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*Patterns of Pesticide Use in California and The Implications for Strategies for Reduction of Pesticides*
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**SUPPLEMENTAL TABLE 1** The cumulative area of vegetable, fruit and nut crops treated in California fields between 1993 and 2000 with pesticides used to control plant diseases that are not on "risk lists" included in Table 1[a]

| Compound[a] | Class[b] | Type | Area treated in year 2000, $km^2$ | Regression estimates, slope in $km^2$ $year^{-1}$ $\pm$ SE[c] |
|---|---|---|---|---|
| Copper | B, F | Inorganic | 6735 | 288 $\pm$ 210 |
| Dicloran | F | Aromatic | 250 | 19 $\pm$ 12 |
| Fenarimol | F | Pyrimidine | 908 | -177 $\pm$ 36*[d] |
| Fosetyl-Al | F | Organophosphorus | 521 | -23 $\pm$ 20 |
| Lime Sulfur | F | Inorganic | 201 | 26 $\pm$ 10* |
| Metalaxyl | F | Anilide | 84 | -276 $\pm$ 66* |
| Oxytetracycline | B | Antibiotic | 278 | 6 $\pm$ 4 |
| Sulfur | F | Inorganic | 24,861 | 551 $\pm$ 374 |
| Thiram | F | Dithiocarbamate | 175 | -9 $\pm$ 4 |
| Ziram | F | Dithiocarbamate | 815 | -20 $\pm$ 43 |

[a] Only compounds in which more than 50 $km^2$ were treated in 2000 are shown.
[b] B, bactericide; F, fungicide.
[c] From 1993 to 2000.
[d] *Slope not equal to 0, $P<0.05$.

**SUPPLEMENTAL TABLE 2** "Conventional" pesticides that were used to control diseases of vegetable, fruit and nut crops in California fields, but whose use started after 1993[a]

| Compound[a] | *Type* | Site of inhibition | Area treated in year 2000, $km^2$ | Year first used commercially in California | Registered with US EPA as a reduced risk product? |
|---|---|---|---|---|---|
| Azoxystrobin | *Strobilurin* | Complex III of the mitochondrial electron transfer chain (ETC) | 2152 | 1997 | Yes |
| Cyprodinil | Anilino-pyrimidine | Unknown; methionine biosynthesis? | 1259 | 1998 | Yes |
| Fenhexamid | Anilide | Unknown | 217 | 1999 | Yes |
| Mefanoxam | Phenylamide | RNA polymerase | 1258 | 1996 | Yes |
| Propiconazole | Triazole | C14 demethylation in sterol biosynthesis (SB) | 468 | 1996 | No |
| Tebuconazole | Trizole | C14 demethylation in SB | 1132 | 1997 | No |
| Trifloxystrobin | Strobilurin | Complex III of the mitochondrial ETC | 793 | 2000 | Yes |
| Triflumizole | Imidazole | C14 demethylation in SB | 632 | 1995 | No |

[a] Only compounds in which more than 200 $km^2$ were treated in 2000 are shown

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**SUPPLEMENTAL TABLE 3** Grower's programs for fungicidal control of powdery mildew on grapes in California

| Region[a] | Requisite days of protection and dates[b] | County[c] | Type of grape[d] | Area planted, 1995, km$^{2}$ [e] | No. growers in 1995[f] | % Growers using less than no. days in column B, 1995[g] |
|---|---|---|---|---|---|---|
| North Coast | 134 da | Napa | Wine | 167 | 198 | 99 |
| | (17 March--28 July) | Sonoma | Wine | 173 | 244 | 95 |
| Central Coast | 168 da (1 March--August 15) | Monterey | Wine | 143 | 31 | 90 |
| Northern SJV | 120 da (17 March--14 July) | San Joaquin | Wine | 272 | 284 | 100 |
| Southern SJV | 119 da (17 March--13 July) except as noted with * for 167 da (17 March--31 August)[h] - | Fresno | Non-wine | 751 | 1426 | 91 |
| | | | Wine | 180 | 216 | 86 |
| | | Madera | Non-wine | 150 | 225 | 88 |
| | | | Wine | 184 | 156 | 89 |
| | | Kern | Non-wine* | 217 | 96 | 97* |
| | | | Wine | 114 | 52 | 79 |
| | | Tulare | Non-wine* | 221 | 239 | 98* |

[a] Regions are from Flaherty et al. (27). SJV, San Joaquin Valley.
[b] Based on Flaherty et al. (27) and personal communications with Cooperative Extension Personnel for the more susceptible varieties. Actual dates are based on the period from bud break to mid-veraison and vary from year to year.
[c] Counties with >150 km$^{2}$ of either wine or "non-wine" vineyards are shown.
[d] Non-wine grapes includes grapes for juicing, raisins, and fresh market.
[e] Area planted of all growers in the county. Data were calculated from the California Pesticide Use Reports
[f] Number of growers after data trimming of sites and exclusion of growers with less than 0.1 km$^{2}$ planted.
[g] The year 1995 was selected because it was before the introduction of the Gubler-Thomas environmentally driven model.
[h] The 119-da period estimate is for vines with wine grapes, and grapes used for juicing and raisins. The 167-da period estimate is for "table" grapes for fresh market, which are typically protected for a longer period. In Kern and Tulare Counties, a greater percentage of non-wine grapes are for fresh market than in the other counties shown. Sixty nine % and 87% of the growers of non-wine grapes in Kern and Tulare counties, respectively, had less than a minimum of 119 days of protection.

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**SUPPLEMENTAL TABLE 4** Vegetable, fruit and nut crops in California fields in which 25 $km^2$ or more were treated with pheromones in 2000 for mating confusion as a component of an insect control program.

| Crop | Cumulative area treated, $km^2$ [a] | Percentage of crop area treated |
|---|---|---|
| Grapes, wine | 141 | 4 |
| Peach | 67 | 13 |
| Tomato, processing | 34 | 3 |
| Nectarine | 33 | 15 |
| Grapes, non-wine | 31 | 2 |
| Pear | 29 | 33 |

[a] On treated sites, the median number of treatments per site was one

**SUPPLEMENTAL TABLE 5** The use of comparatively high usage insecticides that have activity against pests controlled with the *Bacillus thuringiensis* (*Bt*) toxin on cotton plants in the Imperial and Palo Verde Valleys in southern California before and after the introduction of genetically modified (GM) cotton that produces the *Bt* toxin[a]

| | Percentage decrease in use of insecticides in the period after ≥ 80%of the land was planted with genetically modified cotton (1998--2000) in comparison to the period before its introduction (1993--1995) [b] | | | | Avg. kg a.i. applied per year in the period after ≥ 80% of the land was planted with genetically modified cotton (1998--2000) | |
|---|---|---|---|---|---|---|
| | Area treated/ area planted | | Kg ai applied/ area planted | | | |
| | Valley | | | | | |
| Insecticide | Imperial | Palo Verde | Imperial | Palo Verde | Imperial | Palo Verde |
| Acephate | -13 | -22 | -14 | -11 | 3815 | 3329 |
| Amitraz | -93 | -40 | -85 | -26 | 30 | 72 |
| Bifenthrin | -62 | -76 | -50 | -61 | 67 | 73 |
| Chlorpyrifos | -74 | -94 | -77 | -93 | 220 | 277 |
| Endosulfan | -96 | -89 | -95 | -88 | 78 | 431 |
| Fenpropathrin | -36 | -72 | -29 | -63 | 1050 | 863 |
| Methamidophos | -66 | -95 | -81 | -98 | 251 | 1 |

[a] Insecticide use data are from the California Pesticide Use Reports, the area planted data are from the Imperial and Riverside counties' Agricultural Commissioner's Offices, and the GM data are from the California Department of Food and Agriculture's Pink Bollworm Program.
[b] In cases in which the material was not registered in 1993 (i.e., fenpropathrin), the pre-introduction period was limited to the appropriate years.
[c] Data shown are only for those compounds in which more than 50 kg per year were applied in either valley in the 1998 to 2000 period. The six compounds that are not shown also declined in use.

SUPPLEMENTAL NOTES

**Supplemental note 1**. **PUR records.** Each record contains information on the following: a grower identification code; the crop treated; the number of acres of the crop that the grower planted; the grower's identification of the particular field treated (the site location identification); the geographic location of the treated field to within a square mile; the county; the application date; the active ingredient; the number of acres (or other units) treated; the type of units, e.g., acres; the pounds of active ingredient applied; the pesticide product used; the formulation; the pounds of product applied, whether the application was by air or on the ground; and whether a grower or a commercial pest control operator filed the report.

**Supplemental note 2**. **PUR data cleaning.** We limited errors in area planted and area treated in the following way. Because each PUR "site" is limited to a geographical section, which is generally but not always 2.6 $km^2$, if the area planted was greater than 5.2 $km^2$, the area planted was set to 5.2 $km^2$. Then, if area treated was greater than area planted, the area treated was set to the area planted. In cases in which the mass of pesticide applied was calculated, for each chemical in each county in each year, the observations with the 5% highest kg applied per $km^2$ and the 5% lowest kg applied per $km^2$ were "trimmed," i.e., deleted. Then the totals were scaled by total area per area remaining after trimming. That is, the highest and lowest values of application rates in kg per $km^2$ were replaced by the means. Comparisons of the "raw" sums with the trimmed, adjusted sums were discussed previously (7).

**Supplemental note 3. Analysis of the decline in pesticide use between 1998 to 2000.** To determine if the decline between 1998 and 2000 was a trend or a fluctuation, we determined the probability that a value as high as in 1998 would be followed by two-year decline to a value as low as in 2000. We assumed a stationary, normal distribution of values, and determined the *P*-value of a two-year decline from direct integration from a bivariate normal distribution. As examples, the probability that a two-year decline from the high 1998 values to the low 2000 values for the four compounds shown in Supplemental Figure 3 had *P*-values ranging from 0.2 (chlorothalonil) to 0.6 (maneb).

**Supplemental note 4**. **Newer reduced-risk fungicides.** Three "non-conventional" reduced-risk products used to control plant disease have had more limited adoption: in 2000, cinnamaldehyde was applied onto 15 $km^2$, neem oil on 192 $km^2$ and potassium bicarbonate on 241 $km^2$. However, cinnamaldehye and neem oil also are registered to control insects, and cinnamaldehyde has miticidal activity too. Three newer reduced risk fungicides that were registered after 2000 include the following: acibenzolar-S-methyl (Actigard), which induces systemic acquired resistance (19); fluazinam, a phenyl-pyridinamine with possibly multiple modes of action (1) and zoxamide, a benzamide that binds to β-tubulin and is effective against Oomycetes (29). Acibenzolar-S-methyl is a particularly interesting new development in pesticide use because it is effective against fungi, bacteria and viruses, and because development of resistance seems unlikely. However, acibenzolar-S-methyl is more effective in monocots than in dicots (19).

**Supplmental note 5**. **Rationale For Reduction Based On Sustainable Pest-Control.** Much literature suggests that pesticide use can be reduced in particular circumstances without reducing profits and yield (4). In addition, intensive pesticide use can result in new pest management problems. The newer fungicides generally have a single site of action and farmers can inadvertently select for fungicide-resistant populations. Fungicide-resistance has been particularly problematic with benzimidazole and dicarboximide compounds (27). Although more manageable, resistance has also emerged against the pheylamides, sterol biosynthesis inhibitors, morpholines, and strobilurins (15, 27, 28). Consequently, development of resistance to the new compounds shown in Supplemental Table 2 is a major concern for contemporary pesticide management. In bacteria, resistance has developed to copper (5), and antibiotics (16). As indicated above, resistance has been a factor in reduced use of triadimefon (Table 1) to control powdery mildew on grape in California. Resistance to the other sterol biosynthesis inhibitors used to control powdery mildew on grape are also of concern: resistance to myclobutanil is increasingly problematic in early bearing varieties throughout California; and resistance to fenarimol and triflumizole has been shown.

Although acute and residual phytotoxicity of herbicides is of far greater concern than phytoxicity of fungicides, phytoxicity of fungicides and bactericides occurs, and is generally indicated on the pesticide labels. Copper has been used as a fungicide since the 1800s, has low mammalian toxicity, and is inexpensive. Nonetheless, copper residues accumulate in the upper 15 cm of soil, and at the application rates used by some California growers on perennial crops such as walnuts, stone fruits, and citrus (6), long-term copper accumulation could affect soil sustainability (11, 26).

**Supplemental note 6. Rationale for Reduction Based on Social and Environmental Reasons.** Concerns have been raised about health risks to farmworkers handling pesticides, health risks to the public and especially children from chemical residues in food, and health risks to other organisms and especially aquatic organisms exposed to pesticides in the environment and particularly in runoff (23). The California Department of Pesticide Regulation reported there were 555 suspected or confirmed cases of agriculturally related pesticide injury in 1999. The largest number of incidents involved applications of sulfur dust in vineyards and fumigants to soil. In one incident in November 1999 in Tulare County, drift from a sprinkler application of metam sodium resulted in approximately 170 cases of pesticide-induced illness in the town of Earlimart (http://www.cdpr.ca.gov/docs/pressrls/settlement.htm). The increasing suburbanization of California will present continuing challenges regarding pesticide applications, and particularly fumigants, which are all acutely toxic and used in high concentrations. A summary of the "risk" categorization for the "risky" compounds is shown in the right-hand column of Table 1. As part of the Food Quality Protection Act (FQPA), organophosphates, carbamates, and pesticides classified as probable human carcinogens (B2 carcinogens) will be evaluated by the U.S. Environmental Protection Agency's (EPA) Office of Pesticide Policy. In a study based solely on the correlation between age-adjusted cancer rates from the California Cancer Registry and countywide pesticide use, there was an apparently non-random association between countywide captan use and both leukemia incidence in Hispanic males and prostate cancer in black males (17). Research on animals suggests there may be a link between a combination of maneb and the herbicide paraquat on Parkinson's disease (24, 25). Vinclozolin, (2, 12--14, 20), fenarimol (18) and iprodione(14) have potential activity as hormone disrupters. In terms of potential water pollutants, Goss (10) estimated the potential of fungicides for runoff from medium to high. Chlorothalonil, mancozeb, and maneb have comparatively high ranking for aquatic toxicity (23). Chloropicrin and methyl bromide have been detected in ground water (3) and increased use of 1,3-dichloropropene may present concern for groundwater contamination.

**Supplemental note 7**. **Analysis of powdery mildew control (PM).** We examined data for county─type-of-grape with > 150 $km^2$ grapevines planted in 2000 (Supplemental Table 3).

Different fungicides used to control PM have different application intervals. For the minimum days of protection, i.e., for the calendar spray model, we considered that an application of the following materials gave protection from PM for the following minimum number of days: sulfur dust, 7; wettable or micronized sulfur, 10; myclobutanil, 10; and other sterol biosynthesis inhibitors and strobilurins, 14 (http://www.ipm.ucdavis.edu/DISEASE/DATABASE/grapepowderymildew.html. The sterol biosynthesis inhibitors used on grapes in the study period were fenarimol, myclobutanil, tebuconazole, triadimefon, and triflumizole. The strobilurins were azoxystrobin and trifloxystrobin. In order to avoid examining the practices of growers who produce grapes as a hobby, we first removed all growers who managed a total area planted of less than 0.1 $km^2$. For each grower, the average days of protection over all their planted area was determined, using intervals from the calendar spray model. Then, to remove the impact of erroneous records, the sites with the highest 5% and lowest 5% days of protection were removed.

**Supplemental note 8. Analysis of antibiotic use on pears**. For each site, applications of antibiotics were calculated as the sum of area treated for the year per area planted. For each year, we trimmed sites with the highest 5% and lowest 5% of antibiotic use. After trimming, the number of growers ranged from 207 to 225 per year. We then selected growers who could be tracked over the four-year period (n=89), and calculated their number of antibiotic treatments as the cumulative area treated divided by the cumulative area planted over all of their sites. We note that the distribution of growers' number of applications of antibiotics is almost always approximately exponential and that the sample size of the growers who used *P. fluorescens* in 1997 and 1998 is only 15. The hypothesis that growers with the most intensive antibiotic use in 1995 were more likely to use *P. fluorescens* in the later years was demonstrated by logistic regression ($P$=0.012). Of the growers in 1995 who used the median number of applications or less of antibiotics, only 17% used *P. fluorescens* in 1997 and 1998 whereas 60% of the more intensive antibiotic users used *P. fluorescens.*

**Supplemental note 9**. **Reduction of insecticide use in California on transgenic cotton containing the *Bacillus thuringiensis* toxin**. Cotton is the only genetically modified (GM) crop in notable commercial production in California. Cotton that expresses the insectical *Bacillus thuringiensis* toxin (Bt-cotton) and/or herbicide-resistance genes to glyphosate and bromoxynil is available, but only Bt-cotton is grown in a sizeable area (approximately 75 $km^2$). In California, Bt-cotton is planted largely only in the Imperial and Palo Verde Valleys, located in the southernmost portion of the state in Imperial and Riverside Counties. Bt-cotton is not commonly grown in the regions (the San Joaquin and Sacramento Valleys) where >95% of California's cotton is produced. In these more northern valleys, pest pressures are such that increased cost of the GM seed to the grower would not be offset by increased returns. Although Bt-cotton is only planted in a relatively limited area, it was rapidly adopted by growers in the southern valleys, and offers an opportunity to document the change in growers' use of insecticides that have the same spectrum of activity as *B. thuringiensis*.

Between 1993 and 2000, there was average of 24 $km^2$ and 50 $km^2$ cotton in the Imperial and Palo Verde Valleys, respectively. Bt-cotton was first planted commercially in 1996. By 1998, 80% and 94% of the cotton acreage in the Imperial and Palo Verde Valleys, respectively were planted with Bt-cotton (Pink Bollworm Program, California Department of Food and Agriculture) (Supplemental Figure 6). We selected the 13 insecticidal compounds used on cotton in Riverside and Imperial counties from 1993 to 2000 that have activity against lepidopteran pests that are sensitive to *B. thuringiensis* toxin (Bt) (acephate, amitraz, azinphos methyl, bifenthrin, chlorpyrifos, cyfluthrin, cypermethrin, endosulfan, esfenvalerate, fenpropathrin, methamidophos, methomyl, and permethrin). The average number of applications of materials with Bt-like activity are shown in Supplemental Figure 6 and ranged from 6.6 to 12 in the three-year period before Bt-cotton was introduced. In contrast, during the 1999 to 2000 time period, in which Bt-cotton accounted for 89% and 95% of the cotton in the Imperial and Palo Verde valleys, respectively, there was an average of 5 and 2 applications in the two valleys. Overall, in a comparison of the number of applications with Bt-like activity in the three-year periods "pre-Bt-cotton" and "post-Bt-cotton," there was a 47% and a 71% decrease in the Imperial and Palo Verde Valleys, respectively (Supplemental Table 5). Similarly, in the sum of the of the kg ai of the 13 compounds, there was a 44% and 63% decrease in the two valleys, respectively.

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