Petite Sirah (Durif)		
	Riesling		
	Rubired		
	Sangiovese		
	Trousseau (Grey Riesling)		
	Ugni blanc (Tribbiano, St. Emillon)		
	Valdiguie (Napa Gamay)		

Source: University of California Agricultural and Natural Resource, UC Cooperative Extension, Fresno County. Available online at http://www.calagquest.com/PowderyMildewSusceptibilitybyGrapeVariety.pdf.

Table 3: Examples of Powdery Mildew Spraying Programs for High Disease Pressure Regions

Central Coast	San Joaquin Valley	
Winegrapes	**Raisin Grapes**	**Table Grapes**
Rally 2X	Sulfur 1X	Microthiol 2X
Quintec 1X	Sulfur 3X Alternate Rows	Dusting Sulfur 7X
Flint 1X	Rally+ Sulfur 1X	Rally+Microthiol 2X
Stylet Oil 3X	Flint + Sulfur 1X	Rally + Dusting Sulfur 1X

Source: UCCE Cost and Return Studies and consultation with experts.

Table 4: Top Ten Counties by Pounds of Powdery Mildew Pesticides Applied, 2011

	Benzophenone	Biologicals	Cell-Signaling Inhibitors	Contact	Multichemical Formulations	Sterol Inhibitors	Strobilurins	Sulfur	Other*	Total
					Pounds of Active Ingredient					
Fresno	2,715	746	**7,442**	104,425	7,059	**50,924**	**21,591**	**7,901,489**	28,479	8,124,871
San Joaquin	776	461	792	120,650	749	4,363	7,920	5,516,161	619	5,652,473
Madera	328	134	1,929	36,226	1,923	11,354	7,448	4,946,657	2,083	5,008,082
Kern	628	1,706	2,530	95,164	**14,103**	14,980	19,533	3,134,183	**101,728**	3,384,555
Tulare	418	918	1,294	41,406	10,028	10,075	9,475	2,012,894	38,363	2,124,871
Sacramento	487	22	748	72,219	59	1,642	3,643	2,114,368	564	2,193,753
Sonoma	4	5,378	2,321	202,053	7,054	7,389	11,846	1,785,045	5,459	2,026,549
Monterey	383	756	3,883	**778,744**	11,384	11,932	11,471	684,003	18,758	1,521,314
Yolo	**29,334**	11	397	144,159	18	1,405	2,458	1,147,762	1,693	1,327,237
Napa		**5,432**	1,410	164,334	5,619	5,938	7,557	927,216	3,369	1,120,875

* Systemic Acquired Resistance Products are included in the "other" category because of insignificant levels of application in 2011 (20lbs).

Source: Pesticide Use Reports 2011, Department of Pesticide Regulation, UC IPM guidelines for PM management on grapes

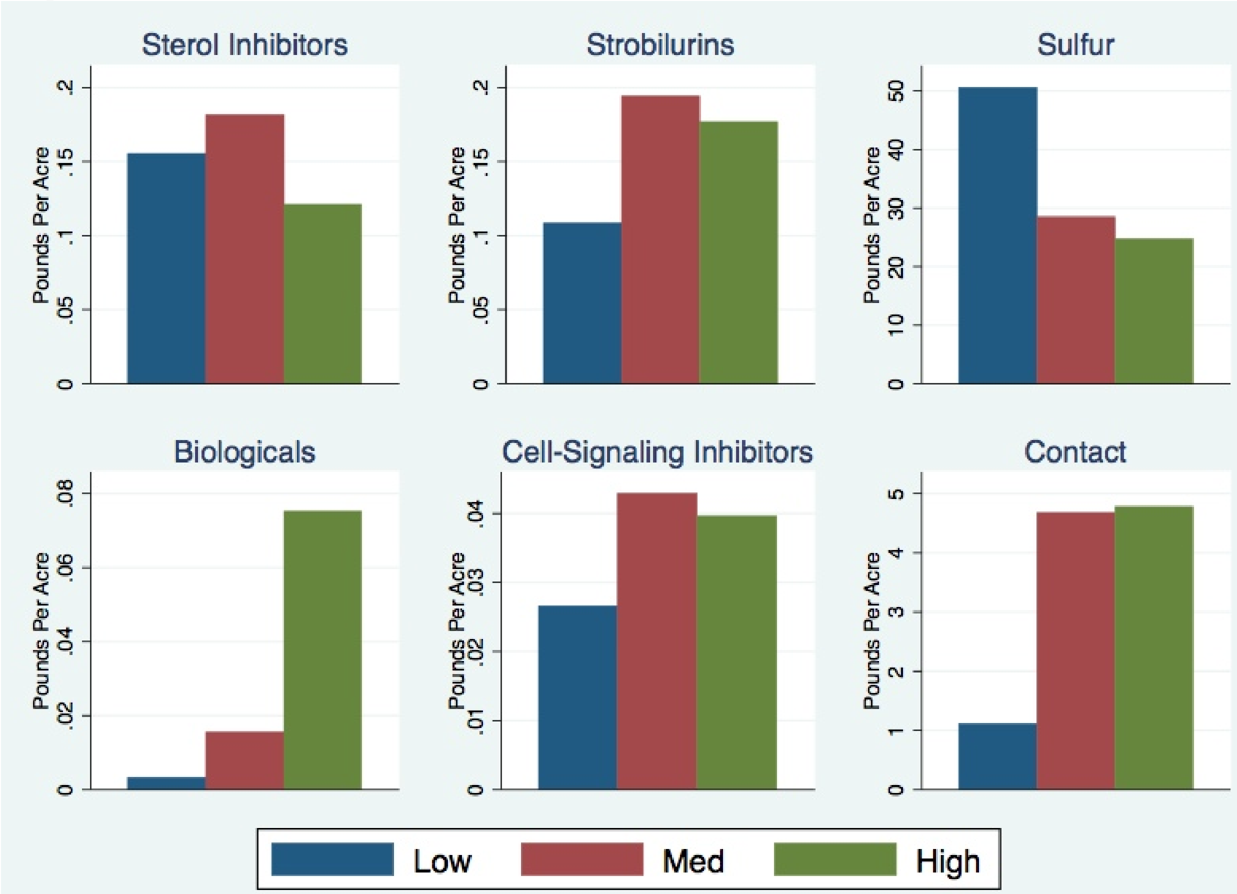
Table 5: Grape Production and Value per Ton by County, 2011

	Area				Production				Price			Crop Value	
	Wine	**Raisin**	**Table**	**Total**	**Wine**	**Raisin***	**Table**	**Total**	**Wine**	**Raisin***	**Table**	**Average**	**Total**
	Thousand Bearing Acres				*Thousand Tons*				*$ per ton*			*$ per ton*	*$ ‘000s*
High-priced grapes													
Napa	43.6			43.6	121.9			121.9	3,474			3,474	423,441
Riverside	2.8		7.7	10.5	6.4		292.0	58.7	1,051		2,263	2,132	125,225
Sonoma	58.1			58.1	166.6			166.6	2,083			2,083	347,080
Santa Clara	1.5			1.5	4.9			4.9	1,343			1,343	6,600
Alameda	2.6			2.6	9.2			9.2	1,297			1,297	11,916
El Dorado	2.0			2.0	4.3			4.3	1,295			1,295	5,137
Santa Barbara	20.5			20.5	60.1			60.1	1,281			1,281	76,958
Mendocino	16.7			16.7	57.4			57.4	1,237			1,237	71,595
Medium-priced grapes													
Lake	8.2			8.2	34.0			34.0	1,176			1,176	39,993
Amador	3.5			3.5	10.2			10.2	1,150			1,150	11,675
Monterey	43.0			43.0	124.0			124.0	1,137			1,137	140,976
San Luis Obispo	37.7			37.7	114.6			114.6	1,132			1,132	129,738
San Benito	3.7			3.7	13.7			13.7	1,024			1,024	14,057
Kern	21.0	19.1	39.4	79.5	292.0	122.2	391.0	805.2	372	439	1,395	879	707,583
Tulare	10.3	17.6	31.3	59.2	149.4	216.5	277.0	642.9	350	678	1,203	828	532,423
Solano	3.9			3.9	14.3			14.3	731			731	10,418,
Contra Costa	2.0			2.0	8.5			8.5	704			704	5,970
Low-priced grapes													
Colusa	2.4			2.4	17.4			17.4	616			616	10,710
Yolo	12.0			12.0	81.6			81.6	598			598	48,757
Glenn	1.1			1.1	6.8			6.8	553			553	3,741
San Joaquin	93.1			93.2	522.0			523.0	549			548	286,728
Sacramento	27.2			27.2	177.0			177.0	525			525	92,926
Stanislaus	11.0			11.0	111.6			111.6	506			506	56,441
Kings	3.5	1.8	1.0	6.3	53.8	25.1	11.8	90.7	309	406	1,490	490	44,436
Merced	11.6	0.5		12.2	116.8	5.5		122.2	430	328		425	51,973
Fresno	40.9	165.7	11.3	217.8	620.0	1714.5	128.5	2463.0	356	339	1,242	390	961,777
Madera	38.4	33.8	2.3	74.5	417.4	363.7	21.9	802.9	320	365	1,578	374	300,681

*Raisin production is calculated on a fresh equivalent basis using conversion rates or average yield per acre from county crop reports.

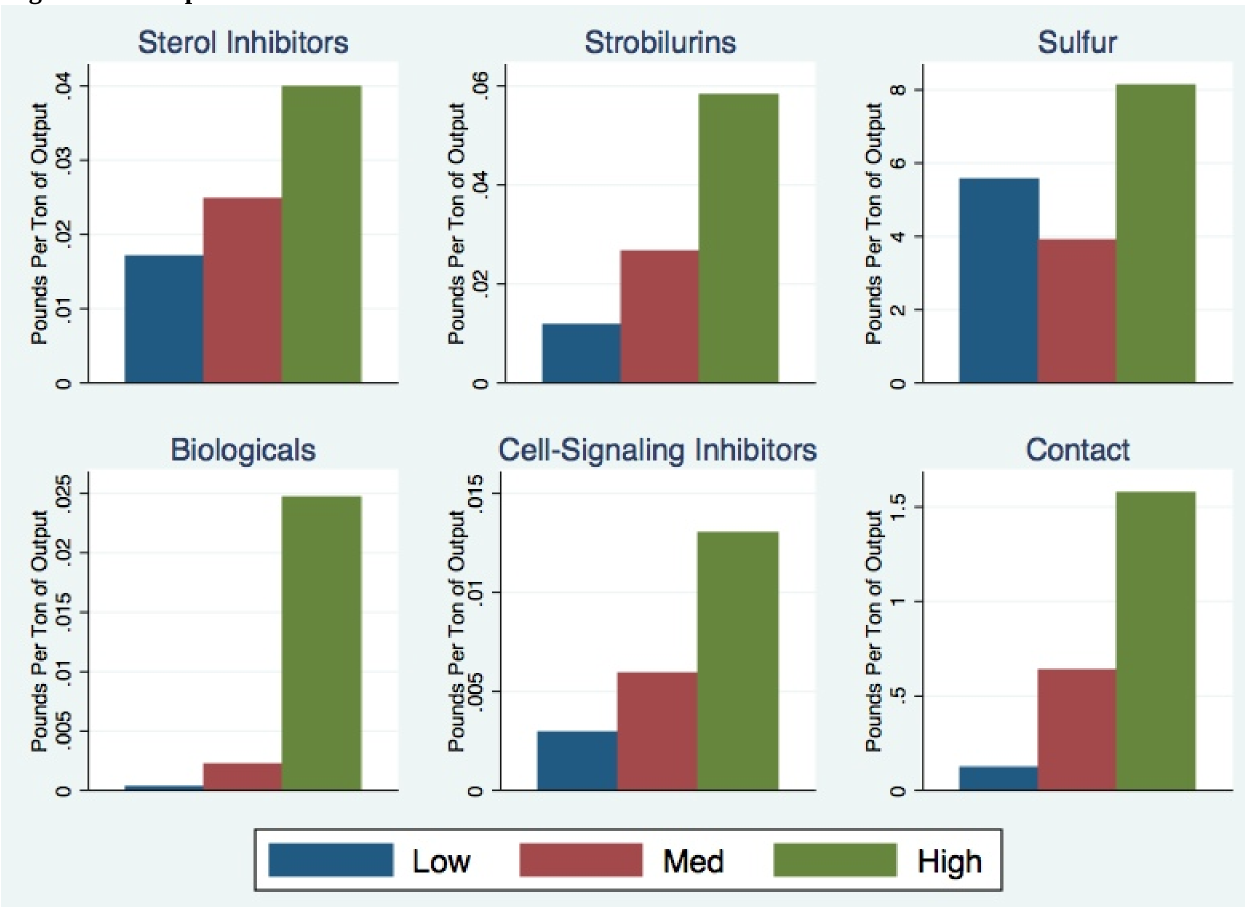
Source: County Crop Reports, 2011

Figure 2a: Annual Pounds of Chemicals Applied Per Acre for Counties with Low-, Medium-, and High-Value Grapes, 2011



Notes: **Annual pounds per acre for all counties included in each price category, weighted by harvested acreage.**

Figure 2b: Annual Pounds of Chemicals Applied Per Ton of Output for Counties with Low-, Medium- and High-Value Grapes



Notes: **Annual pounds per ton of output for all counties included in each price category, weighted by output.**

Table 6: Estimates of Powdery Mildew Management Costs at the County Level, 2011

	Average Price	Total Crop Value	4% of Revenue	5% of Revenue	6% of Revenue
	$ per ton		*Thousands of Dollars*		
High-priced grapes: top 30th percentile by price per ton					
Napa	3,508	423,442	16,938	21,172	25,407
Riverside	2,381	125,225	5,009	6,261	7,514
Sonoma	2,083	347,077	13,883	17,354	20,825
Santa Clara	1,343	6,601	264	330	396
Alameda	1,297	11,916	477	596	715
El Dorado	1,295	5,518	221	276	331
Santa Barbara	1,281	76,959	3,078	3,848	4,618
Mendocino	1,248	71,596	2,864	3,580	4,296
Lake	1,176	39,993	1,600	2,000	2,400
Medium-priced grapes: 31st69th percentiles by price per ton					
Amador	1,150	11,676	467	584	701
Monterey	1,137	140,976	5,639	7,049	8,459
San Luis Obispo	1,132	129,738	5,190	6,487	7,784
San Benito	1,024	14,057	562	703	843
Kern	879	707,583	28,303	35,379	42,455
Tulare	835	532,423	21,297	26,621	31,945
Solano	732	10,419	417	521	625
Contra Costa	704	5,972	239	299	358
Kings	614	44,436	1,777	2,222	2,666
Low-priced grapes: bottom 30th percentile by price per ton					
Yolo	598	48,757	1,950	2,438	2,925
Glenn	553	3,741	150	187	224
San Joaquin	548	286,728	11,469	14,336	17,204
Sacramento	525	92,926	3,717	4,646	5,576
Stanislaus	506	56,431	2,257	2,822	3,386
Madera	485	300,681	12,027	15,034	18,041
Merced	430	51,973	2,079	2,599	3,118
Fresno	390	961,777	38,471	48,089	57,707
Total			**180,345**	**225,431**	**270,517**

Source: Developed by the authors using data from County Crop Reports, 2011, UC Davis Cost and Return Studies.

Table 7: Total Dollar Value of Chemical Products Applied, 2011

Chemical Category*	Pounds Applied	Average Price	Total Dollar Cost	Percent of TC
	Thousand lbs	*$ per lb*	*$ `000's*	*%*
Sulfur	32,500	0.53	17,225	24.41
Sterol Inhibitors	135	116.77	15,727	22.29
Contact	2,356	5.40	12,723	18.03
Strobilurins	122	91.65	11,154	15.81
Multichemical Formulations	64	90.00	5,800	8.22
Benzophenone	37	131.25	4,891	6.93
Cell-Signaling Inhibitors	28	72.58	2,068	2.93
Other	111	7.21	803	1.14
Biologicals	15	10.97	164	0.23
Total	**35,369**		**70,554**	

*Systemic acquired resistance products omitted because of insignificant amount of application
Average price calculated as a weighted average for each category
Source: Developed by the authors based on PUR records, 2011, UC Davis Cost and Return Studies.

Table 8: Per Acre Application Costs, North Coast

A. Per Acre Costs for a Single Application	Napa 2012				Sonoma 2010				Lake 2008			
	Hours	Labor	Equipment	Total	Hours	Labor	Equipment	Total	Hours	Labor	Equipment	Total
			Dollars				*Dollars*				*Dollars*	
Dusting sulfur (dry dust)			not used		0.22	5.31	6.50	**11.81**			not used	
Wettabe sulfur (spray)	1	24.36	22.48	**46.84**	0.38	9.17	12.79	**21.96**	0.69	11.01	19.16	**30.17**
Other fungicides (spray)	1	24.36	22.48	**46.84**	1.15	27.74	38.71	**66.45**	0.69	11.01	19.16	**30.17**

B. Hourly rates for equipment and labor

	Napa 2012		Sonoma 2010		Lake 2008	
			Dollars			
Equipment Operators	20.30	includes 45% payroll overhead	20.10	includes 34% payroll overhead	13.30	includes 33% payroll overhead
Field Workers	17.70	includes 45% payroll overhead	16.08	includes 34% payroll overhead	10.64	includes 33% payroll overhead
Duster	n/a		10.20		n/a	
Sprayer	5.75		14.30		11.60 to 15.8	
Tractor - Spray	15.21	60HP	17.60	60HP	14.70 to 19.1	50HP
Tractor - Dust	15.21	60HP	17.60	60HP	14.70 to 19.1	50HP

C. Extra time allowances

	Napa 2012	Sonoma 2010	Lake 2008
Equipment operator labor	20%	20%	20%
Tractor time	10%	10%	10%

Sources: 2012 Winegrape Cost and Return Studies, North Coast, Napa, http://coststudies.ucdavis.edu/files/WinegrapeNC2012.pdf
2010 Winegrape Costs and Return Studies, North Coast, Sonoma http://coststudies.ucdavis.edu/files/grapewinesonoma2010.pdf
2008 Winegrape Cost and Return Studies, North Coast, Lake, White Varieties http://coststudies.ucdavis.edu/files/grapewinewhitenc2008.pdf
2008 Winegrape Cost and Return Studies, North Coast, Lake, Red Varieties http://coststudies.ucdavis.edu/files/grapewineredlake2008.pdf
2004 Winegrape Cost and Return Studies, North Coast, Sonoma, Chardonnay http://coststudies.ucdavis.edu/files/grapewinenc2004.pdf

Table 9: Per Acre Application Costs, San Joaquin Valley and Sacramento Valley

	San Joaquin Valley North 2012				San Joaquin Valley South 2008				Sacramento Valley 2013			
A. Per Acre Costs for a Single Application												
	Hours	Labor	Equipment	Total	Hours	Labor	Equipment	Total	Hours	Labor	Equipment	Total
			Dollars				*Dollars*				*Dollars*	
Dusting sulfur (dry dust)	0.29	5.60	3.71	**9.30**	0.3	5.27	4.42	**9.68**	0.36	6.65	9.52	**16.17**
Wettabe sulfur (spray)	0.36	6.95	10.05	**16.99**	0.5	8.78	10.20	**18.98**	0.39	7.21	15.93	**23.14**
Other fungicides (spray)	0.36	6.95	10.05	**16.99**	0.5	8.78	10.20	**18.98**	0.39	7.21	15.93	**23.14**

B. Hourly rates for equipment and labor						
			Dollars			
Equipment Operators	16.08	includes 34% payroll overhead	14.63	includes 33% payroll overhead	15.4	includes 34% payroll overhead
Field Workers	13.4	includes 34% payroll overhead	10.97	includes 33% payroll overhead	12.1	includes 34% payroll overhead
Duster	2.96		2.80		4.58	
Sprayer	3.91		8.47		16.3	
Tractor - Spray	21.82	90HP	10.84	60HP	22.32	80HP
Tractor - Dust	8.93	30HP	10.84	60HP	19.87	70HP

C. Extra time allowances			
Equipment operator labor	20%	20%	20%
Tractor time	10%	10%	10%

Sources: 2013 Winegrape Cost and Return Studies, Sacramento Valley, http://coststudies.ucdavis.edu/files/2013/GrapeWineSV2013.pdf
2012 Winegrape Cost and Return Studies, San Joaquin Valley North, http://coststudies.ucdavis.edu/files/GrapeWineVN2012.pdf
2008 ORGANIC Raisin Cost and Return Study, San Joaquin Valley South, http://coststudies.ucdavis.edu/files/graperaisinorgvs08.pdf
2007 Table Grapes Cost and Return Study, San Joaquin Valley South, http://coststudies.ucdavis.edu/files/grapets_vs2007.pdf

Table 10: Costs per Acre to Treat Powdery Mildew: Sample Budgets, 2013

	Central Coast Chardonnay			San Joaquin Valley North Table Grapes			San Joaquin Valley South Raisins		
Chemical	**Labor**	**Machinery**	**Material**	**Labor**	**Machinery**	**Material**	**Labor**	**Machinery**	**Material**
Dusting sulfur	n/a	n/a	n/a	6	5	2	7	5	2
Wettable sulfur (Microthiol)	n/a	n/a	n/a	6	5	2	7	5	3
Sterol Inhibitors (Rally)	15	11	35	18	14	63	13	10	31
Strobilurins (Flint)	15	11	45	6	5	67	n/a	n/a	n/a
Cell-Signaling Inhibitor (Quintec)	8	10	31	n/a	n/a	n/a	n/a	n/a	n/a
Contact Materials (Stylet Oil)	6.7	5.3	31	n/a	n/a	n/a	n/a	n/a	n/a

Source: Developed by the authors based on the UCCE Cost and Return Studies and consultation with experts.

Table 11: Costs per Acre to Treat Powdery Mildew: By Regions, 2013

	Central Coast		North Coast		San Joaquin and Sacramento Valley	
Chemical	**Labor**	**Machinery**	**Labor**	**Machinery**	**Labor**	**Machinery**
Dusting sulfur	6	5	7	6	6	5
Wettable sulfur	10	11	12	13	6	5
Sterol Inhibitors (Rally)	15	11	18	13	15	11
Strobilurins (Flint)	15	11	18	13	15	11
Cell-Signaling Inhibitors (Quintec)	8	10	10	12	7	10
Contact Materials (Stylet Oil)	6.7	5.3	8	6	7	10
Other fungicide sprays*	11	9	13	11	11	11

Source: Developed by the authors based on the UCCE Cost and Return Studies and consultation with experts.
*We assume application rates for other fungicides are the average of all the other liquid sprays.

Table 12: Application Costs for PM Treatments, 2011

Chemical Category	North Coast Area Treated	North Coast Cost per acre	North Coast Total Cost	Central and South Coast Area Treated	Central and South Coast Cost per acre	Central and South Coast Total Cost	Central Valley Area Treated	Central Valley Cost per acre	Central Valley Total Cost	Total All Regions Area Treated	Total All Regions Cost per acre	Total All Regions Total Cost
	Thousand Acres	*$ per acre*	*Thousand $*	*Thousand Acres*	*$ per acre*	*Thousand $*	*Thousand Acres*	*$ per acre*	*Thousand $*	*Thousand Acres*	*$ per acre*	*Thousand $*
Sterol Inhibitors	152	31	4,703	196	26	5,096	634	26	16,486	982	27	26,285
Strobilurins	153	31	4,742	171	26	4,440	622	26	16,164	946	27	25,346
Sulfur	480	13	6,240	348	11	3,829	3,332	11	36,653	4160	11	46,722
Biologicals	54	14	750	8	12	100	27	17	461	89	15	1,311
SARs							0.3	17	5	0.3	17	5
Cell-Sig	45	22	981	93	18	1,675	171	17	2,902	309	18	5,558
Contact	102	14	1,431	250	12	3,001	121	17	2,052	473	14	6,484
Other	10	25	256	4	21	83	47	22	1,025	61	22	1,364
Multchem	36	31	1,114	41	26	1,078	80	26	2,090	157	27	4,282
Benzophenone	0	25	0.4	11	21	231	19	22	413	30	21	644
Total	**1,031**		**20,217**	**1,123**		**19,533**	**5,052**		**78,250**	**7,206**		**118,000**

Source: Calculated by the authors using Pesticide Use Reports, 2011, Cost and Return Studies

Table 13: Most Frequently Used Products for Treating Powdery Mildew by Chemical Category, 2011

Chemical Category	Toxicity According to Label	Product Name
Benzophenone	*Caution*	VIVANDO
Biologicals	*Caution*	SERENADE MAX
	Caution	SONATA
Cell-Signaling Inhibitors	*Caution*	QUINTEC
Contact	*Caution*	JMS STYLET-OIL
	Caution	KALIGREEN
Multichemical Formulations	*Caution*	LUNA EXPERIENCE
	Caution	INSPIRE SUPER
	Caution	QUADRIS TOP
Sterol Inhibitors	*Danger!*	VITICURE
	Warning!	RALLY 40 WSP
Strobilurins	*Caution*	PRISTINE FUNGICIDE
	Caution	SOVRAN FUNGICIDE
	Caution	FLINT FUNGICIDE
Sulfur	*Caution*	SULFUR products

*Label indicates three levels of toxicity: highly toxic (*Danger!*), moderately toxic (*Warning!*) and low toxicity (*Caution*).
Source: California Department of Pesticide Regulation

Table 14: Elements of the Environmental Impact Quotient

Abbreviation	Description	Range of possible values
SY	Systemicity	13
C	Chronic toxicity (long-term health effects)	15
DT	Dermal toxicity	15
F	Toxicity to fish	15
D	Toxicity to birds	15
Z	Toxicity to bees	15
B	Toxicity to beneficial arthropods	15
P	Plant surface residue half-life	15
S	Soil residue half-life	15
R	Surface loss potential	15
L	Groundwater and runoff potential	15

Source: http://www.nysipm.cornell.edu/publications/eiq/methods.asp

Table 15: Environmental Impact Quotient for Powdery Mildew Treatment Chemicals

		EIQ Per Pound of Chemical			
Chemical Category	**Chemical Name**	**Total**	**Farm Worker**	**Consumer**	**Ecology**
Benzophenone	Metrafenone	n/a	n/a	n/a	n/a
Biologicals	Bacillus pumilus	n/a	n/a	n/a	n/a
	Bacillus subtilis	n/a	n/a	n/a	n/a
	Ampelomyces quisqualis	n/a	n/a	n/a	n/a
Cell signaling inhibitor	Quinoxyfen	32	10	6	80
Contact materials	Potassium bicarbonate	8	6	2	16
	Petroleum distillates	n/a	n/a	n/a	n/a
	Neem oil	n/a	n/a	n/a	n/a
	Cinnamaldehyde	n/a	n/a	n/a	n/a
Multichemical Formulatios	Difenoconazole	41.50	15.00	23.50	86.00
	Cyprodinil	26.77	12.15	14.73	53.45
Sterol inhibitors	Tebuconazole	40.33	20	31	70
	Triflumizole	20.42	11.4	6.7	43.15
	Myclobutanil	24.01	8.1	12.15	51.79
	Fenarimol	18.1	12	15	27.3
	Triadimefon	26.96	12.15	15.15	53.57
Strobilurins	Azoxystrobin	26.92	8.1	6.05	66.62
	Trifloxystrobin	29.78	12.15	10.23	66.95
	Kresoxim-methyl	15.07	9	4.5	31.7
	Pyraclostrobin	27.01	8.1	4.05	68.87
	Boscalid	26.44	12.15	21.23	45.95
Sulfur compounds	Sulfur	32.66	21.87	8.29	67.82
	Lime-sulfur	67.67	108	19	76
SARs	Harpin protein	n/a	n/a	n/a	n/a
	L-glutamic acid	n/a	n/a	n/a	n/a
Other	Mancozeb	25.72	20.25	8.13	48.79
	Captan, other related	15.77	12	5	30.3
	Benomyl	30.24	13.8	13.6	63.32

Table 16a: Per Acre Environmental Impact of Powdery Mildew (PM) Control for One Growing Season – Table Grapes

	EIQ per pound of active ingredient						EIQ Per acre for one growing season			
Pesticide Products	**Total**	**Worker**	**Consumer**	**Environment**	**Dose**	**Number of Applications**	**Total**	**Worker**	**Consumer**	**Environment**
					lb of AI/acre					
Table Grapes, Crimson Seedless. San Joaquin Valley South										
PM Products										
Microthiol Flowable Sulfur	32.66	21.87	8.29	67.82	5.20	4	679.33	454.90	172.43	1410.66
Dusting Sulfur	32.66	21.87	8.29	67.82	24.50	8	6401.36	4286.52	1624.84	13292.72
Rally	24.01	8.10	12.15	51.79	0.10	3	7.20	2.43	3.65	15.54
Total PM products							**7087.89**	**4743.85**	**1800.92**	**14718.91**
Other Products										
Abound	26.92	8.1	6.05	66.62	0.20	1	5.38	1.62	1.21	13.32
Ethrel	24.8	21.3	5.65	47.45	2.50	1	62.00	53.25	14.13	118.63
Kryocide	20.16	13.11	4.99	42.37	6.24	1	125.80	81.81	31.14	264.39
Lorsban	26.85	6	2	72.55	1.88	1	50.41	11.27	3.76	136.21
Neutral Zinc (sulfur 1%, Zinc 52%)	32.66	21.87	8.29	67.82	0.03	1	0.98	0.66	0.25	2.03
Provado	36.71	6.9	10.35	92.88	0.05	1	1.84	0.35	0.52	4.64
Roundup	15.33	8	3	35	1.00	1	15.33	8.00	3.00	35.00
Surflan	18.1	9	6	39.3	4.00	1	72.40	36.00	24.00	157.20
Vanguard	26.77	12.15	14.73	53.45	0.47	1	12.55	5.70	6.90	25.05
Total other products							**346.69**	**198.64**	**84.90**	**756.48**
PM EIQ as % of total EIQ							**95**	**95**	**95**	**95**

Sources: Grower budgets based on UC Davis Cost and Return Studies: http://coststudies.ucdavis.edu/files/GrapeWineVN2012.pdf, http://coststudies.ucdavis.edu/files/WinegrapeNC2012.pdf, http://coststudies.ucdavis.edu/files/grapewinewhitenc2008.pdf, http://coststudies.ucdavis.edu/files/grapecrimsonvs2007.pdf, http://coststudies.ucdavis.edu/files/grraistdsj06.pdf, http://coststudies.ucdavis.edu/files/graperaisogsj03.pdf, http://coststudies.ucdavis.edu/files/2013/GrapeWineSV2013.pdf
DPR Pesticide Product Database available online: http://www.cdpr.ca.gov/dprdatabase.htm
Environmental Impact Quotient, New York State IPM Program, http://www.nysipm.cornell.edu/publications/eiq

Table 16b: Per Acre Environmental Impact of Powdery Mildew (PM) Control for One Growing Season – Raisin Grapes

	EIQ per pound of active ingredient						EIQ Per acre for one growing season			
Pesticide Products	**Total**	**Worker**	**Consumer**	**Environment**	**Dose**	**Number of Applications**	**Total**	**Worker**	**Consumer**	**Environment**
Raisin Grapes, Tray Dried Thompson Seedless. San Joaquin Valley										
PM Products										
Sulfur	32.66	21.87	8.29	67.82	24.50	5	3600.77	2411.17	913.97	7477.16
Rally	24.01	8.10	12.15	51.79	0.10	1	2.40	0.81	1.22	5.18
Flint	29.78	12.15	10.23	66.95	0.06	1	1.86	0.76	0.64	4.18
Total PM products							**3605.03**	**2412.74**	**915.83**	**7486.52**
Other Products										
Abound	26.92	8.1	6.05	66.62	0.20	1	5.38	1.62	1.21	13.32
Kryocide	20.16	13.11	4.99	42.37	6.24	1	125.80	81.81	31.14	264.39
Lorsban	26.85	6	2	72.55	1.88	1	50.41	11.27	3.76	136.21
Neutral Zinc (sulfur 1%, Zinc 52%)	32.66	21.87	8.29	67.82	0.03	1	0.98	0.66	0.25	2.03
Provado	36.71	6.9	10.35	92.88	0.05	1	1.84	0.35	0.52	4.64
Roundup	15.33	8	3	35	1.00	2	30.66	16.00	6.00	70.00
Surflan	18.1	9	6	39.3	4.00	1	72.40	36.00	24.00	157.20
Total other products							**287.47**	**147.69**	**66.87**	**647.80**
PM EIQ as % of total EIQ							**92**	**94**	**93**	**92**
Raisin Grapes, DOV Selma Pete, DOVine, or FIESTA. San Joaquin Valley										
PM Products										
Sulfur	32.66	21.87	8.29	67.82	24.50	5	3600.77	2411.17	913.97	7477.16
Rally	24.01	8.10	12.15	51.79	0.10	1	2.40	0.81	1.22	5.18
Flint	29.78	12.15	10.23	66.95	0.06	1	1.86	0.76	0.64	4.18
Total PM products							**3605.03**	**2412.74**	**915.83**	**7486.52**
Other Products										
Neutral Zinc (sulfur 1%, Zinc 52%)	32.66	21.87	8.29	67.82	0.03	1	0.98	0.66	0.25	2.03
Provado	36.71	6.9	10.35	92.88	0.05	1	1.84	0.35	0.52	4.64
Total other products							**2.82**	**1.00**	**0.77**	**6.68**
PM EIQ as % of total EIQ							**99.9**	**99.9**	**99.9**	**99.9**

Sources: Grower budgets based on UC Davis Cost and Return Studies: http://coststudies.ucdavis.edu/files/GrapeWineVN2012.pdf, http://coststudies.ucdavis.edu/files/WinegrapeNC2012.pdf, http://coststudies.ucdavis.edu/files/grapewinewhitenc2008.pdf, http://coststudies.ucdavis.edu/files/grapecrimsonvs2007.pdf, http://coststudies.ucdavis.edu/files/grraistdsj06.pdf, http://coststudies.ucdavis.edu/files/graperaisogsj03.pdf, http://coststudies.ucdavis.edu/files/2013/GrapeWineSV2013.pdf
DPR Pesticide Product Database available online: http://www.cdpr.ca.gov/dprdatabase.htm
Environmental Impact Quotient, New York State IPM Program, http://www.nysipm.cornell.edu/publications/eiq/

Table 16c: Per Acre Environmental Impact of Powdery Mildew (PM) Control for One Growing Season - Winegrapes

Pesticide Products	EIQ per pound of active ingredient: Total	Worker	Consumer	Environment	Dose	Number of Applications	EIQ Per acre for one growing season: Total	Worker	Consumer	Environment
Winegrapes, Chardonnay. Central Coast.										
PM Products										
Rally	24.01	8.10	12.15	51.79	0.10	2	4.80	1.62	2.43	10.36
Quintec	32.00	10.00	6.00	80.00	0.07	1	2.21	0.69	0.41	5.52
Flint	29.78	12.15	10.23	66.95	0.06	1	1.86	0.76	0.64	4.18
Stylet Oil	8.00	6.00	2.00	16.00	0.17	3	4.19	3.15	1.05	8.39
Total PM products							**13.07**	**4.60**	**2.10**	**18.09**
Other Products										
Roundup	15.33	8	3	35	1.00	1	15.33	8.00	3.00	35.00
Surflan	18.1	9	6	39.3	4.00	1	72.40	36.00	24.00	157.20
Vanguard	26.77	12.15	14.73	53.45	0.47	1	12.55	5.70	6.90	25.05
Total other products							**100.28**	**49.70**	**33.90**	**217.25**
PM EIQ as % of total EIQ							**7.69**	**8.4**	**5.8**	**7.6**

Sources: Grower budgets based on UC Davis Cost and Return Studies: http://coststudies.ucdavis.edu/files/GrapeWineVN2012.pdf, http://coststudies.ucdavis.edu/files/WinegrapeNC2012.pdf, http://coststudies.ucdavis.edu/files/grapewinewhitenc2008.pdf, http://coststudies.ucdavis.edu/files/grapecrimsonvs2007.pdf, http://coststudies.ucdavis.edu/files/grraistdsj06.pdf, http://coststudies.ucdavis.edu/files/graperaisogsj03.pdf, http://coststudies.ucdavis.edu/files/2013/GrapeWineSV2013.pdf
DPR Pesticide Product Database available online: http://www.cdpr.ca.gov/dprdatabase.htm
Environmental Impact Quotient, New York State IPM Program, http://www.nysipm.cornell.edu/publications/eiq/

Figure 3: Share of Each PM Chemical Category in Annual PURE Scores from PM Management, 2011