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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 $3.9 billion to the value of farm production in 2011. 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 $48 million per year in the subset of the industry covered by our analysis (Crimson Seedless table grapes, all raisin grapes, and Central Coast Chardonnay wine grapes), but benefits range widely across the different grape production systems.

Keywords: Powdery mildew; Resistant varieties; California grapes; Research benefits

1. Introduction

Powdery mildew (PM) is a fungal disease that damages a wide range of crops.[1] It is especially of concern to grape producers around the world. 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 in the United States to develop PM-resistant grape varieties (e.g., the VitisGen project: http://www.vitisgen.org/). The potential value of these varieties is of interest.

In this paper, we estimate differences in costs of production between conventional and PM-resistant varieties. We do this for four types of raisin grape growing systems in the San Joaquin Valley, Crimson Seedless table grapes, also in the San Joaquin Valley, and Chardonnay wine grapes in the Central Coast region of California. The potential benefits were estimated using detailed partial budgets for hypothetical "representative" individual vineyards, given in Appendix A, which were created for this purpose based on University of California Cooperative Extension (UCCE) Cost Studies. We find that the 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.

1.1. Literature review

The work in this paper relates to and draws on several strands of previous work. The broad context is the general literature on the economics of agricultural innovation, which was recently reviewed by Pardey et al. (2010). This literature has documented the very substantial contributions of agricultural innovation to economic growth and well-being, the high rates of payoff to public and private investments in agricultural

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[1]On most plants, powdery mildew appears as white, powdery spots on leaves, shoots, flowers, or fruit. 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 fruit quality (Davis et al., 2008). 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.

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R&D, and the long time lags involved. It provides a suitable frame of reference for interpreting the results from the present work as well as guidance concerning analytical and empirical methods. Previous studies have also documented a host of modeling, measurement and attribution problems and issues to be taken into account (e.g., Alston et al., 2010). The work here concerns a particular class of agricultural innovations: pest-resistant varietal technologies for perennial crops, innovations for which these general concerns are likely to be of particular relevance.

Much of the literature on agricultural R&D has pertained to crop varietal technologies, including the use of damage-abatement models as is pertinent for pest-management technologies (e.g., Lichtenburg and Zilberman, 1986). However, as can be seen in the review and meta-analysis that was undertaken by Alston et al. (2000), perennial crops and their special characteristics have been largely neglected in this literature, and very little of that work has dealt with the specific characteristics of pest- and disease-resistant varieties for perennial crops. The most closely related work is that by Alston et al. (2014), which also addresses costs and benefits of disease-mitigating varietal technology in the California wine grape industry, in this case pertaining to Pierce's Disease (see also Alston et al., 2013; Tumber et al., 2014). The work in the present paper draws in particular on insights from that prior work on modeling Pierce's Disease, and the literature on which that work draws and builds.

Several studies have modeled and measured pertinent aspects of the economics of powdery mildew and its management. Among these are Lybbert and Gubler (2008) and Lybbert et al. (2012), both of which examine how growers react to information about forecasted powdery mildew pressure. The authors found that the response of growers to forecasting information spans multiple dimensions, including fungicide choice and dose, as well as timing, which was the primary focus of the original forecasting model. In addition, growers respond to forecasting information primarily when the disease pressure is high, and grower response varies with location and crop value, with high-value grape growers being more likely to respond with more aggressive methods. Our work extends on those studies by examining the potential economic benefits if growers planted PM-resistant varieties and as a result did not have to manage powdery mildew at all.

2. Background: 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 $3.9 billion, or 9%, of the $43.5 billion worth of agricultural production in California in 2011 (California Department of Food and Agriculture/National Agricultural Statistics Service, 2012a,b), or 91% of the $4.3 billion value of grape production in the United States (United State Department of Agriculture (USDA), 2013). The three categories of grapes have important similarities—they all use varieties of *Vitis vinifera*, and some 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.

2.1. Table grapes

The vast majority (90% of the bearing acreage in 2011) of California table grapes are grown in the southern San Joaquin Valley, defined as crush districts 12, 13, and 14 (CDFA/NASS, 2012a,b).[2] Many varieties are grown for table grape production—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 54% of the total table grape acreage in 2011 (CDFA/NASS, 2012a,b).

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, which we profile in this paper, 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. Pruning vines and removing leaves to expose fruit to sunlight imposes labor costs of over $2,000 per acre each year (University of California Cooperative Extension (UCCE), 2007).

Over the 10 years 2002–2011, annual average real prices (in 2013 dollars) of table grapes ranged from $435 per ton in 2008 up to $832 per ton in 2011(USDA, 2003–2012).[3] Production of table grape varieties climbed slowly, from 739,000 t in 2002 to 1,031,000 t in 2011. Notably, these annual averages of production and prices of table grape varieties include between 20,000 and 55,000 t that are dried for raisins (USDA, 2003–2012). Fig. 1 shows annual average quantities and deflated prices of table grapes for 2002–2011.

2.2. Raisin grapes

Like table grapes, the vast majority (99% of the bearing acreage in 2011) of raisin grapes are grown in the San Joaquin Valley, where they are sun dried (CDFA/NASS, 2003–2012a, b). Raisin production was once very labor intensive; now much of the harvesting and pruning can be done mechanically (Boriss et al., 2013). 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% (Matthew Fidelibus, UCCE Extension Viticulture Specialist, personal communication). Labor costs for continuous tray dried raisins account for 38% of annual operating costs; and materials account for a similar share of costs (UCCE, 2006a).

[2] California has 17 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.

[3] Nominal prices were deflated using the GDP deflator (2013; http://www.bea.gov/iTable/iTable.cfm?reqid=9&step=3&isuri=1&903=13#reqid=9&step=3&isuri=1&904=2002&903=13&906=a&905=2013&910=x&911=0).

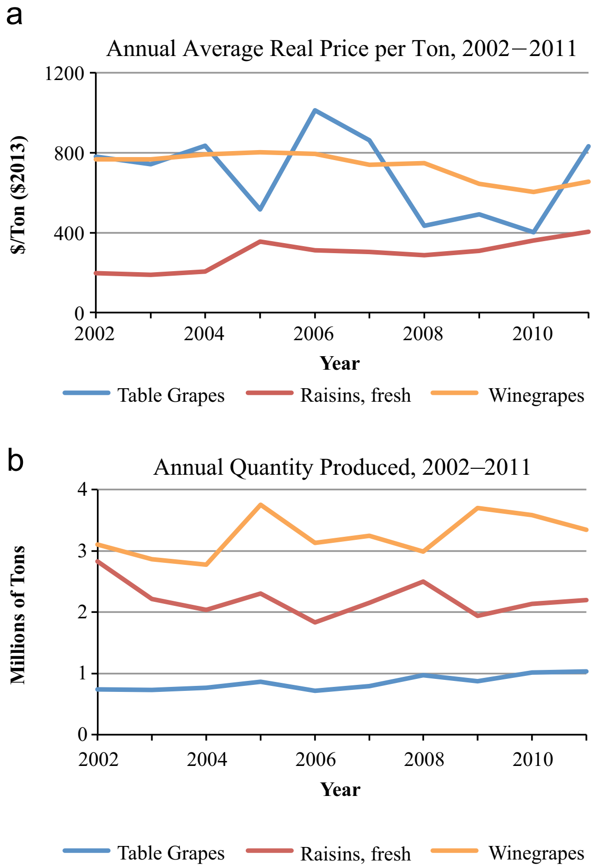

Fig. 1. Annual Average Real Prices and Production of Grapes in California. *Source*: USDA (2003–2012). *Notes*: Raisins and table grapes are reported as the fresh equivalent of fresh and dried fruit. Prices are in 2013 dollars, converted using the BEA GDP deflator (See footnote 3.)

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 common because of the large requirement for short-term labor, which can be difficult to find (Matthew Fidelibus, UCCE Extension Viticulture Specialist, personal communication). Labor accounts for 35% of the total operating costs for this system (UCCE, 2006b).

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 (Matthew Fidelibus, UCCE Extension Viticulture Specialist, personal communication). 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 6 t of dried raisins per acre, while open-gable produces 3 to 4 t per acre, but both types of DOV systems also have somewhat higher costs of establishment and production. Labor costs for these systems are also large, making up between 55% (open-gable trellis) and 67% (overhead trellis) of total operating costs (see UCCE, 2003a, 2003b, respectively). We compare budgets for conventional and resistant systems for each of the four raisin production systems.

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 t of raisins. (The remaining 600,000 t of raisin grapes were sold fresh.) Raisin prices have varied substantially over the past 10 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). Fig. 1 shows annual raisin grape prices (in 2013 dollars) and quantity produced over time—all expressed in fresh equivalents.

2.3. Wine grapes

Wine grapes are the most important type of grape in California in terms of area, quantity, and value of production (CDFA/NASS, 2003–2012a, 2003–2012b). Annual production has varied more for wine grapes across California than for the other grape categories over the past 10 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 (CDFA/NASS, 2003–2012a,b). Fig. 1 shows wine grape production and prices over time.

Wine grapes are produced throughout the state across diverse agroecologies, using a range of production systems, and many varieties. Prices and yields of wine grapes vary widely across the state. In Napa County, on average vineyards produced about 3.3 t per bearing acre of wine grapes per year earning an average crush price of $3145 per ton over the 10 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 t per acre of wine grapes per year and $260 per ton, respectively, over the 10 years, 2002–2011. In the Central Coast region—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 Central Coast was 5.4 t per acre per year during the 10-year time period and the average price was $1,104 per ton (CDFA/NASS, 2003–2012a,b).[4] Lacking adequate detail for each wine grape variety and each region within California, we focus on Central Coast Chardonnay in our analysis.

[4]We calculated the annual average yield as the sum of annual quantities produced during the 2002–2011 time period, divided by the sum of the annual bearing acreage, and calculated annual average nominal price as a quantity-weighted average of nominal prices. Acreage data are from the CDFA/NASS Annual Acreage Reports (CDFA/NASS, 2003–2012a). Price and quantity data are from the CDFA Annual Crush Report (CDFA/NASS, 2003–2012b).

2.4. 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.[5] Conventional breeding work toward 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. Marketing issues may raise some complications when introducing resistance for wine grapes, whether by conventional methods or using transgenic technology. Conventional breeding entails crossing *V. vinifera* varieties, all of which have some susceptibility to PM, with non-*vinifera* grapes, and then back-crossing to obtain a vine with very high *vinifera* content.[6] However, even at nearly 100% *vinifera*, wines made with these hybrid grapes cannot be labeled with the *vinifera* varietal name.[7] For example, if Chardonnay were bred for PM resistance, even if the wine made with those grapes had characteristics identical to that made with Chardonnay, it could not 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* or hybrid grapes historically have not done well in tastings or in the market 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 (M. Andrew Walker, Professor and Grape Plant Breeder, personal communication). 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 some wine consumers might be willing to pay a premium for that aspect (e.g., Bazoche et al., 2008; Schmit et al., 2013). 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). Hence growers could theoretically replace 25% of their volume with PM-resistant "Chardonnay-like" varieties and continue to receive the same or similar price for their grapes.[8]

On the other hand, wines made using grapes from transgenic PM-resistant plants, could potentially 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. (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.) In the markets for table grapes and raisins, varietal labeling is less important, but the potential for market acceptance of transgenic varieties remains uncertain.

3. Methods: Measures of benefits

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 savings in variable costs that would be achieved 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). Then we extrapolate up to the scale of the entire industry under different assumptions about adoption rates.

3.1. Budget models

In most cases, powdery mildew is preventively controlled with a variety of fungicides—yields are not typically affected by the disease. However, the purchase of the fungicides and the costs of applying them entail significant outlays for growers. To examine differences in costs for "conventional" and PM-resistant grape varieties, we constructed budgets (given in Appendix A) for hypothetical "representative" vineyards using a variety of UCCE Cost Studies (UCCE, 2003–2013), combined with consultation with pest control advisors and farm advisors.

We began by obtaining the most recent version of the budget for the production system in question, in the region we were profiling, and the following subsections contain specific information on each of these systems and regions. We then 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, 2010–2013). We used the most recent UCCE Cost Studies available, but in some cases, such as DOV raisin grapes, the most recently available budget was fairly old—10 years for that particular system. The most recent budgets we were able to use were for

[5] Details on conventional breeding of PM-resistant grapes used in this section were elicited from discussion with grape researchers M. Andrew Walker, at the University of California, Davis, and David Ramming, USDA Agricultural Research Service.

[6] An overview of M. Andrew Walker's powdery mildew grape breeding program can be found at http://stream.ucanr.org/fps_wine_research_2011/Walker/index.htm.

[7] Wine labels are regulated by the Alcohol and Tobacco Tax and Trade Bureau. More information can be found at http://www.ttb.gov/wine/wine-labeling.shtml.

[8] If Central Coast Chardonnay growers replaced 25% of their conventional volume of production with that volume grown on resistant stock, the value of that production would be approximately $31.6 million in 2013 dollars, based on the volume-weighted average of the nominal (2011 dollars) price per ton of crushed Chardonnay for the Central Coast of $1,125, and the volume of crushed Chardonnay grapes from that region of 108,925 t (California Department of Food and Agriculture/National Agricultural Statistics Service (CDFA/NASS), 2012a,b). (Price was inflated to 2013 dollars using the BEA GDP deflator; see footnote 2.)

table grapes, which were published for four varieties in 2007. As a result of the lack of availability of recent studies for some of the production systems of interest (especially DOV raisin grape production and Central Coast Chardonnay), we discussed protocols with pest control advisors and drawing on their advice, we derived more recent cost estimates (also based on UCCE grape cost and return studies). Appendix A shows that the resulting budgets borrow from others and, in the case of Central Coast Chardonnay, entail a composite of information from various grape studies (see footnote 9 for the full list of studies from which the Central Coast Chardonnay budget draws). We discussed the revised budgets once again with the appropriate farm or pest control advisors and made further adjustments if necessary.

In the UCCE Cost Studies, which represent specific hypothetical vineyards or a sample of specific farms, in many cases it is not clear which practices are 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 draws 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.

In our sample budgets, the combined cost of fungicide materials and their application amounts to between 9% (for Crimson Seedless table grapes) and 20% (for Central Coast Chardonnay wine grapes) of cultural costs, 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). PM costs are lower for raisins both because they are grown in a relatively low-PM pressure area and because, compared with table grapes, their appearance when they are fresh is much less important since drying them to make raisins obscures many small imperfections.

Table 1
Powdery mildew costs.[a,b]

	Annual PM cost		Costs attributed to PM as a share of		
			Cultural costs[b]	Cash costs	Total costs
	$/acre	*$/t*		*%*	
Raisin grapes					
Continuous tray	222	171	11.7	6.1	4.2
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	15.9	8.2	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

[a]*Source*: See Appendix A for budgets used to make these calculations, and their sources. Costs were 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).

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

3.1.1. Table grapes

Of the available table grape varieties, we chose to profile Crimson Seedless grapes. Crimson Seedless is the second-most most widely planted (after Flame Seedless) in terms of acreage (CDFA/NASS, 2003–2012a,b) and continues to be viewed favorably by growers, unlike several varieties, such as Thompson Seedless, that were once very popular but have now lost favor, most likely because of lower prices and high input costs (see UCCE Cost Studies, 2003–2013).

3.1.2. Raisin grapes

The variety of production systems in use for raisin grapes raises some complexities worth addressing here. Because of a push toward 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. Consequently, we computed the benefit from PM resistance for four raisin production systems: overhead trellis DOV; open gable DOV; traditional tray dried; and continuous tray dried raisin production systems. We assume that all types of raisin production use the same PM protocol, that of the 2006 cost study for continuous tray-dried raisins (UCCE, 2006a), based on advice we received from raisin pest control advisors and a UCCE specialist.

3.1.3. 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 (crush districts 7 and 8) where PM pressures are most severe. Because the latest UCCE Cost and Return study for Chardonnay in the Central Coast was quite old—from 1995, we created a composite budget based on several more recent budgets.[9]

We discussed each of 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

[9]The UCCE Cost and Return studies used to create our Central Coast Chardonnay budget are as follows: Sonoma County Chardonnay (UCCE, 2004), Lake County Sauvignon Blanc (UCCE, 2008), Napa County Sauvignon Blanc (UCCE, 2012a), San Joaquin Valley North Cabernet Sauvignon (UCCE, 2012b), and Sacramento Valley Chardonnay (UCCE, 2013). 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, 2010–2013).

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 the development of fungicide resistance.[10]

3.2. Market level models

We also wanted to examine regional effects, in addition to effects at the vineyard scale. Several points are pertinent here. Not all of the acreage in a given region would be converted immediately to mature PM-resistant vines, even if the technology were immediately available for adoption. Therefore, we allow for an adoption lag. Moreover, even if all the acreage were replaced immediately, growers typically do not begin to apply PM 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.

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 occurs after 20 years of full production, according to the Cost Studies on which we base our budgets), which is represented as a linear 20-year process of increase to the maximum adoption rate, a, and (c) a three-year lag between planting and when powdery mildew treatments typically begin for non-resistant vines, according to the UCCE Cost Studies (UCCE, 2003–2013).

We estimate the total regional change in economic surplus (ΔTS) for each production system over an infinite time horizon, once PM-resistant varieties become available, as the maximum proportion of acreage on which the new resistant varieties will be adopted (a), multiplied by the cost savings from 100% adoption (ΔC), scaled to reflect the 20-year adoption process, and discounted to the present, using a real discount rate, r, of 3% per annum:[11]

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

or

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

[10]Various University of California Cooperative Extension viticultural staff assisted us in compiling budgets for table, raisin, and wine grape production with and without PM-resistant varieties. These staff included Viticultural Specialist Matthew Fidelibus, and Viticultural Farm Advisors Mark Battany, Larry Bettiga, Monica Cooper, and Rhonda Smith. In constructing budgets for table grape production, we consulted additionally with Franka Gabler, Viticulture Research Director, and Ross Jones, Vice President of Viticulture Research and Technical Issues, both at the California Table Grape Commission. We received assistance in constructing raisin budgets from pest control advisors Mike Moriyama, Grower Relations Field Representative, and Rick Stark, Grower Relations Manager, both at Sun-Maid Raisins.

[11]Eqs. (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

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

4. Results and discussion

4.1. Measures of cost savings from resistant varieties

Table 1 shows the total 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 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 PM-resistant varieties. 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. Additionally, because some non-PM treatments are typically applied along with PM treatments, while the materials costs can be easily disaggregated, other elements—including fuel, lube, and tractor repair costs (which are bundled together in the UCCE budgets), as well as the cost of labor to applying the materials—must be attributed to the non-PM treatments in full for the resistant system. Note that, lacking information on how these costs will change, we assume that the PM-resistant vines will cost the same as the conventional 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 $177 per acre in the case of continuous and traditional tray-dried raisin production, and $280 per acre for Central Coast Chardonnay, up to $287 per acre for Crimson Seedless table grapes. The percentage savings in total costs range more widely, from 2% for Crimson Seedless table grapes, up to 6% for Central Coast Chardonnay wine grapes.[12]

4.2. Spillovers: Environmental benefits

While we do not explicitly analyze the potential environmental effects of introducing PM- resistant grape vines, they are worth mentioning here. 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). While the

[12]Note that we are not making any assumptions or inferences about how these cost savings will affect the final markets for grapes, raisins, or wine.

Table 2
Saving in costs per acre from adopting PM-resistant vines.[a]

	Elements of savings in cultural costs				Cost saving as a share of total production cost[b]
	Labor	Fuel, lube, and repair	Materials	Total	
	$/acre/year				%
Raisin grapes					
Continuous tray	25	17	137	178	3.3
Tray	25	16	137	177	3.6
DOV open gable	42	30	137	208	4.4
DOV overhead trellis	43	31	137	211	4.3
Wine grapes					
Central Coast Chardonnay	43	47	190	280	5.8
Table grapes					
Crimson Seedless	77	51	159	287	1.9

[a] *Source:* See Appendix A for budgets used to make these calculations, and their sources. Costs were 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).

[b] 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.

analysis in this paper does not provide a detailed, quantitative analysis of the environmental benefits from switching to PM-resistant vines, we can provide some insight. Table 2 shows our calculated differences in fuel, lube, and repair costs that range from $16 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 less toxic on a per-unit basis than other pesticides 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., 2014), we measure pesticide risk to examine the environmental impact of powdery mildew management using the Environmental Impact Quotient (EIQ), which combines pesticide hazards to farm workers, consumers and the environment. We conclude that sulfur accounts for the largest share of environmental risk using that risk measure, and the benefits from eliminating PM-related fungicide applications would accrue primarily to workers (reduced potential health risks), and through reduced harm to bees and soil.

4.3. 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 effects 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 annual cost saving, by production system, if all current growers in the region were to adopt a new resistant variety. Note that this calculation represents the maximum potential benefit—100% immediate adoption—from these new varieties in the regions we examined. This unrealistic scenario is useful for purposes of illustration as well as to show an intermediate step in our more comprehensive calculations presented in Table 4, which allow for a range of adoption lags and maximum adoption rates. We do not model changes in supply or demand of wine grapes (and therefore wine grape acreage) over time, lacking knowledge about how resistant varieties will fare in the market.

The largest total potential impact is in raisin grapes, which would save $36.4 million per year if all the acreage, 195,899 ac in the San Joaquin Valley in 2011, were converted to PM-resistant production immediately. The corresponding annual cost saving for Central Coast Chardonnay is $7.5 million (at 26,804 ac—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 ac in 2011).

We present estimates of changes in total economic surplus (ΔTS) in Table 4, calculated using methods described in Section 2.3. Lacking information on exactly when these resistant varieties

Table 3
Potential (100% adoption) aggregate annual benefits from adoption of PM-resistant varieties.[a]

	Total area, 2011[b]	Cost reduction per acre[c]	Aggregate benefit, 100% adoption
	Acres	*$/acre/year*	*$million/year*
San Joaquin Valley Raisins			
Continuous Tray	88,155	178	15.7
Tray	58,770	177	10.4
DOV Open Gable	24,487	208	5.1
DOV Overhead Trellis	24,487	211	5.2
Total Raisin	195,899	186	36.4
Central Coast Wine Grapes			
Chardonnay	26,804	280	7.5
San Joaquin Valley Table Grapes			
Crimson Seedless	12,950	287	3.7

[a]See Appendix A for budgets used to make these calculations, and their sources. Costs were 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).

[b]*Source*: CDFA/NASS (2003–2012a,b). Number of acres for individual raisin production systems calculated from CDFA/NASS and Fidelibus (CDFA/NASS, 2013), who estimated percentages in each production system.

[c]Computed as the average of the different production systems, weighted by the number of acres in each.

Table 4
Total present value of benefits from adoption of PM-resistant varieties.[a]

Maximum adoption rate (%)	Lag (L+3, Years)[b]			
	10	20	30	40
	$ Millions			
Raisins: all types[c]				
20	124.0	92.3	68.6	51.1
60	372.0	276.8	205.9	153.2
100	619.9	461.3	343.2	255.4
Wine grapes: Central Coast Chardonnay				
20	25.6	19.0	14.2	10.5
60	76.8	57.1	42.5	31.6
100	127.9	95.2	70.8	52.7
Table grapes: Crimson Seedless				
20	12.6	9.4	7.0	5.2
60	37.9	28.2	21.0	15.6
100	63.2	47.0	35.0	26.0

[a]See Appendix for budgets used to make these calculations, and their sources. Costs were 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). We use a 3% real discount rate.

[b]The total lag includes the R&D lag, L, plus a gestation lag of three years after adoption before costs are affected.

[c]Raisins in this table represent the combined total of continuous tray, traditional tray-dried, and DOV systems.

will become available and the subsequent rates of adoption, we use a range of 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). 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; 10 years is possible for that category, whereas resistant varieties of wine and table grapes could take significantly longer to be developed and become available to growers.[13] Note that we evaluate the change in total surplus based on current acreage; we do not model changes in grape acreage over time.

The range of estimated benefits is substantial. The present value of the benefit from PM-resistant vines for raisins ranges from as low as $51 million if it takes 40 years until the resistant vines are available and they are adopted by only 20% of growers, up to $620 million if they become available in 10 years and are adopted by 100% of growers. In present value terms, the total benefits from PM-resistant varieties of Central Coast Chardonnay winegrapes range from $10 million to $127 million, and the benefits from PM-resistant varieties of Crimson Seedless table grapes range from $5 million to $63 million.

5. Conclusion

PM-resistant varieties of grapes could yield large economic benefits to California grape growers—potentially allowing cost savings as high as $48 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 systems. On a per-acre basis, table grapes have the greatest potential cost savings. In present value terms, the benefits are quite sensitive both to the R&D lag until the resistant varieties become available for adoption and the ultimate maximum rate of adoption. PM-resistant raisin grapes, which will likely be available soonest and adopted more readily, will likely yield the largest overall benefits among the systems and regions we have examined.

Our measures of the potential cost savings represent only part of the economic picture for two reasons. First, they count only part of

[13]We interviewed grape researchers M. Andrew Walker, at the University of California, Davis, and David Ramming, at the USDA Agricultural Research Service (ARS), regarding their research on PM-resistant wine, table, and raisin grape varieties, and the expected time to availability of those varieties.

the potential cost savings. Specifically, the measured cost savings refer only to private pecuniary costs borne 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, the prices of grapes grown using PM-resistant varieties may differ from those of grapes from the conventional varieties they would replace. 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. (Growers could see a large cost of production savings but still be worse off if the price they receive for their grapes decreases sufficiently.) Even if it is not prohibitive, any price discount will offset the benefits from cost savings to some extent.

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Appendix A. Sample Budgets for Conventional and PM Resistant Raisin Grape Production

Tables A1 and A2 are based on the 2006 Continuous Tray Dried Raisin Cost Study (UCCE, 2006a). Tables A3 and A4 are based on the 2006 Tray Dried Raisin Cost Study (UCCE, 2006b). Tables A5 and A6 are based on the 2003 DOV Open Gable Trellis Raisin Cost Study (UCCE, 2003a). Tables A7 and A8 are based on the 2003 DOV Overhead Trellis Raisin Cost Study (UCCE, 2003b). Tables A9 and A10 are based on a variety of cost studies as follows: Sonoma County Chardonnay (UCCE, 2004), Lake County Sauvignon Blanc (UCCE, 2008), Napa County Sauvignon Blanc (UCCE, 2012a), San Joaquin Valley North Cabernet Sauvignon (UCCE, 2012b), and Sacramento Valley Chardonnay (UCCE, 2013). Tables A11 and A12 are based on the 2007 Crimson Seedless Table Grape Cost Study (UCCE, 2007). All budgets were created in consultation with University of California Cooperative Extension staff, including Viticultural Specialist Matthew Fidelibus, and Viticultural Farm Advisors Mark Battany, Larry Bettiga, Monica Cooper, and Rhonda Smith. In constructing budgets for table grape production, we consulted additionally with Frank Gabler, Viticulture Research Director, and Ross Jones, Vice President of Viticulture Research and Technical Issues, both at the California Table Grape Commission. We received assistance in constructing raisin budgets from pest control advisors Mike Moriyama, Grower Relations Field Representative, and Rick Stark, Grower Relations Manager, both at Sun-Maid Raisins. Ending sulfur treatments can result in an erineum mite infestation, so we assume a wettable sulfur treatment would be retained in the resistant production system. For powdery mildew control products applied with other products, we disaggregated the two groups of costs by taking the individual materials costs from the front matter of the cost study (UCCE, 2006a). Labor, fuel, lube, and repair costs were split evenly between the products/applications. All costs are inflated 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, 2010–2013). All entries represent one application or action unless otherwise noted.

Table A1
Costs per acre to produce grapes for raisins (conventional, continuous tray-dried)

Operation	Labor	Fuel, lube, repair	Materials	Custom/rent	Total
PM controls			*$2013/acre*		
Microthiol	6	5	2	0	12
Dusting sulfur 3 × (alternate rows)	17	11	5	0	32
Rally and Microthiol	18	14	65	0	97
Microthiol and Flint	6	5	69	0	80
Typically applied with PM controls					
Phomopsis control (Abound)	6	5	49	0	60
Foliar zinc fertilizer	6	6	8	0	20
Skeletonizer control (Kryocide)	6	5	28	0	38
Berry size (gibberelic acid) and leafhopper control (Provado)	14	11	88	0	113
Other cultural practices					
Prune vines	408	0	0	0	408
Brush disposal (every middle)	7	5	0	0	12
Tie canes	77	0	12	0	89
Winter weed control (Surflan, Roundup)	13	6	71	0	90

Table A1 (*continued*)

Operation	Labor	Fuel, lube, repair	Materials	Custom/rent	Total
Mealybug control (Lorsban)	14	9	42	0	64
Disk middles 2 ×	16	8	0	0	23
Nitrogen fertilizer	0	0	25	0	25
Irrigation	94	0	245	0	338
Spot spray for weeds (Roundup)	43	5	20	0	68
Cane cutting	16	8	0	0	23
Leafhopper control (Provado) and fruit setting (Ethrel)	14	9	79	0	101
Disk and roll middles for harvest prep	8	5	0	0	12
Disk middles and incorporate trash	8	5	0	0	12
Pickup truck use	57	65	0	0	122
ATV use	54	5	0	0	59
Total costs					
Total PM	48	34	140	0	222
Total non-PM cultural	860	154	666	0	1,680
Total cultural	908	188	806	0	1,902
Total harvest	176	63	249	462	951
Total operating	1,084	251	1,055	462	2,853
Total cash overhead					807
Total cash					3,660
Total non-cash overhead					1,668
Total cost per acre					**5,327**

Table A2
Costs per acre to produce grapes for raisins (resistant, continuous tray-dried)

Operation	Labor	Fuel, lube, repair	Materials	Custom/rent	Total
Necessary without PM controls:			*$2013/acre*		
Erineum mite control (wettable sulfur)	4	3	3	0	11
Typically applied with PM controls					
Phomopsis control (Abound)	12	9	49	0	71
Foliar zinc fertilizer	12	11	8	0	31
Skeletonizer control (Kryocide)	12	9	28	0	49
Berry size (gibberelic acid) and leafhopper control (Provado)	14	11	88	0	113
Other cultural practices					
Prune vines	408	0	0	0	408
Brush disposal (every middle)	7	5	0	0	12
Tie canes	77	0	12	0	89
Winter weed control (Surflan, Roundup)	13	6	71	0	90
Mealybug control (Lorsban)	14	9	42	0	64
Disk middles 2 ×	16	8	0	0	23
Nitrogen fertilizer	0	0	25	0	25
Irrigation	94	0	245	0	338
Spot spray for weeds (Roundup)	43	5	20	0	68
Cane cutting	16	8	0	0	23
Leafhopper control (Provado) and fruit setting (Ethrel)	14	9	79	0	101
Disk and roll middles for harvest prep	8	5	0	0	12
Disk middles and incorporate trash	8	5	0	0	12
Pickup truck use	57	65	0	0	122
ATV use	54	5	0	0	59
Total costs					
Total PM	0	0	0	0	0
Total non-PM cultural	883	172	669	0	1,724
Total cultural	883	172	669	0	1,724
Total harvest	176	63	249	462	951
Total operating	1,059	235	919	462	2,674
Total cash overhead					807
Total cash					3,481
Total non-cash overhead					1,668
Total cost per acre					**5,149**

Table A3
Costs per acre to produce grapes for raisins (conventional, tray dried Thompson Seedless).

Operation	Labor Cost	Fuel, lube and repair	Material cost	Custom/rent	Total $/acre
PM controls:					*$2013/acre*
Microthiol	6	5	2	0	12
Dusting sulfur 3 × (alternate rows)	17	11	5	0	32
Rally and Microthiol	18	14	65	0	97
Microthiol and Flint	6	5	69	0	80
Typically applied with PM controls:					
Phomopsis control (Abound)	6	5	49	0	60
Foliar zinc fertilizer	6	5	8	0	19
Skeletonizer control (Kryocide)	6	5	28	0	38
Berry size (gibberelic acid) and leafhopper control (Provado)	14	11	88	0	113
Other cultural practices:					
Prune vines	408	0	0	0	408
Brush disposal (every middle)	6	5	0	0	11
Tie canes	77	0	12	0	89
Winter weed control (Surflan, Roundup)	12	6	71	0	89
Mealybug control (Lorsban)	12	9	42	0	63
Nitrogen fertilizer	0	0	25	0	25
Irrigation	94	0	245	0	339
Spot spray for weeds (Roundup)	37	5	20	0	62
Skirt canes (2 ×)	14	8	0	0	22
Disk middles	20	12	0	0	32
Build terrace and terrace back	20	12	0	0	32
Pickup truck use	55	57	0	0	112
ATV use	48	5	0	0	52
Total costs					
Total PM	48	34	140	0	222
Total non-PM	836	144	587	0	1,567
Total cultural	884	178	727	0	1,789
Total harvest	86	11	119	750	966
Total operating/acre	970	189	846	750	2,755
Total cash overhead					470
Total cash costs/acre					3,224
Total non-cash overhead					1,742
Total cost per acre					**4,966**

Table A4
Costs per acre to produce grapes for raisins (resistant, tray dried Thompson Seedless).

Operation	Labor cost	Fuel, lube and repair	Material cost	Custom/rent	Total $/acre
Necessary without PM controls			*$2013/acre*		
Erineum mite control (wettable sulfur)	4	3	3	0	11
Typically applied with PM controls:					
Phomopsis control (Abound)	12	9	49	0	71
Foliar zinc fertilizer	12	11	8	0	31
Skeletonizer control (Kryocide)	12	9	28	0	49
Berry size (gibberelic acid) and leafhopper control (Provado)	14	11	88	0	113
Other cultural practices:					
Prune vines	408	0	0	0	408
Brush disposal (every middle)	6	5	0	0	11
Tie canes	77	0	12	0	89
Winter weed control (Surflan, Roundup)	12	6	71	0	89
Mealybug control (Lorsban)	12	9	42	0	63
Nitrogen fertilizer	0	0	25	0	25
Irrigation	94	0	245	0	339
Spot spray for weeds (Roundup)	37	5	20	0	62
Skirt canes (2 ×)	14	8	0	0	22
Disk middles	20	12	0	0	32
Build terrace and terrace back	20	12	0	0	32
Pickup truck use	55	57	0	0	112
ATV use	48	5	0	0	52

Table A4 (*continued*)

Operation	Labor cost	Fuel, lube and repair	Material cost	Custom/rent	Total $/acre
Total costs					
Total PM	0	0	0	0	0
Total non-PM	859	162	591	0	1,612
Total cultural	859	162	591	0	1,612
Total harvest	86	11	119	750	966
Total operating/acre	945	173	709	750	2,577
Total cash overhead					470
Total cash costs/acre					3,047
Total non-cash overhead					1,742
Total cost per acre					**4,789**

Table A5
Costs per acre to produce grapes for raisins (conventional, DOV overhead trellis).

Operation	Labor cost	Fuel, lube and repair	Material cost	Custom/rent	Total $/acre
PM controls:			*2013$/acre*		
Microthiol	6	5	2	0	12
Dusting sulfur 3 × (alternate rows)	17	11	5	0	32
Rally and Microthiol	18	14	65	0	97
Microthiol and Flint	6	5	69	0	80
Typically applied with PM controls:					
Worm control (Cryolite) and foliar zinc fertilizer	4	2	28	0	34
Berry size (gibberelic acid) and leafhopper control (Provado)	13	10	83	0	106
Other cultural practices:					
Prune vines	349	0	0	0	349
Tie canes	159	0	0	0	159
Shoot thinning and trunk suckering	60	0	0	0	60
Renewal fruit removal	119	0	0	0	119
Shoot positioning	139	0	0	0	139
Irrigation	2	0	13	0	14
Fertilize	5	0	13	0	18
Spot spray for weeds 20% of acres	13	2	16	0	31
Pickup truck use	65	27	0	0	92
ATV use	43	5	0	0	49
Total costs					
Total PM	48	34	140	0	222
Total non-PM	971	47	153	0	1,170
Total cultural	1,019	81	293	0	1,392
Total harvest	448	33	0	206	687
Total operating/acre	1,467				2,238
Total cash overhead					473
Total cash costs/acre					2,711
Total non-cash overhead					2,152
Total cost per acre					**4,864**

Table A6
Costs per acre to produce grapes for raisins (resistant, DOV overhead trellis).

Operation	Labor cost	Fuel, lube and repair	Material cost	Custom/rent	Total $/acre
Necessary without PM controls					*2013$/acre*
Erineum mite control (wettable sulfur)	4	3	3	0	11
Typically applied with PM controls:					
Worm control (Cryolite) and foliar zinc fertilizer	4	2	28	0	34
Berry size (gibberelic acid) and leafhopper control (Provado)	13	10	83	0	106
Other cultural practices:					
Prune vines	349	0	0	0	349

Table A6 (*continued*)

Operation	Labor cost	Fuel, lube and repair	Material cost	Custom/rent	Total $/acre
Tie canes	159	0	0	0	159
Shoot thinning and trunk suckering	60	0	0	0	60
Renewal fruit removal	119	0	0	0	119
Shoot positioning	139	0	0	0	139
Irrigation	2	0	13	0	14
Nitrogen fertilizer	5	0	13	0	18
Spot spray for weeds (20% of acres)	13	2	16	0	31
Pickup truck use	65	27	0	0	92
ATV use	43	5	0	0	49
Total costs					
Total PM	0	0	0	0	0
Total non-PM	975	50	156	0	1,181
Total cultural	975	50	156	0	1,181
Total harvest	448	33	0	206	687
Total operating/acre					2,571
Total cash overhead					473
Total cash costs/acre					3,045
Total non-cash overhead					2,152
Total cost per acre					**4,653**

Table A7
Costs per acre to produce grapes for raisins (conventional, DOV open gable trellis).

Operation	Labor cost	Fuel, lube and repair	Material cost	Custom/rent	Total $/acre
PM controls:			*2013$/acre*		
Microthiol	6	5	2	0	12
Dusting sulfur 3 × (alternate rows)	17	11	5	0	32
Rally and Microthiol	18	14	65	0	97
Microthiol and Flint	6	5	69	0	80
Typically applied with PM controls:					
Worm control (Cryolite) and foliar zinc fertilizer	4	2	28	0	34
Berry size (gibberelic acid) and leafhopper control (Provado)	13	10	83	0	106
Other cultural practices:					
Prune vines	219	0	0	0	219
Tie canes	110	0	0	0	110
Shoot thinning and trunk suckering	60	0	0	0	60
Renewal fruit removal	90	0	0	0	90
Shoot positioning	60	0	0	0	60
Nitrogen fertilizer	2	0	14	0	16
Irrigation	56	0	219	0	275
Spot spray for weeds (20% of acres)	13	2	16	0	31
Pickup truck use	65	27	0	0	92
ATV use	43	5	0	0	49
Total costs					
Total PM	48	34	140	0	222
Total non-PM	734	47	361	0	1,142
Total cultural	782	81	501	0	1,363
Total harvest	405	61	0	193	660
Total operating/acre					2,157
Total cash overhead					473
Total cash costs/acre					2,630
Total non-cash overhead					2,152
Total cost per acre					**4,782**

Table A8
Costs per acre to produce grapes for raisins (resistant, DOV open gable trellis).

Operation	Labor cost	Fuel, lube and repair	Material cost	Custom/rent	Total $/acre
Necessary without PM controls			*2013$/acre*		
Erineum mite control (wettable sulfur)	4	3	3	0	11
Typically applied with PM controls:					
Worm control (Cryolite) and foliar zinc fertilizer	5	4	28	0	37
Berry size (gibberelic acid) and leafhopper control (Provado)	13	10	83	0	106
Other cultural practices:					
Prune vines	219	0	0	0	219
Tie canes	110	0	0	0	110
Shoot thinning and trunk suckering	60	0	0	0	60
Renewal fruit removal	90	0	0	0	90
Shoot positioning	60	0	0	0	60
Nitrogen fertilizer	2	0	14	0	16
Irrigation	56	0	219	0	275
Spot spray for weeds (20% of acres)	13	2	16	0	31
Pickup truck use	65	27	0	0	92
ATV use	43	5	0	0	49
Total costs					
Total PM	0	0	0	0	0
Total non-PM	740	51	364	0	1,155
Total cultural	740	51	364	0	1,155
Total harvest	405	61	0	193	660
Total operating/acre					1,949
Total cash overhead					473
Total cash costs/acre					2,422
Total non-cash overhead					2,152
Total cost per acre					**4,574**

Table A9
Costs per acre to produce Central Coast winegrapes–Chardonnay (conventional)

Operation	Labor cost	Fuel, lube and repair	Material cost	Custom/rent	Total $/acre
PM controls:			*2013$/acre*		
Rally 2 ×	30	22	70	0	121
Quintec	8	10	31	0	48
Flint	15	11	45	0	70
Stylet oil 3 ×	20	16	93	0	130
Typically applied with PM controls:					
Botrytis control (Vanguard)	24	8	23	0	55
Other cultural practices:					
Prune vines	200	0	0	0	200
Trim vines	13	16	0	0	29
Trunk suckering	66	0	0	0	66
Shoot removal and positioning	199	0	0	0	199
Nitrogen fertilizer 5 × (with irrigation)	0	0	32	0	32
Phosphorus fertilizer 4 × (with irrigation)	0	0	121	0	121
Vertebrate pest control (bait)	5	3	8	0	16
Weed control (disking) 2 ×	15	17	0	0	31
Weed control, 25% of rows 3 × (Roundup)	27	6	19	0	52
Winter weed control (Surflan)	9	2	34	0	45
Frost control	120	0	292	0	412
Irrigation	67	0	35	0	102
Weed control on strip (Roundup)	7	1	3	0	11
Pickup truck use	38	28	0	0	66
ATV use	16	3	0	0	19
PCA and irrigation monitoring fees	0	0	0	55	55
Total costs					
Total PM	85	58	239	0	369
Total non-PM	794	84	566	55	1,511
Total cultural	879	142	805	0	1,880
Total harvest	0	1	10	446	457

Table A9 (*continued*)

Operation	Labor cost	Fuel, lube and repair	Material cost	Custom/rent	Total $/acre
Total operating/acre	879	143	815	501	2,337
Total cash overhead					650
Total cash costs/acre					2,987
Total non-cash overhead					1,809
Total cost per acre					**4,796**

Table A10
Costs per acre to produce Central Coast winegrapes—Chardonnay (resistant).

Operation	Labor cost	Fuel, lube and repair	Material cost	Custom/rent	Total $/acre
Necessary without PM controls			*2013$/acre*		
Erineum mite control (wettable sulfur)	4	3	3	0	11
Typically applied with PM controls:					
Botrytis control (Vanguard)	49	16	68	0	133
Other cultural practices:					
Prune vines	200	0	0	0	200
Trim vines	13	16	0	0	29
Trunk suckering	66	0	0	0	66
Shoot removal and positioning	199	0	0	0	199
Nitrogen fertilizer 5 × (with irrigation)	0	0	32	0	32
Phosphorus fertilizer 4 × (with irrigation)	0	0	121	0	121
Vertebrate pest control (bait)	5	3	8	0	16
Weed control (disking) 2 ×	15	17	0	0	31
Weed control, 25% of rows 3 × (Roundup)	27	6	19	0	52
Winter weed control (Surflan)	9	2	34	0	45
Frost control	120	0	292	0	412
Irrigation	67	0	35	0	102
Weed control on strip (Roundup)	7	1	3	0	11
Pickup truck use	38	28	0	0	66
ATV use	16	3	0	0	19
PCA and irrigation monitoring fees	0	0	0	55	55
Total costs					
Total PM	0	0	1	0	0
Total non-PM	835	95	614	55	1,600
Total cultural	835	95	615	55	1,600
Total harvest	0	0	10	446	456
Total operating/acre	835	95	625	501	2,056
Total cash overhead					650
Total cash costs/acre					2,706
Total non-cash overhead					1,809
Total cost per acre					**4,515**

Table A11
Costs per acre to produce table grapes—Crimson Seedless (conventional).

Operation	Labor cost	Fuel, lube and repair	Material cost	Custom/rent	Total $/acre
PM controls:			*$2013/acre*		
Microthiol 2 ×	11	8	4	0	24
Dusting sulfur 3 ×	22	13	9	0	43
Rally and Microthiol 4 ×	40	30	132	0	201
Dusting sulfur on stem 4 ×	29	17	13	0	59
Typically applied with PM controls:					
Phomopsis (Abound)	7	5	49	0	61
Foliar zinc fertilizer	7	5	7	0	19
Bloom thin (gibberelic acid) and skeletonizer control (Kryocide)	9	7	28	0	44
Berry size (gibberelic acid) and leafhopper control (Provado)	7	5	83	0	95
Other cultural practices:					
Layering missing vines	16	0	0	0	16
Prune vines	623	0	0	0	623

Table A11 (*continued*)

Operation	Labor cost	Fuel, lube and repair	Material cost	Custom/rent	Total $/acre
Shred prunings	13	10	0	0	23
Trellis repair	33	0	14	0	48
Tie canes	130	0	20	0	151
Winter weed control (Surflan, Roundup)	13	7	58	0	78
Vertebrate pest control (various methods)	0	0	22	0	22
Mealybug control (Lorsban)	13	10	36	0	59
Mow middles 3 ×	19	16	0	0	35
Trunk suckering	33	0	0	0	33
Nitrogen fertilizer	0	0	33	0	33
Irrigation	42	0	239	0	281
Shoot positioning and removal	246	0	0	0	246
Fruit exposure and leaf removal	820	0	0	0	820
Cluster thinning	164	0	0	0	164
Girdling	197	0	0	0	197
Cane cutting	7	4	0	0	12
Spot spray for weeds (Roundup)	13	1	6	0	20
Fruit color development (Ethrel)	13	10	12	0	35
Botrytis control (Vanguard)	13	10	68	0	91
Pickup truck use	61	58	0	0	119
ATV use	51	4	0	0	55
Total costs					
Total PM	101	69	159	0	329
Total non-PM	2,548	154	676	0	3,378
Total cultural	2,649	223	836	0	3,707
Total harvest	4,621	23	2,959	1,825	9,427
Total operating/acre	7,270	246	3,794	1,825	13,134
Total cash overhead					426
Total cash costs/acre					13,560
Total non-cash overhead					1,920
Total cost per acre					**15,480**

Table A12
Costs per acre to produce table grapes—Crimson Seedless (resistant).

Operation	Labor cost	Fuel, lube and repair	Material cost	Custom/rent	Total $/acre
Necessary without PM controls:			*2013$/Acre*		
Erineum mite control (wettable sulfur)	4	3	3	0	11
Typically applied with PM controls:					
Phomopsis (Abound)	13	10	49	0	72
Foliar zinc fertilizer	13	10	7	0	30
Bloom thin (gibberelic acid) and skeletonizer control (Kryocide)	13	10	28	0	52
Berry size (gibberelic acid) and leafhopper control (Provado)	13	10	83	0	106
Other cultural practices:					
Layering missing vines	16	0	0	0	16
Prune vines	623	0	0	0	623
Shred prunings	13	10	0	0	23
Trellis repair	33	0	14	0	48
Tie canes	130	0	20	0	151
Winter weed control (Surflan, Roundup)	13	7	58	0	78
Vertebrate pest control (various methods)	0	0	22	0	22
Mealybug control (Lorsban)	13	10	36	0	59
Mow middles 3 ×	19	16	0	0	35
Trunk suckering	33	0	0	0	33
Nitrogen fertilizer	0	0	33	0	33
Irrigation	42	0	239	0	281
Shoot positioning and removal	246	0	0	0	246
Fruit exposure and leaf removal	820	0	0	0	820
Cluster thinning	164	0	0	0	164
Girdling	197	0	0	0	197
Cane cutting	7	4	0	0	12

Table A12 (*continued*)

Operation	Labor cost	Fuel, lube and repair	Material cost	Custom/rent	Total $/acre
Spot spray for weeds (Roundup)	13	1	6	0	20
Fruit color development (Ethrel)	13	10	12	0	35
Botrytis control (Vanguard)	13	10	68	0	91
Pickup truck use	61	58	0	0	119
ATV use	51	4	0	0	55
Total costs					
Total PM	0	0	0	0	0
Total non-PM	2,572	172	676	0	3,421
Total cultural	2,572	172	676	0	3,421
Total harvest	4,621	23	2,959	1,825	9,427
Total operating/acre	7,193	195	3,635	1,825	12,848
Total cash overhead					426
Total cash costs/acre					13,274
Total non-cash overhead					1,920
Total cost per acre					**15,194**

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