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The Value of Powdery Mildew Resistance in Grapes: Evidence from California

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ABSTRACT.
Powdery mildew (PM) is a fungal disease that damages many crops, including grapes. In California, wine, raisin, and table grapes contributed over $3.8 billion to the value of California's farm production in 2011 (California Department of Food and Agriculture, 2012). Grape varieties with resistance to powdery mildew are currently being developed, using either conventional or transgenic approaches, each of which has associated advantages and disadvantages. PM-resistant varieties of grapes could yield large economic benefits to California grape growers—potentially allowing cost savings as high as $70 million per year, but benefits range widely across the different grape production systems. The benefits might be even larger if environmental regulations over the use of pesticides were changed to limit some currently effective PM management protocols. On the other hand, grapes produced using non-*vinifera* or transgenic vines might suffer a price discount compared with conventional alternatives.

Key Words: Powdery mildew, resistant varieties, California grapes, research benefits

JEL codes: Q12; Q16; Q18

1. Introduction

Powdery mildew (PM) is a fungal disease that damages a wide range of crops. Many different species of powdery mildew fungi have been catalogued, but each species attacks only certain plants. In most cases, powdery mildew does not require moist conditions to become established, and consequently it is more prevalent than other leaf-infecting diseases during dry California summers (Davis, et al., 2008).

On most plants, powdery mildew appears as white, powdery spots on leaves, shoots, flowers, or fruit (Figure 1). These spots are the mycelium (fungal tissue) spores, which are the primary means of dispersal of the fungus. 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).

[Figure 1: *Grape powdery mildew*]

Grape powdery mildew, *Erisiphe necator*, can survive the winter in California in buds or as spore structures. When temperatures become warmer and moisture is adequate, the spore structures burst and fungi can spread to neighboring plants. A range of fungicides can help vineyard managers keep the disease in check in most years, but these are costly and may have negative environmental and human health effects (Gubler, et al., 2008; Lee, et al., 2006).

PM-resistant varieties are available for many affected crops, such as melons, squash, and peas (Davis, et al., 2008). Work is now underway to develop PM-resistant grape varieties (e.g., the VitisGen project: http://www.vitisgen.org/). In this paper, we estimate differences in costs of production between conventional and PM-resistant varieties of table, raisin, and wine grapes. We use the differences in costs for hypothetical "representative" individual vineyards to estimate the potential benefits from PM resistance in grapes over several regions of California. We find that potential benefits are large but depend critically on the lag until the resistant varieties become available as well as the subsequent rate of adoption by growers.

2. Grape Production in California

Grapes produced in California fall into three main categories: wine grapes, table grapes, and raisin grapes. These three categories make up an industry that contributed over $3.8 billion to the value of California's farm production in 2011, and much more in terms of total value (California Department of Food and Agriculture (CDFA), 2012). The three categories of grapes have important similarities—they all use varieties of *Vitis vinifera*, and some of the same varieties, such as Thompson Seedless, are used in all three production systems. However, the production systems differ significantly in ways that imply differences in the potential benefits from powdery mildew resistance.

Table Grapes

The vast majority of California table grapes are grown in the southern San Joaquin Valley. Many varieties are grown for this purpose—over 70 in California alone (California Table Grape Commission, 2013), but Red Globe, Crimson Seedless, and Flame Seedless dominate, making up a combined total of 53 percent of the total table grape acreage in 2012 (CDFA/National Agricultural Statistical Service (NASS), 2013). Labor costs are large and important in table grape production—over half of the total operating costs per acre—in particular because table grape vineyards are hand-picked three to four times during the harvest season. In the case of Crimson Seedless in 2007, harvesting costs of $9,400 per acre (or 62% of annual operating costs), included $4,621 per acre in labor costs alone, and over $2,000 per acre in packing materials (University of California Cooperative Extension, 2007). Pruning vines and removing leaves to expose fruit to sunlight imposes labor costs of over $2,000 per acre each year.

Over the ten years 2002–2011, annual average real prices (in 2013 dollars) of table grapes ranged from $406 per ton in 2008 up to $810 per ton in 2011.[1] Production of table grape varieties climbed slowly, from 739,000 tons in 2002 to 1,031,000 tons in 2011. Notably, these annual averages of production and prices of table grape varieties include between 20,000 and 55,000 tons that are dried for raisins (United States Department of Food and Agriculture (USDA), 2003–2012). Figure 2 shows annual average quantities and deflated prices of table grapes for 2002–2011.

[Figure 2: *Annual Average Production and Deflated Prices of California Grapes*]

Raisin Grapes

Like table grapes, the vast majority of raisin grapes are grown in the San Joaquin Valley, where they are sun dried. Raisin production was once very labor intensive; now much of the harvesting and pruning can be done mechanically. Continuous tray dried production systems for raisins, in which grapes are mechanically harvested and dried on a continuous paper tray between rows, represent the greatest share of raisin production acreage—approximately 45% to 50% (Fidelibus, 2013). Labor costs for continuous tray dried raisins account for 27% of annual operating costs; and materials costs account for a similar share of costs (University of California Cooperative Extension, 2006).

Traditional tray dried raisin production, in which bunches of ripe grapes are hand-cut and placed to dry in the sun on rows of individual paper trays, makes up between 30% and 40% of acreage and production of raisin grapes. This system is becoming less

[1] Nominal prices were deflated using the GDP deflator (2013; http://www.bea.gov/iTable/index_nipa.cfm).

common because of the large requirement for short-term labor, which can be difficult to find (Fidelibus, 2013). Labor accounts for 35% of the total operating costs for this system.

Dried-on-the-vine (DOV) raisin production systems allow machines to harvest already dried raisins, minimizing losses from rain damage (Boriss, et al., 2013). Between 10% and 15% of grape acreage is DOV. However, DOV systems can produce much higher yields per acre, so the percentage of the acreage they make up is considerably less than their share of production, which is between 25% and 30% of total raisin volume. DOV systems use two types of trellis—overhead trellis and open-gable trellis. Overhead trellis produces higher yield per acre, on average—these systems can produce six tons of dried raisins per acre, while open-gable produces three to four tons per acre (Fidelibus, 2013), but they also have somewhat higher costs of establishment and production (University of California Cooperative Extension, 2000–2011). Labor costs for these systems are also large, making up between 55% (open-gable trellis) and 67% (overhead trellis) of total operating costs.

In all, 2.2 million tons of raisin grapes were produced in 2011. Of those, 1.6 million tons were dried to become approximately 360,000 tons of raisins. (The remaining 600,000 tons of raisin grapes were sold fresh.) Raisin prices have varied substantially over the past ten years. In 2011, the volume-weighted average real price (in 2013 dollars) for dried raisins was $1,776 per ton, over 3.5 times the real price of $497 in 2002. Real prices for undried raisin grapes as a whole, including those sold fresh, ranged from $196 per ton in 2002 to $405 per ton in 2011 (USDA, 2003–2012). Figure 2 shows annual raisin grape prices (in 2013 dollars) and quantity produced over time—all expressed in fresh equivalents.

Wine Grapes

Wine grapes are the most important type of grape in California in terms of area, quantity, and value of production. Annual production has varied more for wine grapes across California than for the other grape categories over the past ten years, ranging from 2.8 million tons in 2004 up to 3.7 million tons in 2009. Average annual prices have been fairly stable in nominal terms, declining slightly in real terms; crush prices for wine grapes averaged $606 per ton in both 2002 and 2009, and reached a high of $704 in 2006. Figure 2 shows wine grape production and prices over time.

Winegrapes are produced throughout the state across diverse agroecologies, using range of production systems, and many varieties.[2] Prices and yield of wine grapes vary widely across the state. In Napa County, on average vineyards produced about 3.3 tons per bearing acre of wine grapes per year earning an average crush price of $3,145 per ton over the ten years, 2002–2011. On the other hand, in the San Joaquin Valley, average yield is much higher and average prices are much lower—11.3 tons per acre of wine grapes per year and $260 per ton, respectively, over the ten years, 2002–2011. In the Central Coast—Monterey and San Luis Obispo Counties (wine grape crush districts 7 and 8), the average price and yield fall between those extremes. The average yield for the

[2] California has 17 wine grape crush districts, within which prices and production styles are considered to be similar. A map and descriptions can be found at: http://www.nass.usda.gov/Statistics_by_State/California/Publications/Grape_Crush/Final/index.asp

Central Coast was 5.4 tons per acre per year during the ten-year time period and the average price was $1,104 per ton (CDFA/NASS, 2003–2012).[3]

Powdery Mildew Resistant Varieties

Work is currently underway to develop varieties of table, raisin, and wine grapes with resistance to powdery mildew, along with other beneficial characteristics in some cases. These resistance characteristics can be introduced using either conventional or transgenic approaches, each of which has associated advantages and disadvantages.

Conventional breeding work towards PM resistance is especially promising for raisin grapes. Powdery mildew resistance and "natural" DOV traits—in which grapes dry on the vine on their own, without the need for growers to cut the canes—are being introduced in concert using conventional breeding techniques (Ramming, 2013).

For wine grapes, introducing resistance is a complex issue. Conventional breeding entails crossing *Vitis vinifera* varieties, all of which have some susceptibility to PM, with non-*vinifera* grapes, and then back-crossing to obtain a vine with the highest content of *vinifera* possible. However, even at nearly 100% *vinifera*, the wines made with these hybrid grapes cannot be labeled with the *vinifera* varietal name. For example, if chardonnay is bred for PM resistance, even if the wine made with those grapes has characteristics identical to that made with chardonnay, it cannot be labeled as such.

We interviewed various growers, extension agents, and academics to elicit views on how prices of grapes might be affected by adoption of PM-resistant varieties and the associated changes in varietal names. The story is mixed. Wines made with non-*vinifera*

[3] Annual average yield over the ten years, 2002–2011, is calculated as the sum of annual quantities produced during that time period, divided by the sum of the annual bearing acreage. Average price is computed as a quantity-weighted average of nominal prices for that time period. The San Joaquin Valley refers to grape crush districts 12–14.

or hybrid grapes historically have not done well in tastings or in the market (Walker, 2012) and much is unknown about how prices of wines produced with PM-resistant grapes would compare to those of their traditional counterparts. The PM-resistant vines would have a much higher percentage of *vinifera* than hybrids have had historically. While wines produced using these varieties would have to be labeled either without varietal names, or "chardonnay-like" or something similar, which could pose a marketing challenge, they would also require much less pesticide application, and buyers might be willing to pay a premium for that aspect. These wines could also be blended with wine made from a 100% *vinifera* varietal; so long as the *vinifera* varietal accounts for 75% or more of the blend, the label can bear the name of the *vinifera* varietal (United States Department of the Treasury Alcohol and Tobacco Tax and Trade Bureau, 2008).

On the other hand, wines made from grapes from transgenic PM-resistant plants, potentially could be labeled with the traditional *vinifera* varietal name, but could face significant market resistance because of popular views on genetically modified foods, and would need to go through a substantial regulatory process.[4] In the table grape and raisin markets, varietal labeling is not as important, but the potential for market acceptance of transgenic varieties remains uncertain.[5]

[4] To date GM versions of *vinifera* varieties have not been through the regulatory approval process, so it remains to be seen if they could retain the varietal name.

[5] Varietal names are significant in some instances in the table grape market, which includes trademarked varieties/labels such as Midnight Beauty and Scarlotta Seedless (California Table Grape Commission, 2013).

3. Measures of Benefits from Adoption of PM-Resistant Varieties

The introduction and adoption of PM-resistant grapevines will reduce the use of chemical treatments to mitigate PM impacts. We use vineyard-level budget models to assess the saving in variable costs that would occur if PM-resistant vines were available and adopted in specific production systems for each of the three different types of grapes (table, raisin, and wine).

Most powdery mildew is preventively controlled with a variety of fungicides—yields are not typically affected by the disease (Bettiga, 2013; Fidelibus, 2013; Smith, 2013). However, the fungicides and the costs of applying them entail significant outlays for growers. In our sample budgets, the combined cost of fungicide materials and their application amounts to between 9% (for both continuous tray dried raisin grapes and crimson seedless table grapes) and 20% of cultural costs (for Central Coast chardonnay wine grapes), and between 2% (for Crimson Seedless table grapes) and 8% (for Central Coast chardonnay wine grapes) of the total costs of grape production (Table 1). The adoption of technology that substantially reduces or eliminates these costs would have important impacts on the equilibrium quantity and price of each of the various types of grapes in their respective markets.[6]

[Table 1: *Powdery Mildew Costs*]

To examine these differences, we constructed budgets for hypothetical "representative" vineyards using University of California Cooperative Extension (UCCE) Cost Studies (2000–2011). In the UCCE Cost Studies, which represent specific hypothetical vineyards or a sample of specific farms, it is not clear which practices are

[6] In the UCCE Cost Studies, cultural costs are defined as the costs of growing grapes. They are exclusive of harvest and overhead costs.

standard across a given type of production system, and which are specific to a particular agroecology, or the preference of the grower. The same is true of our analysis, which drawing on the UCCE Cost Studies. Importantly, we hold constant everything except the treatments for PM in our comparison of budgets with and without PM-resistant varieties, and the measured differences may be more nearly constant across a range of production systems that may differ from one another in many other attributes. We utilized the most recent UCCE Cost Studies, but in some cases, such as DOV raisin grapes, the most recently available budget is fairly old—ten years for that particular type of grape. The most recent budgets we were able to use were for table grapes, which were published for four varieties in 2007. We inflated all costs to 2013 dollars, using the Index of Prices Paid by Farmers for the years for which it was available (until 2010) and using a simple average of the monthly Index of Prices Paid for Commodities and Services, Interest, Taxes, and Farm Wage Rates for the remaining years (USDA/NASS, 2009; USDA/NASS, 2010–2013).

Table Grapes. Of the available table grape varieties, we chose to profile Crimson Seedless grapes. Crimson Seedless is the most widely planted in terms of acreage (CDFA/NASS, 2013) and continues to be viewed favorably by growers, unlike several varieties that were once very popular, such as Thompson Seedless but have now lost favor owing to lower prices and high input costs (Gabler, 2013; Jones, 2013).

Raisin Grapes. The variety of production systems in use for raisin grapes raises some complexities worth addressing here. Because of a push towards DOV systems, particularly "natural" DOV, any new resistant varieties are likely to be grown on DOV systems rather than tray or continuous tray dried. We created budgets for all four of these systems—both types of tray dried and both types of DOV—, but modeling the change from a conventional tray dried system to a PM-resistant natural DOV system was not feasible using the available production budgets. Consequently, we computed the benefit from PM resistance within a given production system, for four types of raisin production, specifically: overhead trellis DOV; open gable DOV; traditional tray dried; and continuous tray dried raisin production systems.[7]

Wine Grapes. Because of the great diversity in wine grape growing practices and market characteristics, we opted to focus on the variety that is most affected by powdery mildew, chardonnay, which is the most economically important white wine variety. We also opted to focus on a single region, the Central Coast, where PM pressures are most severe (Dokoozlian, 2013; Gubler, 2013).[8]

Budget Details and Modeling Assumptions

We discussed our budgets with experts on each type of grape production system in the regions of interest. This group included extension advisors, pest control advisors, academics, and other researchers. This budget validation process was necessitated by the age of the UCCE budgets and our specific interest in PM management costs, since in many cases the standard protocol has changed regarding which fungicides to use and how they should be rotated to avoid resistance.

Table 1 shows the PM-associated costs (fungicides and their application) for each of the grape production systems. Apportioning costs between treatments for PM and other activities is complicated because some fungicide treatments primarily used for PM

[7] We assume that all types of raisin production use the same PM protocol, based on advice we received from pest control advisors (Moriyama, 2013; Stark, 2013).

[8] We define the Central Coast as wine grape crush districts 7 and 8.

also have other beneficial effects, and in some cases, treatments for multiple problems are applied jointly. Not all these costs would be saved, even if PM were effectively eliminated. Table 2 shows the differences in labor, materials, and other costs between various wine grape production systems using conventional and resistant grapes. The difference in cost between the two systems does not simply equal the cost of PM treatments because ending sulfur treatments may result in an erineum mite infestation, so we assume a wettable sulfur treatment would be retained (Fidelibus, 2013; Ramming, 2013). Additionally, because some non-PM treatments are typically applied along with PM treatments, while the materials costs can be easily disaggregated, the labor and fuel, lube, and tractor repair costs must be attributed to the non-PM treatments in full for the resistant system.

[Table 2: *Saving in Cultural Costs per Acre from PM-Resistant Vines*]

In every case, the resistant system has lower costs than the conventional system, although the difference in costs varies widely. Total annual cost savings range from $179 per acre in the case of continuous and traditional tray-dried raisin production, up to $287 per acre for Crimson Seedless table grapes. The annual cost savings for Central Coast chardonnay are $280 per acre. The percentage changes, however, are somewhat different since some studies report higher total cultural costs than others. The percentage savings in total costs ranges from 2% for Crimson Seedless table grapes, up to 4.3% for both DOV open gable raisins, and Central Coast chardonnay wine grapes.

Spillovers: Environmental Benefits

Fuel, lube, and repair costs are a measure of tractor use. Since tractors emit carbon dioxide, fine particulate matter (PM 2.5), and a host of other pollutants, curbing their use has been a topic of increasing conversation in the San Joaquin Valley, where table and raisin grapes are grown, and where air quality has become an issue of concern in recent years (Bailey, 2012; Ngo, et al., 2010). Table 2 shows differences in fuel, lube, and repair costs, which range from $13.2 per acre for traditional tray dried raisin grape production to $51 per acre for Crimson Seedless table grapes. The implication is that PM-resistant varieties would allow some reduction in vineyard operations with an attendant decrease in ambient pollution.

The reduction in application of chemical fungicides may also yield benefits to the environment and human health. Various sources have speculated that sulfur, the most heavily used agricultural chemical, causes respiratory illnesses and other adverse health effects (e.g. Clean County Coalition, 2011; McGourty, 2008). However, much is unknown about what kind of respiratory effects are induced and what type of exposure causes them (Lee, et al., 2006). In soil, sulfur is slowly converted by bacteria to sulfate, which generally does not cause harm (Cornell University Pesticide Managment Education Program/ExToxNet, 1995). Other synthetic compounds used for PM treatment and prevention, such as sterol inhibitors and strobilurns have not been reported as having negative environmental or human health effects (Fischel, 2005).

While the fungicides used for powdery mildew control are relatively non-toxic to both humans and the environment, because of the large volume and frequency of applications, powdery mildew controls cause the bulk of the environmental impact from grape production. The elimination of these environmental and human health costs is an element of the benefits from PM-resistant varieties. In a related paper (Sambucci, et al., 2013) we use two measures of pesticide risk to examine the environmental impact of powdery mildew management: the Environmental Impact Quotient (EIQ), which combines pesticide hazards to farm workers, consumers and the environment, and Pesticide Use Risk Evaluation (PURE), which is a California-specific index that quantifies the environmental risk to soil, surface water, ground water, air, and bees. We conclude that sulfur accounts for the largest share of environmental risk using both risk measures, and the benefits from eliminating PM-related fungicide applications would accrue primarily to workers (reduce potential health risks), and through reduced harm to bees and soil (Sambucci, et al., 2013).

Market Level Analysis

The analysis conducted thus far has been at a very small scale—per acre effects for a "representative" vineyard. We now scale up the effect to represent the regions we have chosen to analyze: the Central Coast for chardonnay wine grapes, and the San Joaquin Valley for Crimson Seedless table grapes and all types of raisin grapes. Table 3 presents regional acreage and the total cost saving, by production system, if all growers in the region were to adopt a new resistant variety immediately. The largest total potential impact is in raisin grapes, which would save $43.8 million per year if all the acreage, 195,899 acres in the San Joaquin Valley in 2011, were converted to PM-resistant production immediately. The corresponding annual cost saving for Central Coast chardonnay is $27.2 million (at 97,041 acres—approximately half that of raisins) and for Crimson Seedless it is $3.7 million (a high per-acre cost reduction, of $287 per acre per year applied to a comparatively small total acreage of 12,950 acres in 2011).

[Table 3: *Potential Aggregate Benefits from Adoption of PM-Resistant Varieties*]

In reality, however, all of the acreage in a given region would not be converted immediately converted to mature PM-resistant vines, even if the technology were immediately available for adoption. Moreover, even if all the acreage were replaced immediately, growers typically do not begin to apply powdery mildew controls until the third year after planting, and vines would not become commercially bearing for approximately five years. Hence, meaningful savings would take some time to be felt, and would increase progressively over time.

In the analysis below we allow for (a) an R&D lag (*L*, an estimate of the number of years until PM-resistant varieties become available for adoption), (b) an adoption lag (reflecting the fact that growers will be unlikely to remove healthy vines to replace them with PM-resistant vines but rather will wait until vines are due for replacement), which is represented as a linear 20-year process of increase to the maximum adoption rate, *a*, and (c) a three-year a lag between planting and when powdery mildew treatments typically begin for non-resistant vines, according to the UCCE Cost Studies (UCCE, 2000–2011). We estimate the total annual average regional change in economic surplus (ΔTS) for each production system in any given future year as the maximum proportion of acreage on which the new resistant varieties will be adopted (*a*), multiplied by the cost savings from 100% adoption reported in Table 2 (ΔC), and discounted to the present, using a real discount rate of 3% per annum:[9]

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[9] Equations (1) and (2) are equivalent because $\lim_{x\to\infty} \sum_{m=0}^{x} \frac{1}{(1+r)^m} = \frac{1}{r}$, and

$\sum_{n=21}^{\infty} \frac{1}{(1+r)^{L+3+n}} = \left(\frac{1}{(1+r)^{21+L+3}}\right) \sum_{m=0}^{\infty} \frac{1}{(1+r)^m}$,

so $\sum_{n=21}^{\infty} \frac{1}{(1+r)^{L+3+n}} = \left(\frac{1}{(1+r)^{21+L+3}}\right)\left(\frac{1}{r}\right)$.

(1) $$\Delta TS = a\Delta C\left(\sum_{n=1}^{20}\frac{n}{20}\,\frac{1}{(1+r)^{L+3+n}}+\sum_{n=21}^{\infty}\frac{1}{(1+r)^{L+3+n}}\right),\text{ or,}$$

(2) $$\Delta TS = a\Delta C\left[\sum_{n=1}^{20}\left(\frac{n}{20}\,\frac{1}{(1+r)^{L+3+n}}\right)+\left(\frac{1}{(1+r)^{21+L+3}}\right)\left(\frac{1}{r}\right)\right]$$

In Table 4 we present values for (ΔTS) based on alternative assumptions about the length of the lag until the resistant vines become available (the R&D lag, *L*) and the maximum adoption rate (*a*).

[Table 4: Total Present Value of Benefits from Adoption of PM-Resistant Varieties]

Based on our conversations with researchers, adoption rates would likely be higher, at least initially, for table and raisin grapes than for wine grapes. Raisin grapes are likely to have the shortest lag; ten years is possible for that category (Ramming, 2013), whereas resistant varieties of wine and table grapes could take significantly longer to be developed and become available to growers.

The range of estimated benefits is substantial. The present value of the benefit from PM-resistant vines for raisins ranges from as low as $19 million if the resistant vines are bearing commercially in 40 years and are adopted by 20% of growers, up to $228 million if all growers adopt the new varieties when they become available. The total present value of benefits from PM-resistant vines for Central Coast chardonnay grape range from $12 million to $141 million, and benefits to Crimson Seedless table grapes range from $2 to $19 million.

4. Conclusion

PM-resistant varieties of grapes could yield large economic benefits to California grape growers—potentially allowing cost savings as high as $70 million per year in the subset of the industry covered by our analysis. Our estimates of the cost savings attributable to PM-resistant varieties range widely across the different grape production system, with the greatest potential in the raisin grape industry. But within a system in present value terms the benefits are very sensitive to the R&D lag until the resistant varieties become available for adoption and ultimate maximum rate of adoption.

These measures of potential cost savings represent only part of the economic picture for two reasons. First, they only count part of the potential cost savings. Specifically, the measured cost savings refer only to private pecuniary costs born by growers; they do not include nonpecuniary benefits to growers or the external benefits to others from reduced use of toxic pesticides by growers. These omitted elements of costs could be important to growers and society, and might affect adoption rates.

Second, we have implicitly assumed prices of grapes grown using PM-resistant varieties would be the same as prices for grapes from conventional varieties they would replace. However, table, raisin, and wine grapes produced using non-*vinifera* or transgenic vines might well suffer a price discount compared with conventional alternatives, and if the price discount is greater than the cost savings from resistance, then it will not make economic sense for growers to adopt them. Even if it is not prohibitive, any price discount will offset the benefits from cost savings to some extent.

On the other hand, the benefits might be even larger than the computations here would indicate. For instance, if environmental regulations over the use of pesticides were changed to prohibit or limit some currently effective and widely used PM management protocols, the benefits from PM resistant varietal technology may be much more valuable than at present and while reasonably effective chemical technologies continue to be available to growers.

Table 1: Powdery Mildew Costs

	Annual PM Cost		Costs Attributed to PM as a Share of		
			Cultural Costs	Cash Costs	Total Costs
	$/acre	$/ton		%	
Raisin Grapes					
Continuous Tray	222	171	8.7	4.6	3.4
Tray	222	111	12.4	6.9	4.5
DOV Open Gable	222	52	16.3	8.4	4.6
DOV Overhead Trellis	222	44	16.3	8.3	4.6
Wine Grapes					
Central Coast Chardonnay	369	68	19.6	12.4	7.7
Table Grapes					
Crimson Seedless	329	35	8.9	2.4	2.1

Notes: Continuous Tray and Tray-Dried Raisin grape budgets use Thompson Seedless Grapes. DOV budgets use numbers representative of any of the following: DOVine, Selma Pete, or Fiesta (early ripening varieties). Sources are UCCE Cost and Returns Studies (2000–2011). Costs have been inflated to 2013 dollars using the Index of Prices Paid by Farmers for available years (until 2009) (USDA/NASS, 2009) and a simple average of monthly indexes for the remaining years, 2010–2013 (USDA/NASS, 2010–2013).

Table 2: Saving in Costs per Acre from Adopting PM-Resistant Vines

	Elements of Savings in Cultural Costs				Cost Saving as a Share of Total Production Cost
	Labor	Fuel, Lube, and Repair	Materials	Total	
	$/Acre/Year				*%*
Raisin Grapes					
Continuous Tray	24.9	17.1	136.6	178.6	2.8
Tray	24.9	16.4	137.2	178.5	3.6
DOV Open Gable	41.6	29.7	136.8	208.0	4.3
DOV Overhead Trellis	43.3	13.2	124.0	180.5	3.7
Wine Grapes					
Central Coast Chardonnay	43.5	46.8	190.0	280.3	4.3
Table Grapes					
Crimson Seedless	76.8	50.7	159.1	286.6	1.9

Notes: Costs were inflated to 2013 dollars using the Index of Prices Paid by Farmers for years when it is available (until 2009) (USDA/NASS, 2009) and a simple average of monthly indexes for the remaining years, 2010–2013 (USDA/NASS, 2010–2013). The cost saving as a share of total production cost is computed as the total saving in cultural costs per acre, divided by the total costs per acre for non-resistant grape production, for the grape category specified.

Table 3: Potential Aggregate Benefits from Adoption of PM-Resistant Varieties

	Total Area, 2011	Cost Reduction per Acre	Aggregate Benefit, 100% adoption
	acres	*$/acre/year*	*$m/year*
San Joaquin Valley Raisins			
Continuous Tray	88,155	278	24.51
Tray	58,770	167	9.81
DOV Open Gable	24,487	208	5.09
DOV Overhead Trellis	24,487	181	4.43
Total Raisin	195,899	224	43.85
Central Coast Wine Grapes			
Chardonnay	97,041	280	27.17
San Joaquin Valley Table Grapes			
Crimson Seedless	12,950	287	3.72

Notes: Source for number of acres is CDFA/NASS (2012). Number of acres for individual raisin production systems calculated from CDFA/NASS and Fidelibus (2013), who estimated percentages in each production system. The total raisin cost of reduction per acre is an average of the different production systems, weighted by the number of acres in each. Costs have been inflated to 2013 dollars using the Index of Prices Paid by Farmers for available years (until 2009) (USDA/NASS, 2009) and a simple average of monthly indexes for the remaining years, 2010–2013 (USDA/NASS, 2010–2013).

Table 4: Total Present Value of Benefits from Adoption of PM-Resistant Varieties

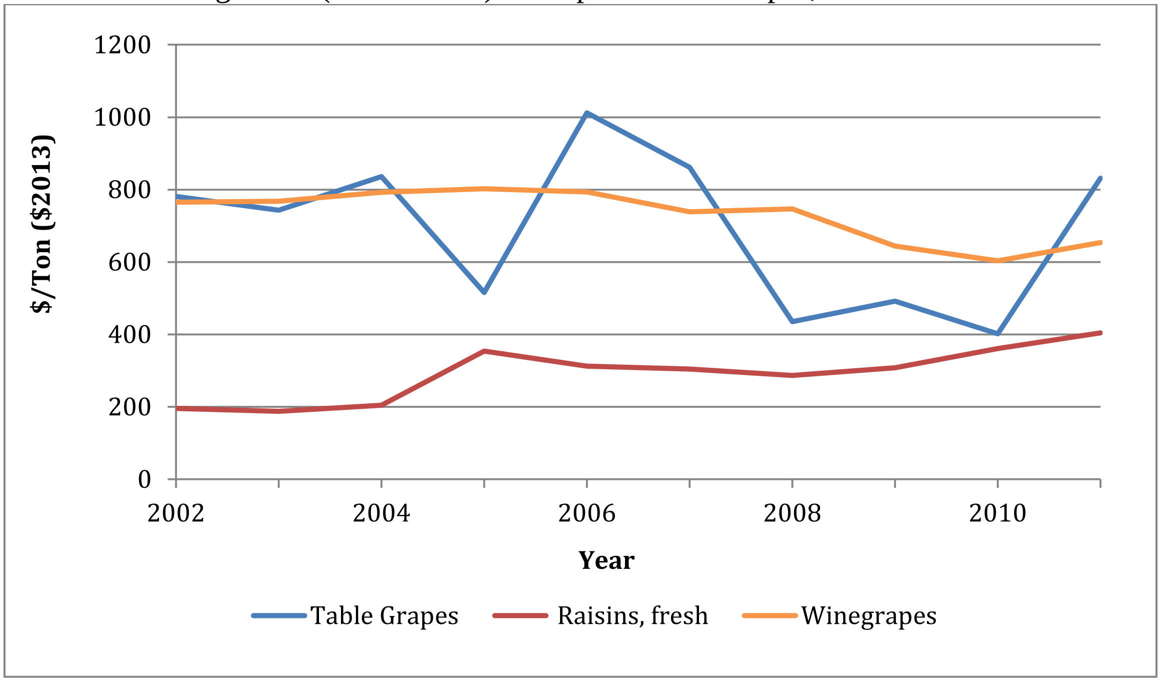
Maximum Adoption Rate (%)	Lag (*L*+3, Years) 10	20	30	40
	$ Millions/Year			
Raisins: all				
20	45.5	33.9	25.2	18.8
40	91.0	67.7	50.4	37.5
60	136.5	101.6	75.6	56.3
80	182.0	135.5	100.8	75.0
100	227.6	169.3	126.0	93.8
Wine Grapes: Central Coast Chardonnay				
20	28.2	21.0	15.6	11.6
40	56.4	42.0	31.2	23.2
60	84.6	63.0	46.8	34.9
80	112.8	83.9	62.5	46.5
100	141.0	104.9	78.1	58.1
Table Grapes: Crimson Seedless				
20	3.9	2.9	2.1	1.6
40	7.7	5.7	4.3	3.2
60	11.6	8.6	6.4	4.8
80	15.4	11.5	8.5	6.4
100	19.3	14.4	10.7	7.9

Notes: Raisins in this table represent the combined total of all production systems—continuous tray, traditional tray-dried, and DOV systems. Both table and raisin grape acreage was computed for the San Joaquin Valley, as in Table 3. We use a 3% real discount rate. The total lag includes the R&D lag, *L* plus a gestation lag of three years after adoption before costs are affected.

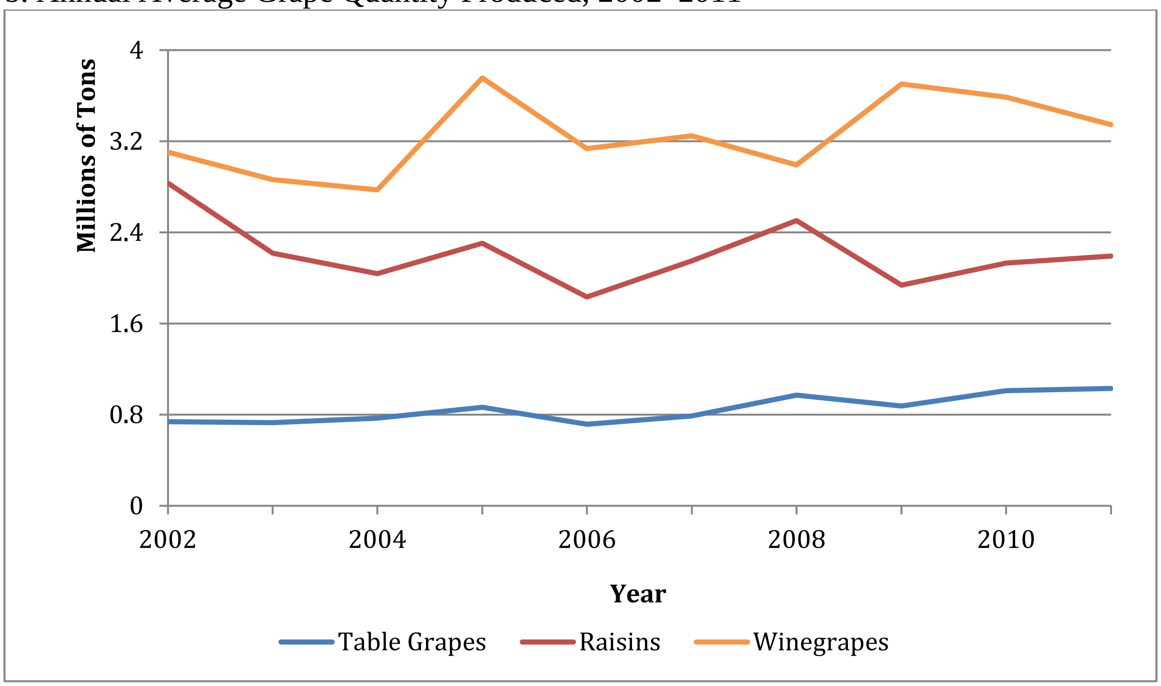
Figure 1: Grape powdery mildew

Photo source: Jack Kelly Clark. Available from: http://www.ipm.ucdavis.edu/PMG/U/D-GR-UNEC-FO.002.html

a. Annual Average Real (2013 Dollar) Price per Ton of Grapes, 2002–2011



b. Annual Average Grape Quantity Produced, 2002–2011



Source: USDA (2003–2012).
Notes: Both raisins and table grapes are reported as the fresh equivalent of fresh and dried fruit. Prices are in 2013 dollars, converted using the BEA GDP deflator (2013; http://www.bea.gov/iTable)

Figure 2: Annual Average Production and Deflated Prices of California Grapes

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