Dormant Season Organophosphate Use in California Almonds[1]

Minghua Zhang, Larry Wilhoit, and Chris Geiger

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Department of Pesticide Regulation
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Executive Summary

Purpose

The purpose of this study was to examine the trends and regional patterns of organophosphate (OP) use in California almond orchards from 1992 to 2000, and to identify factors that may have influenced those trends, including weather, pest pressure, and use of alternative practices to control pests.

Background

Growers use OP pesticides to control arthropod pests in almonds. An OP may be applied to dormant orchards during the winter (called a dormant OP spray). These dormant OPs are usually applied with a narrow-range oil, which is added to improve the effectiveness of the OP and because the oil itself kills some arthropods by suffocating them. Dormant OPs with oils are used primarily to control peach twig borer (PTB), San Jose scale (SJS), European red mite, and brown mite. Dormant sprays have traditionally been considered the most effective way to control all these pests. Applications during the winter are considered less disruptive to non-target organisms, such as natural enemies, than applications during the spring and summer since most organisms are less active during the winter. Thus, in the past a dormant OP spray was routinely applied. However, recent monitoring studies have detected three OPs (diazinon, chlorpyrifos, and methidathion) in surface waters in the Sacramento and San Joaquin River basins at concentrations high enough to harm some aquatic organisms. These studies indicate that routine dormant spray applications may need to be reduced or discontinued and replaced with alternative pest management strategies for control of peach twig borer, scales, and mites.

To address these surface water concerns, the Department of Pesticide Regulation (DPR) and other organizations have encouraged the use of alternative pest management practices to dormant OPs. These organizations have funded several projects to develop alternative practices, demonstrate their effectiveness, and encourage their adoption. Among the alternatives are dormant applications of pyrethroids or oils with no other insecticide; bloom time *Bacillus thuringiensis* (Bt); or in-season applications of OPs or pyrethroids.

Methods

To determine if use of dormant OPs and the alternatives to dormant OPs in almonds have changed and why changes might have occurred, DPR staff analyzed trends and patterns of almond pesticide use from 1992 to 2000 along with weather data and almond nut damage.

Pesticide use

We analyzed data from DPR's Pesticide Use Reporting (PUR) system for the period December 10, 1991 through December 9, 2000. The PUR is California's full-use pesticide reporting system. Although the PUR is extensively checked for errors, errors still occur especially in the information used to identify agricultural fields. For our analyses we carried out addition error checking and cleaning processes. Linear regression and correlation analyses were used to assess trends and relationships among OPs, pyrethroids, oils, and *Bacillus thuringiensis* (Bt). In most of these analyses the measure of pesticide use was pounds of active ingredient per acre planted. However, we also looked at percent of almond acres treated and number of growers using different pesticides. These latter two measures allowed us to also look at the number of fields and growers that used no insecticides.

We looked at uses in each of the 13 main almond growing counties. These counties comprise 98% of California's almond acreage. Geographical Information Systems software was used to display the variation in pesticide use among these counties.

We looked at uses during both the dormant season and in-season. Dormant season for pesticide use was defined as December 10 to March 20. This time period was chosen to capture both dormant applications and most bloom-time Bt applications. In-season for pesticide use was defined as March 21 to December 9

Weather (temperature and rainfall)

Weather data were obtained from the California Irrigation Management Information System, which administers and collects data from weather stations throughout California's agricultural counties. We selected one weather station for each county in the almond-growing region.

We used three different measures to summarize temperature: cumulative chilling hours, minimum air temperature, and average temperature. Chilling hours were calculated as the cumulative sum of hourly temperatures below a threshold temperature of either 30° or 40° F. Chilling hours were also summed for two different time periods in the dormant season: November 1 to March 20, and January 15 to February 15. The minimum and average temperatures were calculated from the daily average temperatures during the period November 1 to March 20. Two measures of rainfall were used, each summed over the two dormant season time periods: total rainfall (sum of daily amount of rainfall) and the number of rain days (the number of days with rainfall greater than 0).

Pest pressure

Since few data exist on historical pest damage or pest population, we used percent almond nut rejects as an indicator for pest pressure. Processors will reject damaged almond nuts and historical records of the percent rejected are kept. Most damage is due to ants, navel orangeworms, and peach twig borers. The percent of nut rejects were obtained from the Almond Board of California for each county and each year.

Results and Discussion

Trends and patterns of pesticide use

DORMANT SEASON TRENDS. From 1992 to 2000, use of dormant OPs decreased as measured by pounds of active ingredients per almond planted acres, percentage acres treated, and number of growers. Dormant OP use decreased in all 13 of the major almond-growing counties. From 1992 to 1994, dormant OPs were by far the most commonly used insecticides to control almond overwintering pests, applied to 40 to 50% of the almond acreage. By 2000, only 9% of the almond acres were treated with dormant OPs.

In contrast, use of some of the alternatives to dormant OPs increased. The most often used alternative was no dormant insecticide. The number of growers and the percent acres treated using no dormant insecticide increased from 1992 to 2000. By 2000, 57% of the total almond acreage received no dormant treatments, by far the most common practice.

All measures of use of dormant pyrethoids significantly increased; for example, percent of acres treated with dormant pyrethroids increased from 2% in 1992 to 16% in 2000. Although the pounds of dormant oil alone per acre planted did not increase, the percent acres treated and number of growers using dormant oil alone increased from 1992 to 2000. Percent acres treated by dormant oil alone increased from 2% in 1992 to 7% in 2000. There were no overall increasing or decreasing trends by any measure of bloom time Bt use from 1992 to 2000. Bt use increased from 6% acres treated in1992 to 27% in 1995, but after 1995 its use declined to 12% by 2000. Other reduced-risk insecticides, such as spinosad, pheromones, and insect growth regulators, were rarely used, but their use is starting to increase.

IN-SEASON TRENDS. Another alternative to dormant OPs is the use of insecticides during the growing season. As with the dormant season, in-season use of OPs (as measured by pounds of OP per acre, number of growers, and percentage acres planted) decreased in the major almond growing region from 1992 to 2000. In-season OP use decreased from 45% acres treated in 1992 to 31% treated in 2000. Pyrethroid, oil alone, and Bt use in the growing season increased by all measures from 1992 to 2000. Pyrethroid use increased from 6% acres treated in 1992 to 15% in 2000; acres treated with oil alone increased from 1% in 1992 to 2% in 2000; and acres treated with Bt increased from 3% in 1992 to 6% in 2000. There were no trends in use of no in-season insecticides; in 1992, 45% of the almond acres were not treated with insecticides and in 2000, 42% of the acres were not treated.

Relationship between insecticide use and winter weather

Decreased OP and oil alone use was associated with increased rainfall in the major almond growing region. The most likely explanation for this trend is the difficulty in getting spray equipment into muddy fields. Decreased uses of OPs and of oils alone during the dormant season were also associated with warmer temperatures. This association is probably an indirect effect caused by the correlation between rainfall and temperature and not an effect of temperature on either pests or spray decisions. However, the relationships were too weak to explain most of the decrease in OP use from 1992 to 2000.

Relationship between insecticide use and percent nut reject

There were significant associations between higher percent nut rejects and greater insecticide use in the following year. This suggests that growers may respond to finding higher rejects by applying more pesticides the next year. There were weaker negative correlations between insecticide use and percentage rejects in the nuts harvested from the treated fields. That is, when more insecticides were applied, percent rejects were only slightly lower. These results are not surprising because there are two conflicting effects involved in this relationship. First, growers may apply more pesticides in "problem" areas—areas with higher reject rates, leading to a positive correlation between percentage rejects and pesticide use. Second, pesticide applications should reduce pest populations, which would lead to a negative relationship between rejects and pesticide use. Therefore, the correlation between pesticide use and that year's percent rejects would be expected to be weak.

Associations between dormant and in-season insecticide use.
Decreased OP use in the dormant season was associated with decreased OP use during the immediately following growing season and with decreased use in the subsequent dormant season. This may mean that growers who use less dormant OPs tend to use less in-season OPs as well. In contrast, decreased dormant OP use was associated with increased in-season use of pyrethroids, Bt, and oil alone and with increased use of pyrethroids in next year's dormant season.

Our analyses also suggest that growers who used lower risk dormant season alternatives did not use more OPs or pyrethroids in either the growing season following the dormant season or in the following dormant season. This result could mean that forgoing OP use did not significantly worsen pest problems and that alternatives to OPs are working.

Conclusions

Although dormant OP use on California almonds decreased dramatically from 1992 to 2000, the reduction in OP use did not appear to affect almond productivity, which remained high during this period. This decrease is probably a result of many complex factors, such as pesticide and commodity prices, pesticide resistance, grower perceptions, and reduced-risk programs funded by the government and universities. This study demonstrated that dormant OPs were partly replaced with dormant pyrethroids, dormant oils with no other insecticide, but primarily with no dormant insecticides at all. Dormant OPs may also have been partly replaced by in-season pesticide applications since in-season use of pyrethroids, oil alone, and Bt increased from 1992 to 2000. Winter rain and pest pressure appeared to have some affect on dormant OP use but these factors cannot explain most of the decrease.

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Abstract

During the early 1980s, agricultural extension specialists from the University of California commonly recommended organophosphate (OP) pesticide applications during the dormant season to control overwintering insects such as peach twig borer, San Jose scale, European red mite, and brown mite in California almond and stone fruit orchards. However, in the late 1980s dormant OP use fell under increased scrutiny due to surface water contamination concerns. The purpose of this study was to assess the trends and regional patterns of OP use in almond orchards, and to identify factors that may have influenced those trends, including weather, pest pressures, and use of alternatives to OPs such as pyrethroids, dormant oils, and *Bacillus thuringiensis* (Bt). Pesticide use data were obtained from the California Department of Pesticide Regulation's Pesticide Use Reporting system. Regression analyses were used to assess trends from 1992 through 2000, and a Geographic Information System (GIS) was used to visualize the spatial variation in pesticide use. Results from this study indicated, statewide dormant OP use on almonds decreased while the use of some alternative methods, such as dormant pyrethroids and no dormant insecticides; and in-season, pyrethroids, oil alone, and Bt, increased in the last nine years. The significant decreasing trend of OP use was observed for the measures of pounds per acre planted, percentage of total planted acres treated, and numbers of growers who applied dormant OPs. The reduction of dormant OP use appeared in all major almond-growing counties. Correlation analyses revealed that rainfall was positively correlated with less dormant OP use. Higher percent almond rejects were related to higher OP use in the following dormant and in-season periods. However, the effects of weather and percent nut rejects can only explain a small portion of the variation in dormant OP use. Therefore, in addition to weather and pest pressure, economic pressures and various outreach and extension programs may also have played a role in encouraging farmers to reduce their use of dormant OPs. These factors were not examined in this report.

Introduction

During the past decade, California growers used 1 to 1.5 million pounds of OPs annually during the dormant season to control overwintering agricultural pests. California almond orchards, which produce 99% of the U.S. almond crop, accounted for 10 to 33% of the state's total dormant OP used from 1992 to 2000. Insecticides are used during winter months primarily for control of peach twig borer (PTB), San Jose scale (SJS), and European red mite and brown mite. During the early 1980s, dormant OPs were recommended as an effective control for overwintering insects in almond orchards, and were considered safer to the environment and human health (UCIPM, 2002). Although OPs are still effective in controlling these pests, their use has raised concerns in California due to their appearance in surface water. Concentrations of diazinon in the Sacramento and San Joaquin River watersheds were documented at levels high enough to be toxic to some aquatic organisms (Grieshop and Raj, 1992; Ross et al, 1999; Spurlock, 2002). The major source of the OP runoff has been attributed to applications during the winter rainy season in California, typically from November through March (Domagalski et al., 1997; Dubrovsky et al., 1998; Guo et al., 2003).

Consequently, the California Department of Pesticide Regulation (DPR) and other organizations have been encouraging the use of alternatives to OPs. Some of the alternatives include dormant pyrethroids, spinosad, oil with no other insecticide, bloom time *Bacillus thuringiensis* (Bt), as well as in-season use of OPs, pyrethroids, spinosad, oil alone, and pheromones. Starting in 1997, DPR funded several projects to develop alternative methods for managing these pest problems that would protect surface water quality, demonstrate their effectiveness, and encourage their adoption (DPR, 2002). Organizations such as the University of California Sustainable Agriculture Research and Education Program (UC SAREP), the UC Statewide Integrated Pest Management Program (UC IPM), the United States Environmental Protection Agency (US EPA), the United States Department of Agriculture (USDA), and the Almond Board of California have funded similar projects in the past (Swezey and Broome, 2001; UC SAREP, 2002). In almonds, some of these projects have been in place for several years, building on each others' successes (Almond Board, 2001).

Pest management decisions, in general, depend on many factors including pest pressures, management strategies, weather, economics, as well as available reduced-use programs in the region. The presence and density of pests are primary considerations in pest management decisions. Higher pest pressures usually lead to more pesticide use. Weather, on the other hand, can affect pesticide use by changing insect population densities and/or by changing farmers' ability to use pesticides. This is because heavy rainfall can make almond fields so wet they are inaccessible for pesticide applications. Moreover, the availability of affordable and low risk alternatives to dormant OPs can influence pest management decisions.

To determine whether dormant OP use decreased, DPR's Pesticide Use Report (PUR) database was used. The PUR tracks pesticide use by location and time (DPR, 2000) and can be used to assess pesticide use trends in California. Recent analyses have shown that dormant OP use on almonds and other tree crops has declined as measured by pounds applied, area treated, and number of growers who treated from 1992 to 1997 (Epstein et al., 2001 a, b; Flint et al., 1993, Hendricks, 1995). Although it is more difficult to determine why changes in use occur, some clues could be revealed through various statistical analyses of pesticide use along with weather and indicators of pest pressure. We believe that government, university, and industry programs to encourage reduction in use of pesticides found in surface waters have played a major role, but it is difficult to quantify.

The objectives of this study were to assess the use trends of dormant OPs and some of their alternatives in California almonds from 1992 to 2000, to investigate possible causes for the changes, and to determine if these changes have been accompanied by other alternatives that may affect environmental or human health.

Materials and Methods

1. Study areas and data sources

For this study, we selected thirteen counties (Figure 1) comprising 98% of California's almond-growing acreage: Butte, Colusa, Glenn, Sutter, Tehama, Yolo (Northern California); Merced, San Joaquin, Stanislaus (Central California); and Fresno, Kern, Madera, Tulare (Southern California). We refer to these counties as the major almond-growing region.

The PUR contains information on nearly all production agricultural pesticide use and some non-agricultural pesticide use in California since 1990. Data collected includes information such as: the pesticide product and amount applied, the area treated, the grower's identification code, the date of application, the specific field treated, and the application location to a square-mile section (DPR, 2000). We used PUR data from December 10, 1991 to March 20, 2000 for this study.

The main alternatives to OPs included pyrethroids, oils, and Bt. Some reduced-risk insecticides such as spinosad, pheromones, and insect growth regulators, were rarely used and therefore not included. The PUR for almonds contains 15 different OP active ingredients, 5 pyrethroids, 5 oils, 12 Bts, and 52 other insecticides (Table 1). "Oils" is a heterogeneous category and can be used as adjuvants, insecticides, fungicides, or for other purposes. In the winter season, oils are usually used as dormant insecticide applications. In this study the category "oil alone" was defined as any non-adjuvant oil applied to fields that did not receive any application of OPs, pyrethroids, carbamates, Bt, or spinosad during the defined dormant period. Dormant oil without other insecticides is one low risk alternative to dormant OPs.

The dormant season for pesticide use was defined as December 10 of the previous calendar year through March 20 of the calendar year being described, while in-season use was defined as March 21 through December 9 of the year being described. This dormant period was chosen to capture the most common dormant applications and bloom time Bt applications. For the weather data, the winter period was defined as November 1 through March 20 because weather during that period can influence arthropod survival.

Weather information was obtained from the California Irrigation Management Information System (CIMIS, 2002), which administers and collects data from more than 100 computerized weather stations throughout California's agricultural counties. Although several weather stations may be located in a county, not all the weather stations have data continuously from 1991 to 2000. The criteria for selecting the weather station in each county were (1) the proximity of the station to almond-growing areas, and (2) continuity of data from 1991 to the present. Figure 2 shows the weather station locations. Descriptions of stations used in this study are provided in Table 2.

Since little documentation exists to provide quantitative information about historical pest damage or pest populations, we used percent nut rejects as an indicator for pest pressure. The percent of nut rejects were obtained from the Almond Board of California for each county. Most of the rejects were due to damage by PTB, navel orangeworm (NOW), and ants.

2. Measures and methods

Measures of pesticide use

There are many ways to measure pesticide use and weather conditions (Table 3). Measures of pesticide use include pounds of active ingredient (AI) applied, pounds of AI per acre planted (includes both bearing and non-bearing acres), cumulative acres treated, acres treated per acres planted, percent acres treated, and number of growers using pesticides. We used pounds of AI per acre planted for more detailed regression and correlation analyses because this measure removes the effect of differences in acres planted when comparing use between different counties.

Measures of weather

We used two types of winter weather variables: temperature and rainfall. Three different measures were associated with temperature: cumulative chilling hours, minimum air temperature, and average air temperature. Cumulative chilling hours are the sum of hourly temperatures, T_{hr}, below the threshold temperature, T_{th}, that is,

$$chilling\ hours = \sum_{hr=A}^{B} Max(T_{th} - T_{hr}, 0)$$

We calculated chilling hours with two different threshold temperatures, 30°F and 40°F, and for two different time periods, November 1 of previous calendar year to March 20 of this calendar year and January 15 to February 15 of the same calendar year. Average temperature refers to the average of all daily average temperatures during the period November 1 to March 20, while average minimum temperature is the average of daily minimum temperatures during the period November 1 to March 20. These different temperature measures represent different possible ways temperature could affect arthropods (Zalom personal communication).

Two different measures were associated with rainfall: total amount of rainfall and number of rain days. Both rainfall measures were calculated over the two winter season time periods: November 1 to March 20 and January 15 to February 15. Total rainfall refers to the sum of daily rainfall in inches, while number of rain days refers to the number of days with rainfall greater than 0.

Since we use weather information from only one station in each county we do not know the range of weather within a county and this introduces some unknown variation in the analyses. However, in most of the almond growing regions, the within-county variation in weather is fairly small.

Occasionally, CIMIS data had missing or erroneous values. We replaced these missing or erroneous values with interpolated values. For daily average temperature we interpolated using a straight line from the value on the day previous to a set of missing or erroneous values to the value on the first day after that set. The daily rainfall for any missing or erroneous value was set to the average rainfall during its month using valid daily rainfall data reported for that month. For the hourly temperature data we did not want to use linear interpolation if there were more than 6 consecutive hours of missing or erroneous data because the daily temperature pattern usually follows a cyclical pattern. If there were more than 6 hours of erroneous data, the cumulative chilling hours for that day was treated as missing. If there were 6 hours or less of erroneous data, we estimated the missing hourly temperatures with linear interpolation. We then calculated the cumulative chilling hours for each day estimating the missing daily cumulative chilling hours using linear interpolation.

Methods

Regression analyses were used to examine use trends for OP, pyrethroids, oils alone, and Bt within each county and for the almond-growing region as a whole, while correlation analyses were used to investigate the associations among temperature, rainfall, nut rejects, and the different pesticide types. We analyzed the relationships by county because of interest expressed by the agricultural community, and because there may be significant differences between counties. These differences are due not only to climatic differences but also to the variations of pest management recommendations by regional farm advisors.

The regression slopes and the percent changes based on the linear regression slope were used to compare the use trends among counties from 1992 to 2000. Because predicted values in a given year (1992 or 2000) were sometimes negative, we used mid-point percent change by applying the pesticide use value in 1996 as the denominator rather than values in either 1992 or 2000, that is, percent change is

[100 * ($X_{2000} - X_{1992}$)/(X_{1996})], where X_{1992} was the regression predicted measure of use in year 1992, X_{1996} was the measure in 1996, and X_{2000} was the measure in 2000.

Correlations were calculated between dormant and in-season insecticide use, as measured by pounds per acre planted, percent almond nut rejects and winter weather variables. For the latter two variables, data from the same year of pesticide use and data from the previous year were examined. Correlations were calculated for each county in the major almond region as well for the 13 counties as a whole. Region-wide measures of temperature, rainfall, and percent rejects were calculated as weighted sums of the county level measures, using almond planted acres as the weighting factor. For example,

$$R_{region} = \frac{\sum_c A_c * R_c}{\sum_c A_c}$$

where R_{region} is the region-wide rainfall, A_c is the almond acreage in county c and R_c is the rainfall in county c.

To assure correct interpretation of the correlation analysis, Bonferroni's inequality is used to determine the minimum pairwise alpha level. This inequality holds even if the variables are not independent. Using Bonferroni's inequality for the case with 22 variables, the pairwise level of significance should be 0.0002 to insure a family 0.05 level of significance. We also provide some confirmation of the significance of particular relationships by carrying out the same analyses for each county.

A GIS computer program was used to visualize the spatial distribution of the pesticide use trends in California among counties (Zhang and Wilhoit, 2001). A GIS program is designed to retrieve, store, analyze and display spatial data and is a powerful tool for understanding the spatial distributions and patterns of OP use.

3. Data quality

Despite the extensive error checking of the PUR data before it gets into the database, errors still occasionally appear. For this study, we performed additional error checking and data cleaning on several PUR variables such as rates of use, grower identifications and site location identification. These error-checking procedures are described more completely in the appendix.

Some reported applications had such high rates of use (pounds of AI per acre treated) they were almost certainly incorrect. For these applications we replaced the pounds used with a value calculated from the median rate from all uses of the pesticide product applied to almonds. A rate of use was considered high if it was greater than (1) 200 pounds of AI per acre treated, (2) 50 times the median pounds of product per acre for all uses of that product on almonds, or (3) a value determined by a neural network (Wilhoit et al., 1999; 2001).

The grower and site location identifications were cleaned by removing spaces, hyphens, and, in places that should contain only numbers, converting letters to similar appearing numbers. For example, we replaced "O" with "0", "I" with "1", "Z" with "2", "S" with "5". We also developed algorithms for determining the most likely correct value for the geographical location and acres planted for an almond field when different reported applications to that field had different values for location or acres planted.

The effect of replacing outlier rates with median rates on total pounds of AI used statewide was less than 6.5% for all years. For most counties, the percent difference between total actual reported pounds of chemicals with total pounds in which outlier values were replaced with values calculated from median rates was less than 10% and most of these were in 1992 and 1993. Less than 0.55% of the PUR records had an extremely high rate of use for each year from 1992 to 2000 when we compared the original data with the cleaned data. This percentage was less than 1% for all years and counties of interest except in three situations, the highest being 3.5% error rate in Tehama in 1999. Only one extremely large error in reported pounds will have a large effect on the percent difference and most of the large error rates were due to a few errors in the pounds of methyl bromide (Appendix).

The data cleaning procedures for grower and site location identifications could affect the number of grower and almond fields calculated from the PUR. However, these procedures had no effect on number of growers for all years after 1992 in all counties except for Stanislaus, Sutter, and Yolo Counties. The error rate in these 3 counties varied between 0.05% and 3.5% in different years. In 1992, the statewide error rate was 0.68%. In contrast, the data cleaning procedures had a fairly large effect on the apparent number of almond fields. The years with the largest number of errors were from 1995 to 1999, with 7 to 14% change in the number of fields statewide. The years with the fewest number of errors were 1994 and 2000, with only 0.1% change in number of fields. These errors were found in all counties. The high number of errors in the later years (except for 2000) was mostly from trailing or leading spaces in the site location identifications.

The almond acreage calculated from the PUR using the data cleaning procedures differed from the almond acres reported by California Agricultural Statistical Service (CASS) between 0.14% to 4.0% each year between 1993 and 2000. In 1992, the PUR calculated acres planted for California were 16% higher than the CASS acres. For most measures, the PUR data is of good quality for the analysis when we aggregate at the grower, county, and state levels.

Results

1. Trends and patterns of insecticide use

Dormant season

Almond dormant OP use decreased statewide from 1992 to 2000 by all measures. Pounds of AI per almond planted acres decreased by 130% (this is the mid-point percent change) from 0.98 to 0.17, percentage acres treated decreased from 52% to 9%, and number of growers applying dormant OPs decreased from 2,300 to 408 (Figure 3, Table 4). The decrease, as measured by pounds of AI per acre planted, was statistically significant statewide and for each major almond county except Sutter (Table 4). When measured by acres treated, the decrease was statistically significant for all the counties in the region. There was one unusually heavy application reported in the 1996 Sutter County data. If this application were left out, Sutter would also show a statistically significant decrease in use. By mid-point percent change, the counties with the largest decrease in dormant OPs from 1992 to 2000 were Merced, Colusa, Yolo, and Stanislaus (Table 4 and Figure 4).

In contrast, the use of the main alternative practice to dormant OPs, no treatment of insecticides, increased from 1992 to 2000 (Figure 3). The number of growers who used no dormant insecticides increased from 1,298 in the year 1992 to 2,069 in the year 2000 (60% increase), while the percent of acres with no dormant insecticides increased from 35% in 1992 to 57% in 2000 (Figure 3). The use of dormant pyrethroids, another alternative to dormant OP, also generally increased (Figure 3). Pounds of dormant pyrethroid per acre planted increased by 86%, from 0.004 in 1992 to 0.012 in 2000. Statewide and in 4 out of 13 major almond-growing counties the increase in pyrethroid use was statistically significant (Table 4). The counties with the largest percent increase of dormant pyrethroids were Fresno, Kern, Tehama, Merced, and Tulare (Table 4 and Figure 5). Except for Tehama, these counties are located in the southern San Joaquin Valley. On the other hand, the use of dormant pyrethroids declined in Sutter, Yolo, Glenn, and Butte, all in the Sacramento Valley (Table 4 and Figure 5).

Use of dormant oil alone increased as measured by percentage acres treated and number of growers, but fluctuated from year to year in pounds per acre planted (Figure 3). Kern County had the largest percent increase, and Glenn, Yolo, and Madera had the largest percent decrease in dormant oils alone (Table 4).

However, there was no significant overall trend in the use of bloom time Bt, another alternative to OPs, by any measure during the entire period 1992-2000 (Figure 3). The use of Bt increased from 1992 to 1995, but generally decreased after that. This pattern occurred statewide.

In-season

Almond in-season OP use decreased statewide from 1992 to 2000 as measured by pounds of active ingredients per almond planted acres, percentage acres treated, and number of growers (Figure 6). A large reduction occurred between 1997 and 1998. The 34% decrease in pounds per acre planted was significant statewide and in 6 out of the 13 major almond-growing counties (Table 5). The counties with the largest percent reduction of in-season OPs were San Joaquin, Colusa, Madera, Merced, and Yolo (Table 5 and Figure 7).

Although there were variations, the in-season use of pyrethroids, oil alone, and Bt generally increased from 1992 to 2000. The trend was similar in all measures (Figure 6). In-season pyrethroids increased by 120% and oils alone increased by 142% (Table 5). The percent acres treated and number of growers using no in-season insecticides fluctuated from year to year. Counties with the greatest percent increase of in-season pyrethroids were Sutter and Kern (Table 5 and Figure 8), but no clear spatial patterns emerged in pyrethroid use among almond growing counties.

2. Relationship between insecticide use and winter weather

Relationship between insecticide use and current year's winter weather

For the major almond-growing region, reduction of dormant OP use was related to increased winter rainfall and warmer temperatures, but most correlations were not significant at the 0.05 level (Table 6 and Figure 9). Similarly, reduction of use of dormant oil alone was related to increased rainfall and warm temperatures, but in this case most of the correlations were significant at the 0.05 level. On the other hand, reduction of dormant pyrethroid and Bt was related to less winter rainfall and colder temperature. These patterns were similar from county to county. There were no clear or consistent patterns in correlations between winter weather and in-season insecticide use.

Relationship between insecticide use and previous year's winter weather

For the major almond growing region, reduction of dormant OP use was associated with previous year increased rainfall and warmer temperature, but none of the correlations were statistically significant (Table 7 and Figure 10). Dormant pyrethroid use was positively correlated with previous year's winter rainfall and with temperature, and most correlations were statistically significant at least at the 0.05 level (Table 7). Most of the correlations between dormant oil alone and previous year's winter weather and between bloom time Bt and weather were positive, but none of them were statistically significant.

In 8 of the 13 almond counties, increased use of dormant pyrethroid was correlated with higher winter rainfall and warmer temperatures in the previous year and in 7 counties the reduction of dormant OP use was correlated with increased rainfall and warm temperature (Table 7). Most of the correlations, however, were not significant.

The relationships between in-season insecticide use and previous year's winter weather were similar to the relationships with dormant insecticide use, except for Bt. In-season Bt use was positively correlated with previous year's winter rainfall and temperature, and nearly all correlations were statistically significant. These relationships appeared for most individual counties as well. The use of Bt appeared to be more weather dependent than other pesticides.

3. Relationship between insecticide use and percent almond rejects

Although most of the correlations between insecticide use and percent almond rejects during the same year were not statistically significant, most correlations were negative for the major almond-growing region and for individual counties (Tables 6 and 7 and Figure 9). The strongest negative correlations were for dormant pyrethroids and oil alone. Percent rejects declined slightly during the 1990's but the decrease was not significant. Also, in nearly all cases percent reject was positively correlated with current year's winter rainfall and temperature.

Most of the correlations between insecticide use and previous year's almond rejects were positive region wide and within individual counties (Table 7 and Figure 10). The strongest positive correlations were for dormant and in-season OP and pyrethroid use. Percent rejects were positively correlated with previous winter's rainfall and temperature but the correlations were weaker than the correlations between percent rejects and current year's winter weather.

4. Relationships among insecticide use variables

Associations among dormant insecticide use types and among in-season insecticide use types

There were no significant correlations among the four dormant season insecticide use types (OP, pyrethroid, Bt, and oils alone) for the major almond-growing region (Table 8 and Figure 11). The largest correlation was a negative correlation between dormant OP and dormant pyrethroid. This relationship was strongest in Kern and Fresno counties, which indicated that OP use was clearly replaced by dormant pyrethroids in these two counties. The replacement of other alternatives was not as clear because the correlations among the different insecticide uses were not statistically significant.

The reduction of in-season OP use was related to increases in other alternatives such as the use of pyrethroids, oils alone and Bt. These other uses were positively correlated among themselves (Table 8 and Figure 11). The patterns varied among different counties, but the pattern in most northern San Joaquin valley counties was similar to the region-wide pattern.

Associations between dormant insecticide use and following growing and dormant season insecticide use

The reduced use of OP region wide was associated with reduced use of OP in-season, but related to the increased use of in-season pyrethroid, oil alone, and Bt (Table 7 and Figure 11). This trend occurred in nearly all counties. The increased use of dormant pyrethroid region wide was related to reduced in-season OP use and increased in-season pyrethroid, oil alone, and Bt use. These patterns were similar in many counties.

Region-wide dormant OP use was positively correlated with dormant OP use in the following year and negatively correlated with dormant pyrethroid use in the following year (Table 7 and Figure 12). The correlations between dormant OP and next year’s in-season insecticide use were similar to that between dormant OP and the same year’s in-season insecticide use. Similarly, the correlations between dormant pyrethroid and next year’s in-season insecticide use were similar to that between dormant pyrethroid and the same year’s in-season insecticide use (Table 7). Again these patterns were similar in most counties, especially the positive correlations between dormant OP and next year’s dormant and in-season OP uses.

The percent of growers who continued to use dormant OPs from one year to the next declined from 67% in the 1993 to 29% in 2000 (Figure 13). The percent of growers who switched from dormant OPs in one year to no dormant insecticides in the next year increased from 18% in 1993 to 38% in 2000. The percent of growers who switched to other insecticides fluctuated from year to year but remained around 20% in the last decade (Figure 13).

Similarly, the growers who used reduced-risk alternatives to dormant OPs did not use more in-season insecticides (Figure 14). The percent of growers who used dormant and in-season OPs, decreased from 56% in 1992 to 43 % in 1999 (Figure 14 A). An average of 35% of the growers who used dormant OP applied no in-season insecticides in the last decade. The percent of these growers that applied in-season pyrethroids, increased from 8% in 1992 to a 26% in 1998 (Figure 14 A). The in-season insecticide use among growers who applied dormant pyrethroids was similar, except that the percentage using no in-season insecticides was less and the percentage that used in-season pyrethroids remained around an average of 25% from 1992 to 1998 (Figure 14 B). The growers who used bloom time Bt treatments applied less in-season OPs and pyrethroids and used more in-season Bt than growers who applied dormant OPs and pyrethroids. The growers who used bloom time Bt treatments also increased the use of in-season Bt from, 19% in 1992 to 40% in 1999 (Figure 14 C). These growers also increased the use of in-season pyrethroids, but not other alternatives (Figure 14 C). About 50% of growers who used only dormant oils applied no in-season insecticides and about 65% who used no dormant insecticides applied no in-season insecticides (Figure 14 D & E). However, the growers who used no dormant insecticides applied more in-season pyrethroids and less in-season OPs (Figure 14 E).

Discussion

The significant declining trend of dormant OP use on almonds, whether it was measured by pounds per planted acres or by percent acres treated, illustrates the profound changes in pest management strategies in the California almond farm community (Epstein et al, 2001a, b, Swezey and Broome, 2001, CDPR, 2001). The decrease of dormant OP use is probably a result of many complex factors. Since almond production has been rather stable (CDFA, 2001) and the almond damage rate as measured by nut rejects stayed fairly constant during the last decade (Almond Board), these trends suggest that either the chemical alternatives to OP use were successful and/or almond growers focused on strategies that were less reliant on insecticides (Thrupp, 2001; Hendricks, 1995). The reduced-risk programs funded by the government and universities may have played a role in the reduction of dormant OP use in California.

Given the pesticide use data, the decrease of dormant OP use was probably not due primarily to growers who used dormant OPs leaving almond production and new growers starting production using alternatives. We found instead that growers were switching from using dormant OPs to alternative practices (Figure 14). In addition, growers were not generally replacing dormant OP use with in-season OP or other insecticide use (Table 8, Figure 14).

From 1992 to 1994, dormant OPs were by far the most commonly used insecticides to control almond overwintering pests, applied to 40 to 50% of the almond acreage (Figure 3). In 1992, dormant OPs were used on over 20 times more acreage than pyrethroids or oils alone, and nine times more acreage than Bt (Figure 3). In 2000, both dormant season pyrethroids and Bt were used on more almond acreage than OPs (Figure 3). But the most common alternative to dormant OPs was to spray nothing at all during the dormant season. By 2000, 57% of the total almond acreage received no dormant treatments, compared to 16% of the acreage treated with the next most common dormant season alternative, pyrethroids.

The increased use of pyrethroids may be due to their inexpensive price. They also can be applied at the same times as dormant OPs. However, the trends of Bt use are less clear-cut than the OP or pyrethroid trends. Bt use is affected by several factors. Growers spray Bt at bloom time (from February to March) to control peach twig borer, and at hull split (in July) to control navel orangeworm. Despite its expense, growers sometimes favor Bt because it does not disrupt natural enemy populations or cause mite outbreaks, and because of its very low mammalian toxicity.

The most widely used alternative to dormant OP in recent years was no dormant insecticide. This may be because in some areas the overwintering pests are not a big problem or that in-season pesticide applications are sufficient to maintain almond productivity. In addition, it is possible that some growers find that they do not need to spray every year to get adequate control of wintering pests. Another likely explanation is the poorer economic conditions in the late 1990's, which could have led growers to cut back on expenses such as pesticide applications. However, applying no dormant insecticides does not necessarily mean they are doing nothing else to control these pests. In fact, innovative farm practices, such as orchard sanitation and conserving beneficial arthropods in farm fields have been reported as effective ways to reduce the use of more hazardous pesticides (Hendricks, 1995). Growers who understand ecological farming principles and apply their local knowledge to their farm pest management can often use less pesticide to achieve similar productivity (Thrupp, 2001). It is clear that DPR and other agencies have promoted such an integrated approach in various projects during the 1990s (DPR, 2002; Swezey and Broome, 2001; Thrupp, 2001).

The decline in OP use is good news for the many agencies working to reduce OP surface water runoff. Although the relationship between dormant OP use and residues of OP in surface water depends on many factors, such as coincidence of rain and applications, distance from a river, and method of application, in general one would expect less dormant OP use to result in reduced OP concentrations in surface water (Guo et al, 2003). Previous studies of OP runoff suggested that dormant OP use was a major source for surface water contamination (Domagalski et al., 1997; Dubrovsky et al., 1998).

Many factors could affect growers' decisions on dormant season pest management actions and, in particular, whether or not to use dormant OPs. Pest pressures are an obvious important factor. High pest populations in the current season or damage in previous years are likely reasons many growers apply pesticides.

Weather is an important factor in determining size of pest populations. Cold winters can result in higher arthropod mortality. Different temperature measures were used because of several possible ways that temperature could affect arthropod populations. Some species may be able to survive long periods of relatively cold weather but not a short time at temperatures below some threshold. In this case there might be no relationship between high cumulative chilling hours and mortality but a strong relationship between minimum temperature and mortality (Tables 6 and 7). On the other hand, some species may have the opposite reaction in which mortality increases with long periods of relatively cold temperatures but mortality is not affected by brief periods of very cold temperatures (Zalom personal communication, 2002). We used two different time periods because some species, such as PTB, may be most sensitive to weather in late January or early February. PTB is more sensitive at that time because they sometimes emerge from their protective environments during that period.

During the growing season temperatures above or below optimal levels will slow the development of arthropods, which will affect the timing of different events. For peach twig borer in almonds, population size is probably not as important as timing of larval emergence relative to almond hull split. This relative timing cannot be easily predicted. However, general levels of PTB are important because it increases the chances of damage and because in orchards with historically high PTB populations growers are more likely to spray. Rain can have several possible effects on arthropod populations. Greater rainfall can increase insect pathogen growth and thus lower insect populations. The main overwintering arthropods in almonds (PTB, European red mite, and San Jose scale) are probably most sensitive to low winter temperatures and rainfall in January (Zalom, personal communication, 2002).

There are many other factors that could affect grower decisions. For example, high rainfall creates muddy fields, making it difficult to get spray equipment into a field and possibly resulting in fewer dormant applications (Table 6, 7). If growers believe that cold or wet winters are likely to lead to fewer pest problems in the coming season, they would be less likely to apply a dormant spray when winters are cold or wet. Some growers may respond to outreach from various agencies discouraging spraying OPs during rainy periods due to surface water pollution concerns. There are additional social factors that will affect grower decisions such as what their neighbors do, what they have done in the past, and whom they trust to provide advise. Judging by conversations with various almond growers and industry leaders, the most important factors affecting grower decisions are probably market considerations, including commodity prices and pesticide costs.

Correlation does not imply causality. However, it can tell us whether hypothetical causal explanations are consistent with observed relationships. For example, because we know it is difficult to spray in muddy fields, we expect a negative correlation between rainfall and dormant pesticide use. Consistent with our expectation, most correlations between rainfall and dormant OP or oil use were indeed negative although weak. For reasons stated earlier, we might also expect colder winter temperatures to result in lower pest populations—and therefore less pesticide use—later in the same year or in the following year. We did not see many positive correlations between winter temperature and pesticide use in the following season, but we did see many positive correlations with pesticide use in the following year, both in the dormant period and in-season. The strongest correlations were for pyrethroid and Bt use; temperature accounted for about 50% of the variation in dormant pyrethroid use and about 70% of the variation in in-season Bt use (Table 6, 7). We can only speculate why the relationships are stronger for pyrethroid and Bt, two of the main alternatives to OP. Given the weakness of most correlations between weather variables and dormant OP or pyrethroid use, however, it does not appear that weather has been a factor of overriding importance in the overall trends (Table 6, 7).

There were also associations between higher percentage rejects, most of which is due to ants, NOW, and PTB damage, and higher insecticide use in the following year. Percent rejects accounted for about 30% of the variation in dormant OP use and about 65% of the variation in dormant pyrethroid use. This suggests that growers may respond to finding higher rejects in their fields by applying more pesticides the next year. But when more insecticides were applied, percent rejects from the treated orchards were only somewhat lower.

These results are not surprising because there are two conflicting effects involved in this relationship. First, growers may apply more pesticides in "problem" areas, areas with higher reject rates, leading to a positive correlation between pesticide use and that year's percent rejects. Second, pesticide applications should reduce pest populations, which would lead to a negative relationship between pesticide use and percent rejects. Therefore, the correlation between pesticide use and that year's percent rejects would be expected to be weak.

The relationships among the uses of different insecticide types were mostly what would be expected based on the general trends of use. These relationships suggest that pyrethroids were generally replacing OPs at the county and region-wide level. To more fully understand the relationship between the uses of different insecticide types would require analysis at the grower and field levels.

Reduced dormant OP use does not necessarily mean that overall risk from pesticides has been reduced. Lower dormant OP use could result in more pest damage, leading to more pesticide use later. For example, certain secondary pest populations previously suppressed by OP use could build up over time, causing economic damage. This has been the case in some San Joaquin Valley stone fruit orchards, which have seen an increase in katydids and cucumber beetles (*Diabrotica undecimpunctata*) since stopping OP use In addition, the use of dormant pyrethroids has increased and these chemicals carry their own set of environmental risks (Werner et al, 2002). Pyrethroids can disrupt natural enemy populations, causing outbreaks of mites or other secondary pests, thus potentially increasing in-season pesticide use (UCIPM, 2002a, b). Some pyrethroids also pose hazards to bees and certain aquatic species, such as the fat head minnow (Werner et al., 2002).

Although nearly everyone considers Bt a reduced-risk alternative to dormant OPs, it is in itself not a complete substitute because dormant OPs control scales, mites, and PTB, while Bt controls only PTB. Replacing dormant OPs with Bt could result in increased scale and mite populations, which may then cause growers to use, for example, in-season OPs to control scales or propargite (a probable carcinogen) to control mites (UCIPM, 2002a).

Our analyses suggest that growers who used lower risk dormant season alternatives did not tend to use more OPs or pyrethroids later, either in the in-season following the dormant season or in the following dormant season. This finding could mean that stopping OP use has not significantly worsened pest problems, and that alternatives to OPs are working. To be conclusive, other analyses should be conducted to examine pesticide use patterns at the grower/field level of resolution.

This study clearly depicts the decline of dormant OP use in California almonds. It also examines the relative effects of nut damage, weather variables, and use of alternative pesticides on OP use. While these factors are important, we acknowledge that other variables such as pesticide and commodity prices, pesticide resistance, pest population size, and grower perceptions could also affect pesticide use trends in almonds. These data are needed to paint a complete picture of pesticide use trends and grower decision-making in almonds.

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Table 1. All reported insecticide active ingredients applied to almonds from 1992 to 2000 and their class from DPR's Pesticide Use Reports.

Active Ingredient	OP	pyrethroid	oil	Bt	other
Azinphos Methyl	Y				
Chlorpyrifos	Y				
Ddvp	Y				
Diazinon	Y				
Dimethoate	Y				
Disulfoton	Y				
Ethoprop	Y				
Fenamiphos	Y				
Malathion	Y				
Methidathion	Y				
Methyl Parathion	Y				
Naled	Y				
Parathion	Y				
Phosalone	Y				
Phosmet	Y				
Cyfluthrin		Y			
Esfenvalerate		Y			
Permethrin		Y			
Pyrethrins		Y			
Tau-Fluvalinate		Y			
Mineral Oil			Y		
Petroleum Distillates			Y		
Petroleum Distillates, Refined			Y		
Petroleum Hydrocarbons			Y		
Petroleum Oil, Unclassified			Y		
Bacillus thuringiensis (Berliner)				Y	
Bacillus thuringiensis (Berliner), Subsp. Aizawai, Gc-91 Protein				Y	
Bacillus thuringiensis (Berliner), Subsp. Aizawai, Serotype H-7				Y	
Bacillus thuringiensis (Berliner), Subsp. Kurstaki Strain Sa-12				Y	
Bacillus thuringiensis (Berliner), Subsp. Kurstaki, Serotype 3a,3b				Y	
Bacillus thuringiensis (Berliner), Subsp. Kurstaki, Strain Eg 2348				Y	
Bacillus thuringiensis (Berliner), Subsp. Kurstaki, Strain Eg2371				Y	
Bacillus thuringiensis (Berliner), Subsp. Kurstaki, Strain Sa-11				Y	
Bacillus thuringiensis Subspecies Kurstaki, Genetically Engineered Strain Eg7841 Lepidopteran Active Toxin				Y	
Bacillus thuringiensis, Subsp. Kurstaki, Strain Hd-1				Y	
Bacillus thuringiensis, Var. Kurstaki Delta Endotoxins Cry 1a(C) And Cry 1c (Genetically Engineered) Encapsulated In Pseudomonas Fluorescens (Killed)				Y	
Encapsulated Delta Endotoxin Of Bacillus thuringiensis Var. Kurstaki In Killed Pseudomonas Fluorescens				Y	

Table 1 (cont.)

Active Ingredient	**OP**	**pyrethroid**	**oil**	**Bt**	**other**
(E)-5-Decenol					Y
(E)-5-Decenyl Acetate					Y
(Z,E)-7,11-Hexadecadien-1-Yl Acetate					Y
(Z,Z)-7,11-Hexadecadien-1-Yl Acetate					Y
2-(2-Butoxy Ethoxy) Ethyl Thiocyanate					Y
Aluminum Phosphide					Y
Amitraz					Y
Avermectin					Y
Azadirachtin					Y
Boric Acid					Y
Carbaryl					Y
Carbophenothion					Y
Cinnamaldehyde					Y
Clarified Hydrophobic Extract Of Neem Oil					Y
Corn Product, Hydrolyzed					Y
Cryolite					Y
Ddvp, Other Related					Y
Demeton					Y
Diatomaceous Earth					Y
Dicrotophos					Y
Diflubenzuron					Y
E,E-8,10-Dodecadien-1-Ol					Y
E-8-Dodecenyl Acetate					Y
Endosulfan					Y
Ethion					Y
Formetanate Hydrochloride					Y
Heptachlor					Y
Heptachlor, Other Related					Y
Hexachlorophene					Y
Hydramethylnon					Y
Kaolin					Y
Lindane					Y
Magnesium Phosphide					Y
Methomyl					Y
Methoxychlor					Y
Methyl Parathion, Other Related					Y
Mevinphos					Y
Mevinphos, Other Related					Y
Monocrotophos					Y
Parathion, Other Related					Y
Piperonyl Butoxide					Y
Piperonyl Butoxide, Other Related					Y
Potash Soap					Y

Table 1 (cont.)

Active Ingredient	**OP**	**pyrethroid**	**oil**	**Bt**	**other**
Pyridaben					Y
Pyriproxyfen					Y
Rotenone					Y
Rotenone, Other Related					Y
Soybean Oil					Y
Spinosad					Y
Tebufenozide					Y
Z-8-Dodecenol					Y
Z-8-Dodecenyl Acetate					Y

Table 2. Weather Station Descriptions (source: CIMIS website)

Station Code	*Station Name*	*Nearby City*	*County*	*Starting Date*	*Latitude*	*Longitude*	*Elevation (ft)*
2	FivePoints	Five Points	Fresno	6/7/1982	36.336	-120.113	285
5	Shafter	Shafter	Kern	6/1/1982	35.533	-119.281	360
8	Gerber	Gerber	Tehama	9/22/1982	40.045	-122.164	250
12	Durham	Chico	Butte	10/19/1982	39.609	-121.823	130
27	Zamore	Woodland	Yolo	12/5/1982	38.808	-121.908	50
30	Nicolaus	Nicolaus	Sutter	1/3/1983	38.871	-121.545	32
32	Colusa	Colusa	Colusa	1/13/1983	39.226	-122.024	55
61	Orland	Orland	Glenn	5/13/1987	39.692	-122.152	198
70	Manteca	Manteca	San Joaquin	11/21/1987	37.835	-121.223	33
71	Modesto	Modesto	Stanislaus	6/25/1987	37.645	-121.188	35
80	FresnoState	Fresno	Fresno	10/3/1988	36.821	-119.742	339
86	Lindcove	Lindcove	Tulare	5/31/1989	36.357	-119.059	480
92	Kesterson	Gustine	Merced	10/13/1989	37.033	-120.88	75

Table 3. Variable Descriptions. All measures of pesticide use and almond acres planted are from DPR's Pesticide Use Reports.

Variables	Descriptions
Pounds	Sum of reported pounds of active ingredient (AI) applied
Pounds per acre planted	Sum of pounds of AI applied divided by acres planted
Cumulative acres treated	The sum of acres treated from all applications even when the same field is treated more than once
Acres treated per acre planted	Cumulative acre treated divided by acres planted
Percent acres treated	The sum of base acres treated for all almond fields divided by acres planted, where base acres treated of a field is the maximum of the cumulative acres treated for the field and the acres planted for the field
Number of growers	The number of almond growers reporting use of a particular pesticide or pesticide type to DPR where a grower is distinguished by the last 7 characters of the grower_id
Dormant 30° chilling hours	The sum of hourly temperatures in Fahrenheit, T_{hr}, below the threshold temperature 30°F during the period November 1 through March 20, that is, $chilling\ hours = \sum_{hr=A}^{B} Max(T_{th} - 30, 0)$
Dormant 40° chilling hours	The sum of hourly temperatures below 40°F during the period November 1 through March 20
January 30° chilling hours	The sum of hourly temperatures below 30°F during the period January 15 and February 15
January 40° chilling hours	The sum of hourly temperatures below 40°F during the period January 15 and February 15
Rainfall	Sum of the daily rainfall in inches during the period November 1 through March 20
Rain Days	Number of the days that had any rainfall during the period November 1 through March 20
Average temperature	Daily average temperature during the period November 1 through March 20
Minimum temperature	Daily minimum temperature during the period November 1 through March 20

Table 4. Dormant season pesticide use trends. Regression slopes and percent change of pesticide use trends for OPs, pyrethroids, and oils alone in dormant season using pounds per acre planted as a measure. Percent change = 100 * ($X_{2000} – X_{1992}$)/X_{1996}, where X_y was the regression predicted measure of use in year y.
Significance levels: ** $p < 0.01$, * $p < 0.05$.

	Lbs OP per Acre Planted			*Lbs Pyrethroids per Acre Planted*			*Lbs Oil Alone per Acre Planted*		
County	*Slope*	*Percent Change*	*Sig. Rank*	*Slope*	*Percent Change*	*Sig. Rank*	*Slope*	*Percent Change*	*Sig. Rank*
BUTTE	-0.078	-126	*	-0.0001	-3		0.005	9	
COLUSA	-0.079	-230	**	0.0000	10		0.023	28	
FRESNO	-0.150	-151	**	0.0030	294	**	-0.004	-4	
GLENN	-0.086	-139	*	-0.0012	-44		-0.166	-220	
KERN	-0.108	-101	**	0.0030	202	**	0.062	134	*
MADERA	-0.081	-146	**	0.0020	113	*	-0.168	-113	**
MERCED	-0.077	-238	**	0.0021	172		-0.040	-28	
SAN JOAQUIN	-0.077	-108	**	0.0006	37		-0.084	-35	
STANISLAUS	-0.102	-184	**	0.0019	63		0.104	70	
SUTTER	-0.058	-97		-0.0025	-99		0.064	66	
TEHAMA	-0.095	-132	*	0.0018	200		-0.018	-52	
TULARE	-0.068	-73	*	0.0022	162	**	-0.008	-16	
YOLO	-0.030	-205	**	-0.0001	-99		-0.056	-113	
CALIFORNIA	-0.089	-130	**	0.0017	86	*	-0.011	-10	

Table 5. In-season pesticide use trends. Regression slopes and percent change of the pesticide use trends for OPs, pyrethroids, and oils alone in the growing season using pounds per acre planted as a measure. Percent change = 100 * ($X_{2000} – X_{1992}$)/X_{1996}, where X_y was the regression predicted measure of use in year y.
Significance levels: ** $p < 0.01$, * $p < 0.05$.

	Lbs OP per Acre Planted			*Lbs Pyrethroids per Acre Planted*			*Lbs Oil Alone per / Acre Planted*		
County	*Slope*	*Percent Change*	*Sig. Rank*	*Slope*	*Percent Change*	*Sig. Rank*	*Slope*	*Percent Change*	*Sig. Rank*
BUTTE	-0.035	-49		-0.0010	-53		-0.001	-32	
COLUSA	-0.029	-93	**	0.0003	201		-0.024	-177	
FRESNO	-0.071	-53	*	0.0035	111		0.063	307	*
GLENN	0.021	30		-0.0015	-124		-0.014	-206	
KERN	-0.078	-28		0.0031	718	**	0.030	160	
MADERA	-0.096	-90	**	0.0046	149	*	0.003	45	
MERCED	-0.062	-84	**	0.0016	47	*	0.018	159	
SAN JOAQUIN	-0.050	-96	**	0.0022	26		0.013	186	
STANISLAUS	-0.049	-51	*	0.0016	44		0.027	283	**
SUTTER	-0.005	-42		0.0012	820		-0.035	-164	
TEHAMA	0.008	9		-0.0013	-764		0.001	228	
TULARE	-0.020	-12		0.0010	265		-0.037	-111	
YOLO	-0.015	-76		0.0004	270		-0.004	-30	
CALIFORNIA	-0.041	-34	**	0.0017	120	*	0.020	142	*

Table 6. Correlation coefficients between insecticide use, percent almond nut rejects, and winter weather. Insecticide use was measured by lbs AI/acre planted for both dormant ("dor") and in-season ("sea") periods. Cells in darker gray are correlations with p-value < 0.0002, which is the pairwise level of significance to insure overall significance of 0.05; cells in lighter gray have p-value < 0.05. The correlations were calculated for the region that includes the 13 primary almond-growing counties from 1992 to 2000. Insecticides are classified as OPs, pyrethroids, oil with no other insecticide, and *Bacillus thuringiensis* (Bt). The weather data include the total rainfall and number of days of rain from November 1 to March 20 and from January. 15 to Feb 15 (labeled "jan" in the column headings); the average of the minimum daily temperatures from both time periods, and the cumulative chilling hours below 30° F and 40° F for both time periods.

	year	dor op	dor pyr	dor oil	dor bt	sea op	sea pyr	sea oil	sea bt	per cent reject	rain fall	rain days	rain fall jan	rain days jan	Tmin	Tave	Tmin jan	Tave jan	chill30	chill40	chill30 jan	chill40 jan
year	1.00	-0.94	0.74	-0.17	0.12	-0.80	0.79	0.81	0.68	-0.29	-0.24	0.53	0.22	0.62	0.03	0.09	0.38	0.56	0.32	0.02	-0.12	-0.46
dor op	-0.94	1.00	-0.59	0.16	-0.44	0.57	-0.79	-0.64	-0.61	0.14	0.07	-0.57	-0.11	-0.59	-0.23	-0.22	-0.55	-0.70	-0.12	0.19	0.24	0.63
dor pyr	0.74	-0.59	1.00	0.03	0.03	-0.68	0.71	0.69	0.93	-0.51	-0.33	0.28	0.09	0.28	-0.08	0.03	0.01	0.23	0.50	0.13	0.14	-0.14
dor oil alone	-0.17	0.16	0.03	1.00	0.02	0.03	-0.31	0.16	0.08	-0.64	-0.57	-0.33	-0.79	-0.36	-0.74	-0.73	-0.72	-0.56	0.52	0.71	0.81	0.71
dor bt	0.12	-0.44	0.03	0.02	1.00	0.39	0.36	-0.19	0.26	0.20	0.42	0.26	-0.25	0.02	0.56	0.40	0.46	0.50	-0.39	-0.54	-0.25	-0.55
sea op	-0.80	0.57	-0.68	0.03	0.39	1.00	-0.44	-0.81	-0.49	0.36	0.36	-0.46	-0.38	-0.66	0.34	0.25	0.01	-0.16	-0.59	-0.40	-0.14	0.04
sea pyr	0.79	-0.79	0.71	-0.31	0.36	-0.44	1.00	0.62	0.83	-0.31	0.00	0.28	0.13	0.20	0.23	0.30	0.34	0.53	0.05	-0.24	-0.18	-0.57
sea oil alone	0.81	-0.64	0.69	0.16	-0.19	-0.81	0.62	1.00	0.67	-0.58	-0.53	0.17	0.03	0.27	-0.45	-0.38	-0.16	-0.02	0.60	0.46	0.35	0.08
sea bt	0.68	-0.61	0.93	0.08	0.26	-0.49	0.83	0.67	1.00	-0.56	-0.24	0.16	-0.06	0.07	-0.04	0.04	-0.03	0.20	0.39	0.07	0.18	-0.17
% rejects	-0.29	0.14	-0.51	-0.64	0.20	0.36	-0.31	-0.58	-0.56	1.00	0.70	0.31	0.61	0.35	0.76	0.59	0.63	0.33	-0.67	-0.70	-0.66	-0.46
rainfall	-0.24	0.07	-0.33	-0.57	0.42	0.36	0.00	-0.53	-0.24	0.70	1.00	0.52	0.50	0.19	0.67	0.40	0.55	0.31	-0.44	-0.55	-0.70	-0.60
raindays	0.53	-0.57	0.28	-0.33	0.26	-0.46	0.28	0.17	0.16	0.31	0.52	1.00	0.51	0.80	0.35	0.10	0.64	0.55	0.22	-0.13	-0.58	-0.63
rainfall jan	0.22	-0.11	0.09	-0.79	-0.25	-0.38	0.13	0.03	-0.06	0.61	0.50	0.51	1.00	0.64	0.46	0.40	0.45	0.30	-0.22	-0.37	-0.51	-0.42
raindays jan	0.62	-0.59	0.28	-0.36	0.02	-0.66	0.20	0.27	0.07	0.35	0.19	0.80	0.64	1.00	0.29	0.22	0.55	0.59	0.05	-0.17	-0.37	-0.49
Tmin	0.03	-0.23	-0.08	-0.74	0.56	0.34	0.23	-0.45	-0.04	0.76	0.67	0.35	0.46	0.29	1.00	0.91	0.84	0.72	-0.72	-0.96	-0.79	-0.81
Tave	0.09	-0.22	0.03	-0.73	0.40	0.25	0.30	-0.38	0.04	0.59	0.40	0.10	0.40	0.22	0.91	1.00	0.73	0.74	-0.78	-0.96	-0.65	-0.73
Tmin jan	0.38	-0.55	0.01	-0.72	0.46	0.01	0.34	-0.16	-0.03	0.63	0.55	0.64	0.45	0.55	0.84	0.73	1.00	0.88	-0.44	-0.75	-0.91	-0.94
Tave jan	0.56	-0.70	0.23	-0.56	0.50	-0.16	0.53	-0.02	0.20	0.33	0.31	0.55	0.30	0.59	0.72	0.74	0.88	1.00	-0.41	-0.69	-0.70	-0.92
chill hr30	0.32	-0.12	0.50	0.52	-0.39	-0.59	0.05	0.60	0.39	-0.67	-0.44	0.22	-0.22	0.05	-0.72	-0.78	-0.44	-0.41	1.00	0.86	0.40	0.44
chill hr40	0.02	0.19	0.13	0.71	-0.54	-0.40	-0.24	0.46	0.07	-0.70	-0.55	-0.13	-0.37	-0.17	-0.96	-0.96	-0.75	-0.69	0.86	1.00	0.68	0.75
chill hr30 jan	-0.12	0.24	0.14	0.81	-0.25	-0.14	-0.18	0.35	0.18	-0.66	-0.70	-0.58	-0.51	-0.37	-0.79	-0.65	-0.91	-0.70	0.40	0.68	1.00	0.85
chill hr40 jan	-0.46	0.63	-0.14	0.71	-0.55	0.04	-0.57	0.08	-0.17	-0.46	-0.60	-0.63	-0.42	-0.49	-0.81	-0.73	-0.94	-0.92	0.44	0.75	0.85	1.00

Table 7. Correlation coefficients between insecticide use and previous year's percent almond nut rejects and winter weather. Insecticide use was measured by lbs AI/acre planted for both dormant (“dor”) and in-season (“sea”) periods. Cells in darker gray are correlations with p-value < 0.0002, which is the pairwise level of significance to insure overall significance of 0.05; cells in lighter gray have p-value < 0.05. The correlations were calculated for the region that includes the 13 primary almond-growing counties from 1992 to 2000. Insecticides are classified as OPs, pyrethroids, oil with no other insecticide, and *Bacillus thuringiensis* (Bt). The weather data include the total rainfall and number of days of rain from November 1 to March 20 and from January 15 to Feb 15 (labeled "jan" in the column headings); the average of the minimum daily temperatures from both time periods, and the cumulative chilling hours below 30° F and 40° F for both time periods.

	year	dor op	dor pyr	dor oil	dor bt	sea op	sea pyr	sea oil	sea bt	per cent reject	rain fall	rain days	rain fall jan	rain days jan	Tmin	Tave	Tmin jan	Tave jan	chill30	chill40	chill30 jan	chill40 jan
year	1.00	-0.94	0.74	-0.17	0.12	-0.80	0.79	0.81	0.68	-0.49	-0.04	0.63	0.44	0.66	0.33	0.22	0.47	0.36	-0.33	-0.32	-0.51	-0.47
dor op	-0.94	1.00	-0.59	0.16	-0.44	0.57	-0.79	-0.64	-0.61	0.62	0.25	-0.46	-0.32	-0.61	-0.27	-0.21	-0.35	-0.24	0.42	0.32	0.49	0.30
dor pyr	0.74	-0.59	1.00	0.03	0.03	-0.68	0.71	0.69	0.93	0.12	0.59	0.81	0.67	0.77	0.80	0.62	0.86	0.72	-0.55	-0.72	-0.69	-0.88
dor oil alone	-0.17	0.16	0.03	1.00	0.02	0.03	-0.31	0.16	0.08	0.08	0.39	0.14	0.48	0.30	0.02	-0.05	-0.09	-0.28	-0.30	-0.08	-0.18	0.07
dor bt	0.12	-0.44	0.03	0.02	1.00	0.39	0.36	-0.19	0.26	-0.36	-0.34	-0.18	-0.03	0.18	0.25	0.29	0.11	-0.03	-0.63	-0.42	-0.36	0.06
sea op	-0.80	0.57	-0.68	0.03	0.39	1.00	-0.44	-0.81	-0.49	0.26	-0.25	-0.62	-0.48	-0.46	-0.23	-0.07	-0.41	-0.24	0.13	0.16	0.38	0.49
sea pyr	0.79	-0.79	0.71	-0.31	0.36	-0.44	1.00	0.62	0.83	-0.28	0.04	0.51	0.49	0.63	0.67	0.66	0.72	0.62	-0.58	-0.67	-0.71	-0.64
sea oil alone	0.81	-0.64	0.69	0.16	-0.19	-0.81	0.62	1.00	0.67	-0.33	0.24	0.57	0.58	0.54	0.35	0.33	0.41	0.43	-0.26	-0.32	-0.43	-0.56
sea bt	0.68	-0.61	0.93	0.08	0.26	-0.49	0.83	0.67	1.00	0.06	0.52	0.69	0.71	0.77	0.90	0.80	0.89	0.75	-0.72	-0.87	-0.80	-0.88
% rejects	-0.49	0.62	0.12	0.08	-0.36	0.26	-0.28	-0.33	0.06	1.00	0.61	0.09	0.20	0.03	0.36	0.34	0.28	0.32	0.09	-0.23	0.12	-0.27
rainfall	-0.04	0.25	0.59	0.39	-0.34	-0.25	0.04	0.24	0.52	0.61	1.00	0.58	0.52	0.37	0.64	0.47	0.66	0.55	-0.32	-0.53	-0.43	-0.75
raindays	0.63	-0.46	0.81	0.14	-0.18	-0.62	0.51	0.57	0.69	0.09	0.58	1.00	0.62	0.85	0.51	0.24	0.71	0.53	-0.30	-0.37	-0.60	-0.68
rainfall jan	0.44	-0.32	0.67	0.48	-0.03	-0.48	0.49	0.58	0.71	0.20	0.52	0.62	1.00	0.80	0.65	0.54	0.64	0.25	-0.63	-0.63	-0.73	-0.52
raindays jan	0.66	-0.61	0.77	0.30	0.18	-0.46	0.63	0.54	0.77	0.03	0.37	0.85	0.80	1.00	0.58	0.38	0.66	0.38	-0.54	-0.51	-0.69	-0.52
Tmin	0.33	-0.27	0.80	0.02	0.25	-0.23	0.67	0.35	0.90	0.36	0.64	0.51	0.65	0.58	1.00	0.93	0.94	0.74	-0.76	-0.97	-0.78	-0.88
Tave	0.22	-0.21	0.62	-0.05	0.29	-0.07	0.66	0.33	0.80	0.34	0.47	0.24	0.54	0.38	0.93	1.00	0.78	0.75	-0.67	-0.93	-0.61	-0.77
Tmin jan	0.47	-0.35	0.86	-0.09	0.11	-0.41	0.72	0.41	0.89	0.28	0.66	0.71	0.64	0.66	0.94	0.78	1.00	0.75	-0.67	-0.86	-0.83	-0.92
Tave jan	0.36	-0.24	0.72	-0.28	-0.03	-0.24	0.62	0.43	0.75	0.32	0.55	0.53	0.25	0.38	0.74	0.75	0.75	1.00	-0.24	-0.63	-0.36	-0.88
chill hr30	-0.33	0.42	-0.55	-0.30	-0.63	0.13	-0.58	-0.26	-0.72	0.09	-0.32	-0.30	-0.63	-0.54	-0.76	-0.67	-0.67	-0.24	1.00	0.87	0.90	0.51
chill hr40	-0.32	0.32	-0.72	-0.08	-0.42	0.16	-0.67	-0.32	-0.87	-0.23	-0.53	-0.37	-0.63	-0.51	-0.97	-0.93	-0.86	-0.63	0.87	1.00	0.81	0.79
chill hr30 jan	-0.51	0.49	-0.69	-0.18	-0.36	0.38	-0.71	-0.43	-0.80	0.12	-0.43	-0.60	-0.73	-0.69	-0.78	-0.61	-0.83	-0.36	0.90	0.81	1.00	0.66
chill hr40 jan	-0.47	0.30	-0.88	0.07	0.06	0.49	-0.64	-0.56	-0.88	-0.27	-0.75	-0.68	-0.52	-0.52	-0.88	-0.77	-0.92	-0.88	0.51	0.79	0.66	1.00

Table 8. Correlation coefficients between insecticide use in two consecutive years. Insecticide use was measured by lbs AI/acre planted for both dormant and in-season periods. The top half of this table is identical to the upper left had section of Table 6. Cells in darker gray are correlations with p-value < 0.000468, which is the pairwise level of significance to insure overall significance of 0.05; cells in lighter gray have p-value < 0.05. The correlations were calculated for the region that includes the 13 primary almond-growing counties from 1992 to 2000. Insecticides are classified as OPs, pyrethroids, oil with no other insecticide, and *Bacillus thuringiensis* (Bt).

	year	dormant OP	dormant pyrethroid	dormant oil alone	dormant Bt	season OP	season pyrethroid	season oil alone	season Bt
year	1.00	-0.94	0.74	-0.17	0.12	-0.80	0.79	0.81	0.68
dormant OP	-0.94	1.00	-0.59	0.16	-0.44	0.57	-0.79	-0.64	-0.61
dormant pyr.	0.74	-0.59	1.00	0.03	0.03	-0.68	0.71	0.69	0.93
dormant oil alone	-0.17	0.16	0.03	1.00	0.02	0.03	-0.31	0.16	0.08
dormant Bt	0.12	-0.44	0.03	0.02	1.00	0.39	0.36	-0.19	0.26
season OP	-0.80	0.57	-0.68	0.03	0.39	1.00	-0.44	-0.81	-0.49
season pyr	0.79	-0.79	0.71	-0.31	0.36	-0.44	1.00	0.62	0.83
season oil alone	0.81	-0.64	0.69	0.16	-0.19	-0.81	0.62	1.00	0.67
season Bt	0.68	-0.61	0.93	0.08	0.26	-0.49	0.83	0.67	1.00
next year's dor OP	-0.91	0.83	-0.91	-0.29	-0.25	0.69	-0.67	-0.78	-0.90
next year's dor pyr.	0.63	-0.78	0.39	-0.55	0.62	-0.22	0.63	0.16	0.44
next year's dor oil	-0.38	0.47	-0.35	-0.10	-0.28	-0.07	-0.28	-0.23	-0.36
next year's dor Bt	-0.29	0.15	-0.14	0.59	0.27	0.38	-0.27	-0.22	-0.08
next year's sea OP	-0.80	0.70	-0.60	0.33	-0.09	0.61	-0.76	-0.71	-0.65
next year's sea pyr.	0.68	-0.68	0.75	-0.30	0.31	-0.31	0.59	0.23	0.67
next year's sea oil	0.77	-0.62	0.78	-0.42	0.07	-0.66	0.83	0.53	0.78
next year's sea Bt	0.50	-0.64	0.40	-0.63	0.61	-0.10	0.59	-0.06	0.42

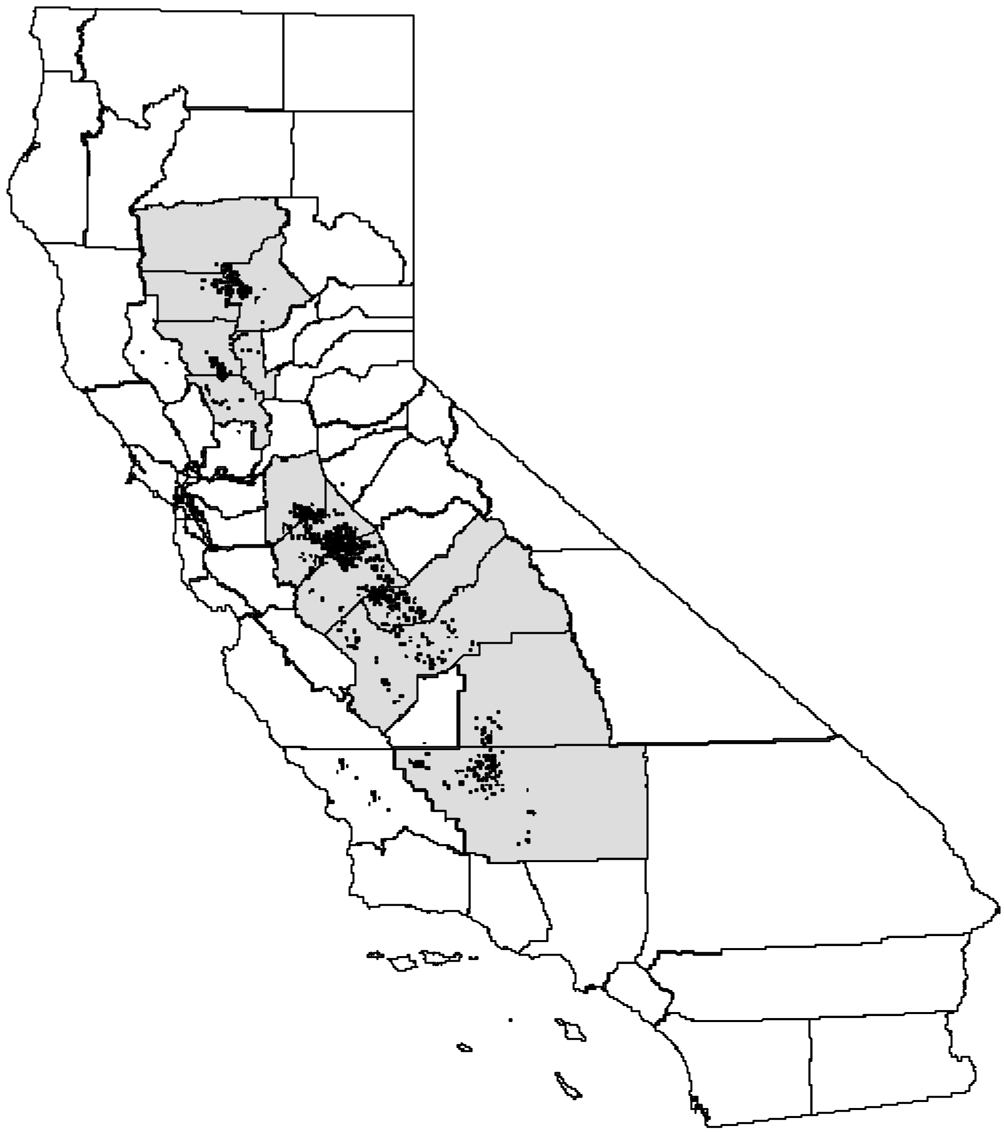

Figure 1. Major almond growing counties in California shown shaded; the dark dots are 1 square mile sections with almond orchards.

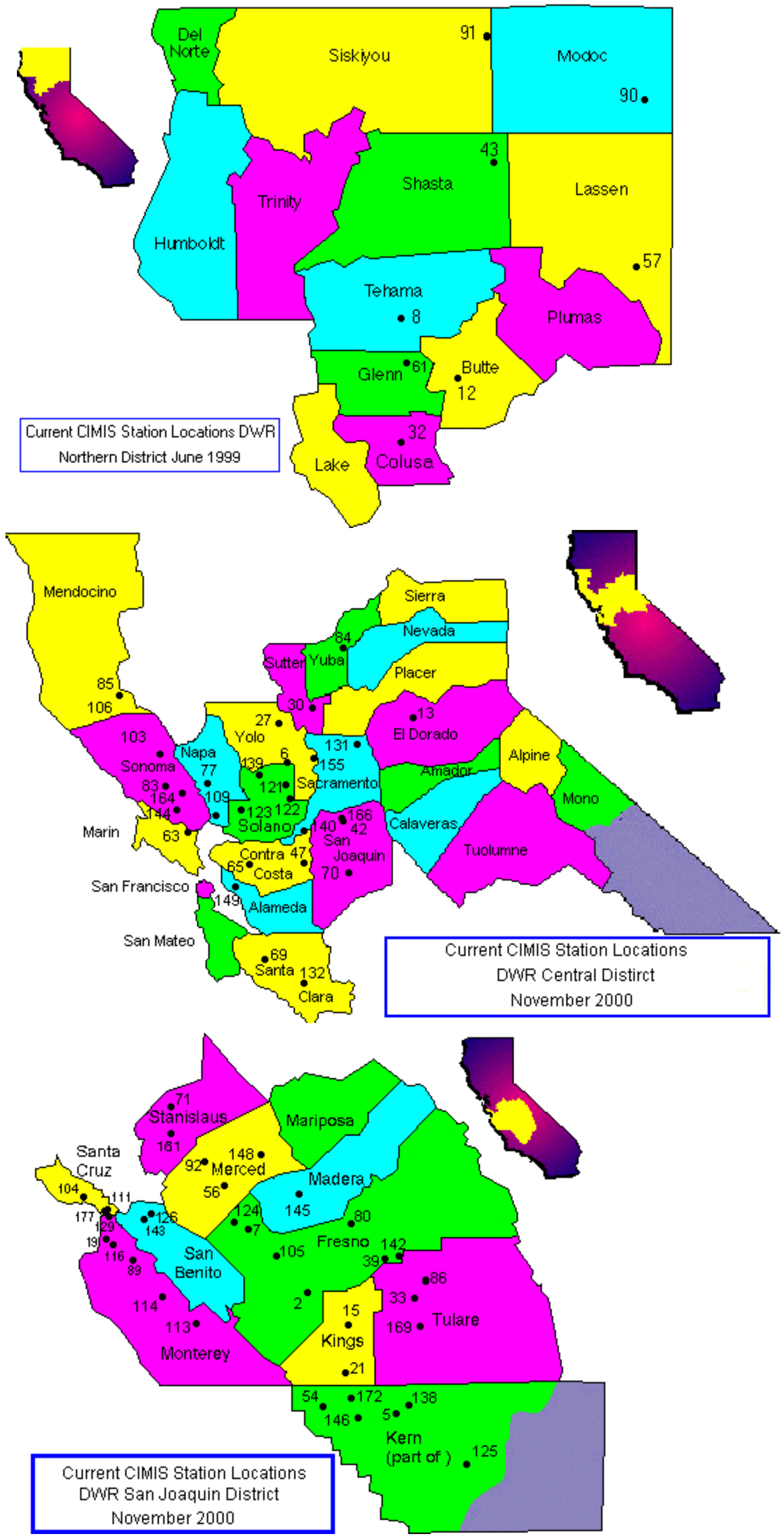

Figure 2. CIMIS weather stations

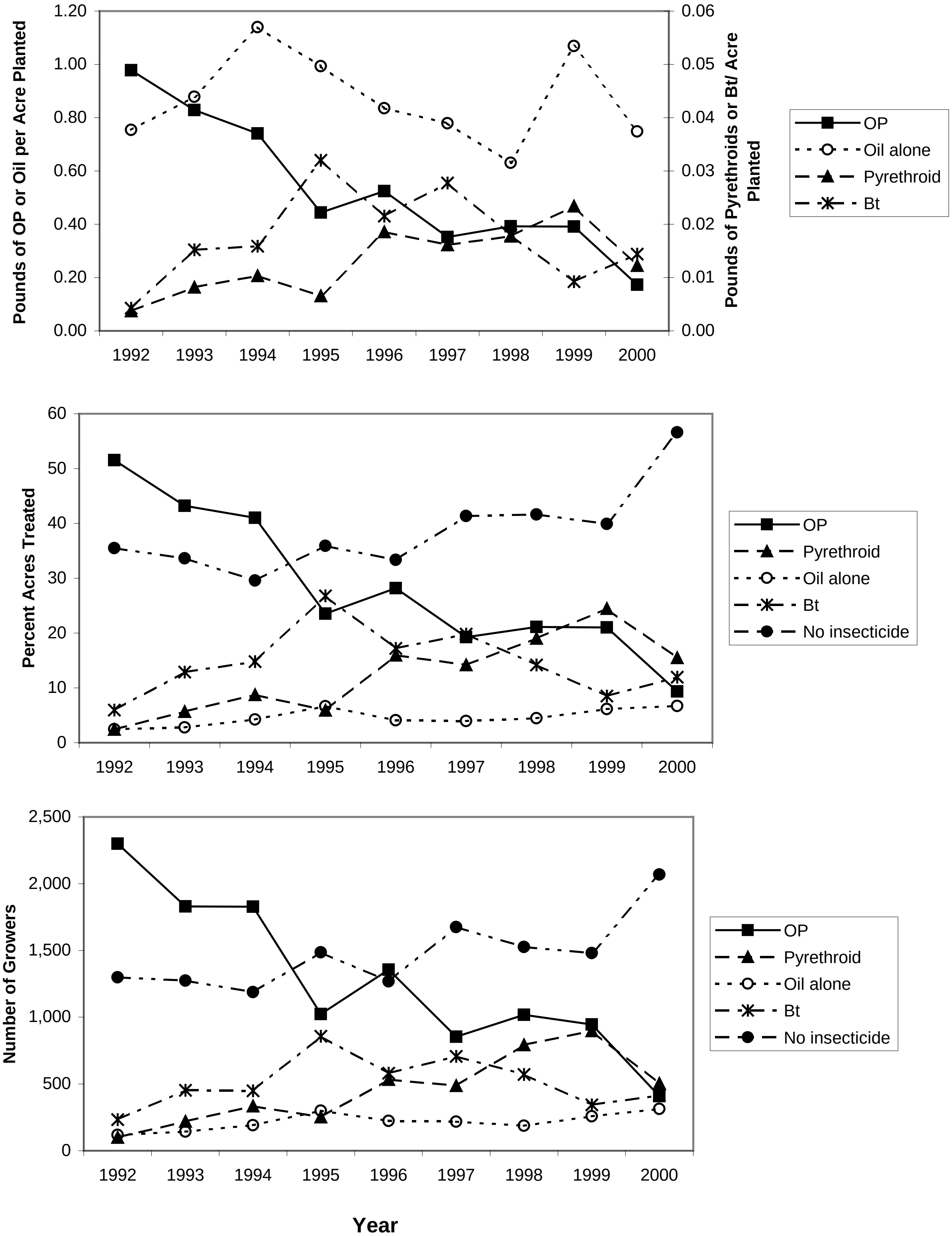

Figure 3. Dormant season pesticide use. Pounds of AI per almond acres planted, percent of almond acres treated and number of almond growers using various dormant season insecticide practices from 1992 - 2000.

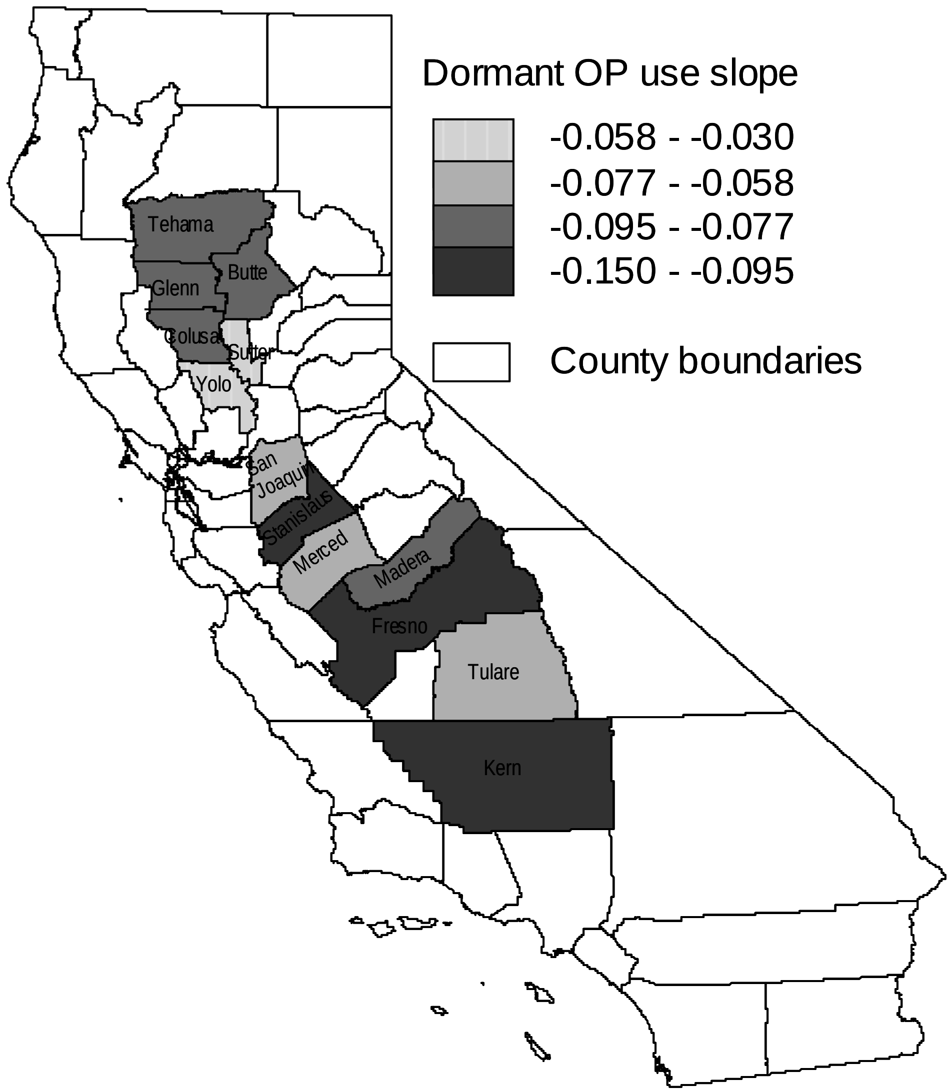

Figure 4. Trends of dormant OP use (lbs AI per acre planted) between 1992 and 2000 in California almond growing counties. The different shadings represent different values of slope (change in lbs AI per acre per year).

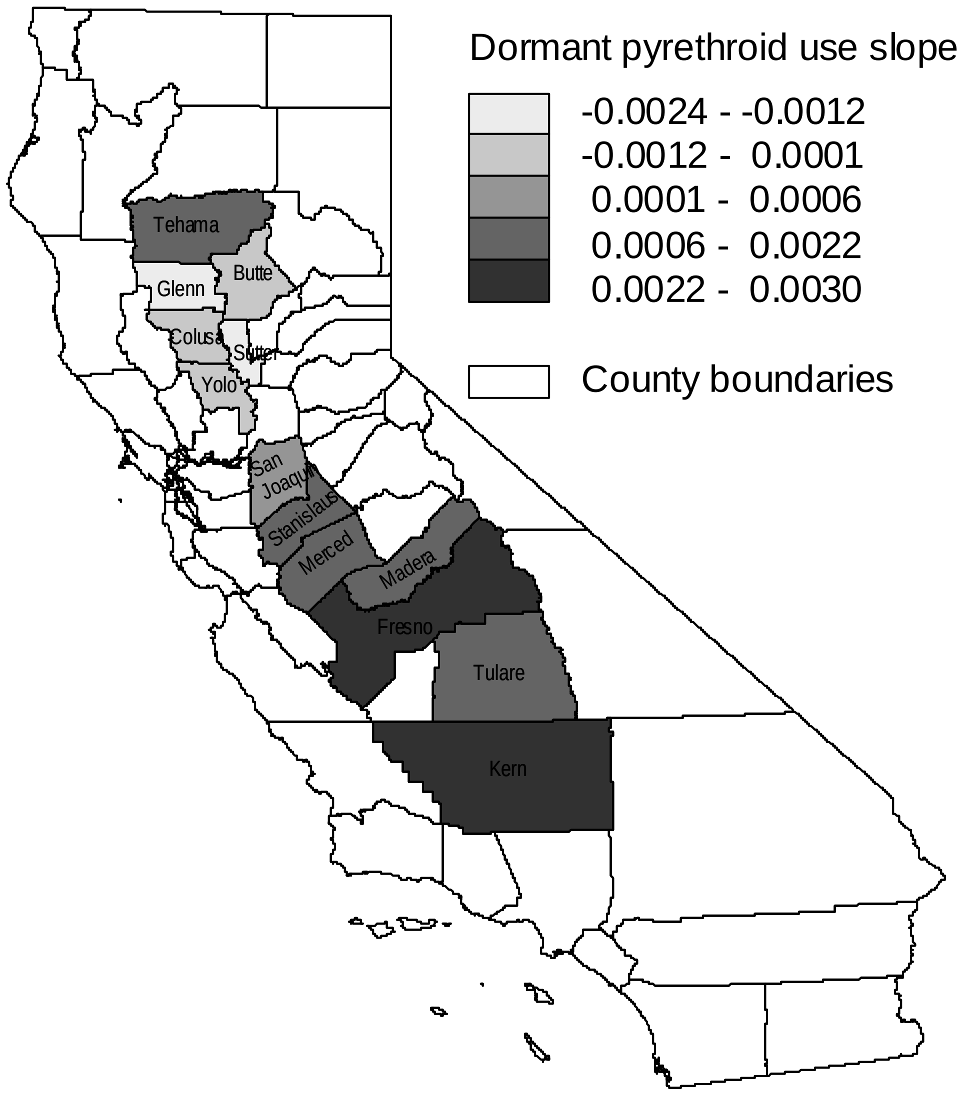

Figure 5. Trends of dormant pyrethroid use (lbs AI per acre planted) between 1992 and 2000 in California almond growing counties. The different shadings represent different values of slope (change in lbs AI per acre per year).

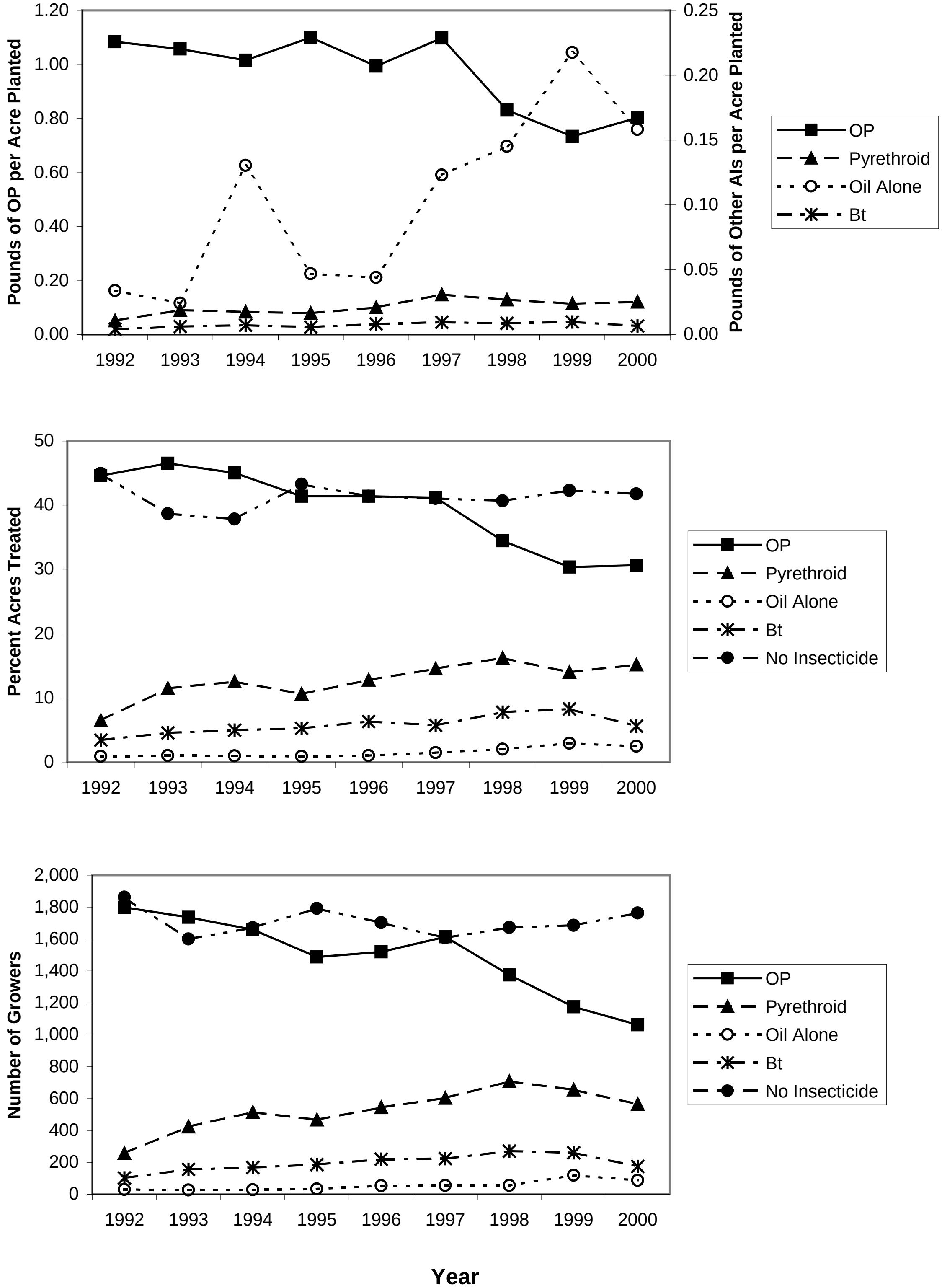

Figure 6. In-season pesticide use. Pounds of AI per almond acres planted, percent of almond acres treated and number of almond growers using various growing season practices to control insects.

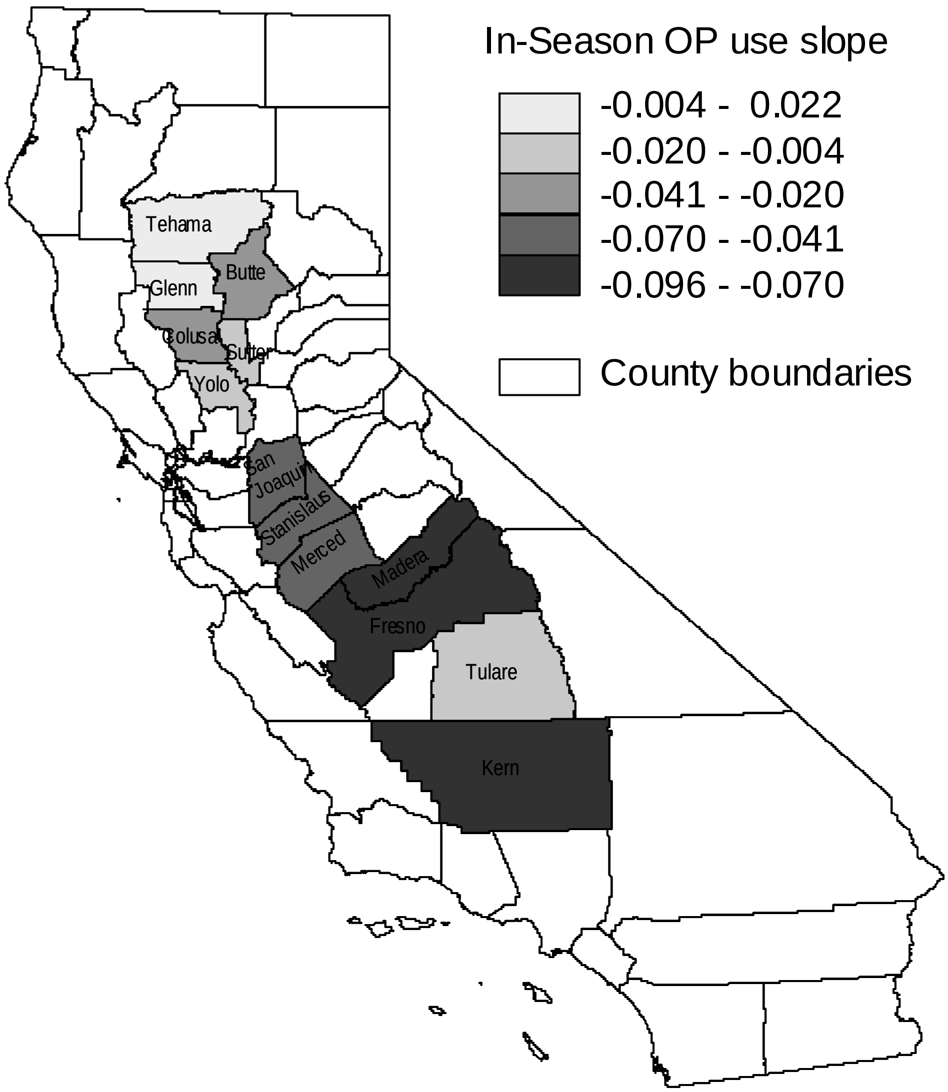

Figure 7. Trends of in-season OP use (lbs AI per acre planted) between 1992 and 2000 in California almond growing counties. The different shadings represent different values of slope (change in lbs AI per acre per year).

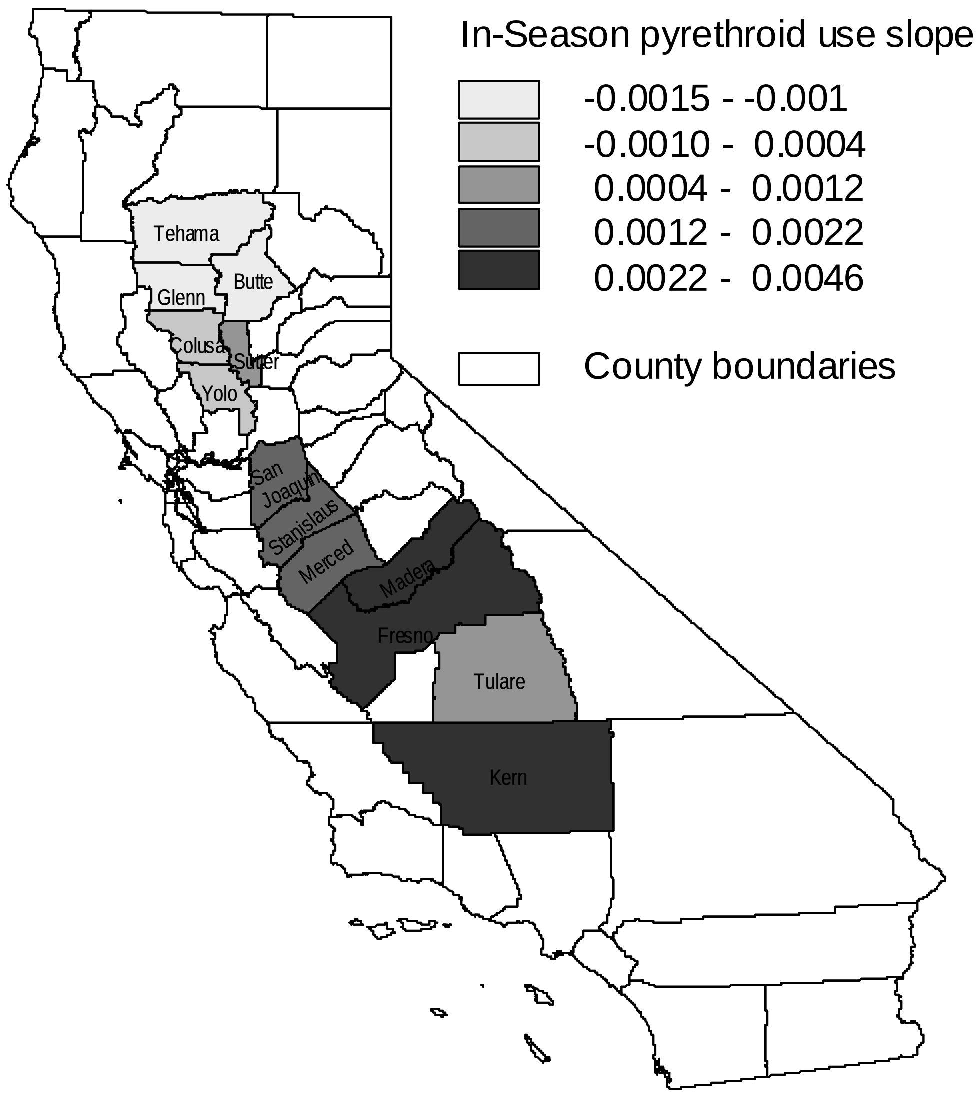

Figure 8. Trends of in-season pyrethroid use (lbs AI per acre planted) between 1992 and 2000 in California almond growing counties. The different shadings represent different values of slope (change in lbs AI per acre per year).

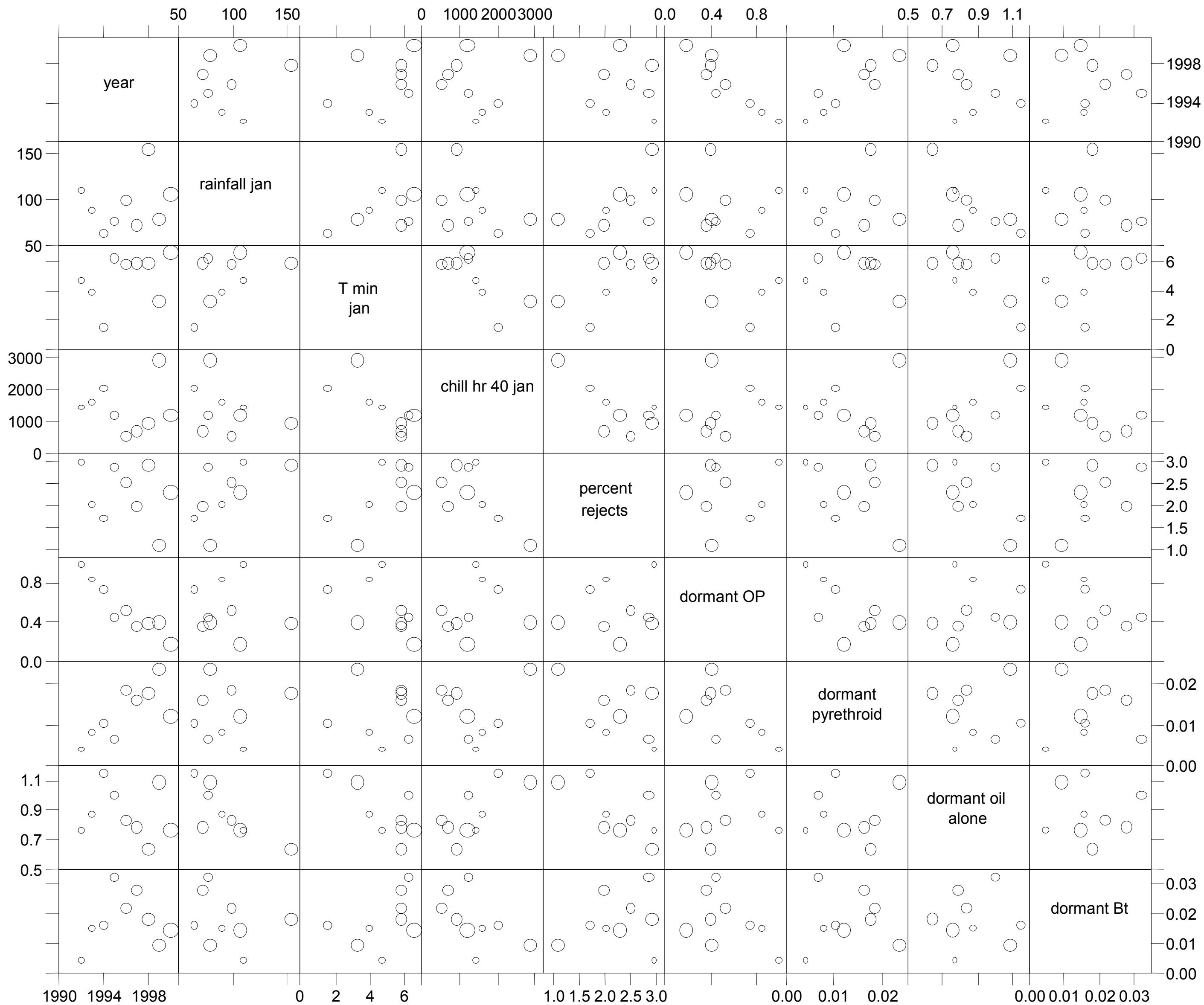

Figure 9. Relationships between dormant insecticide use, percent almond nut rejects, and winter weather. The data represent the region that includes the 13 primary almond-growing counties from 1992 to 2000. Insecticides are classified as OPs, pyrethroids, oil with no other insecticide, and *Bacillus thuringiensis* (Bt). The weather data include the total rainfall, average of the minimum daily temperatures, and the cumulative chilling hours below 40° F from January 15 to February 15.

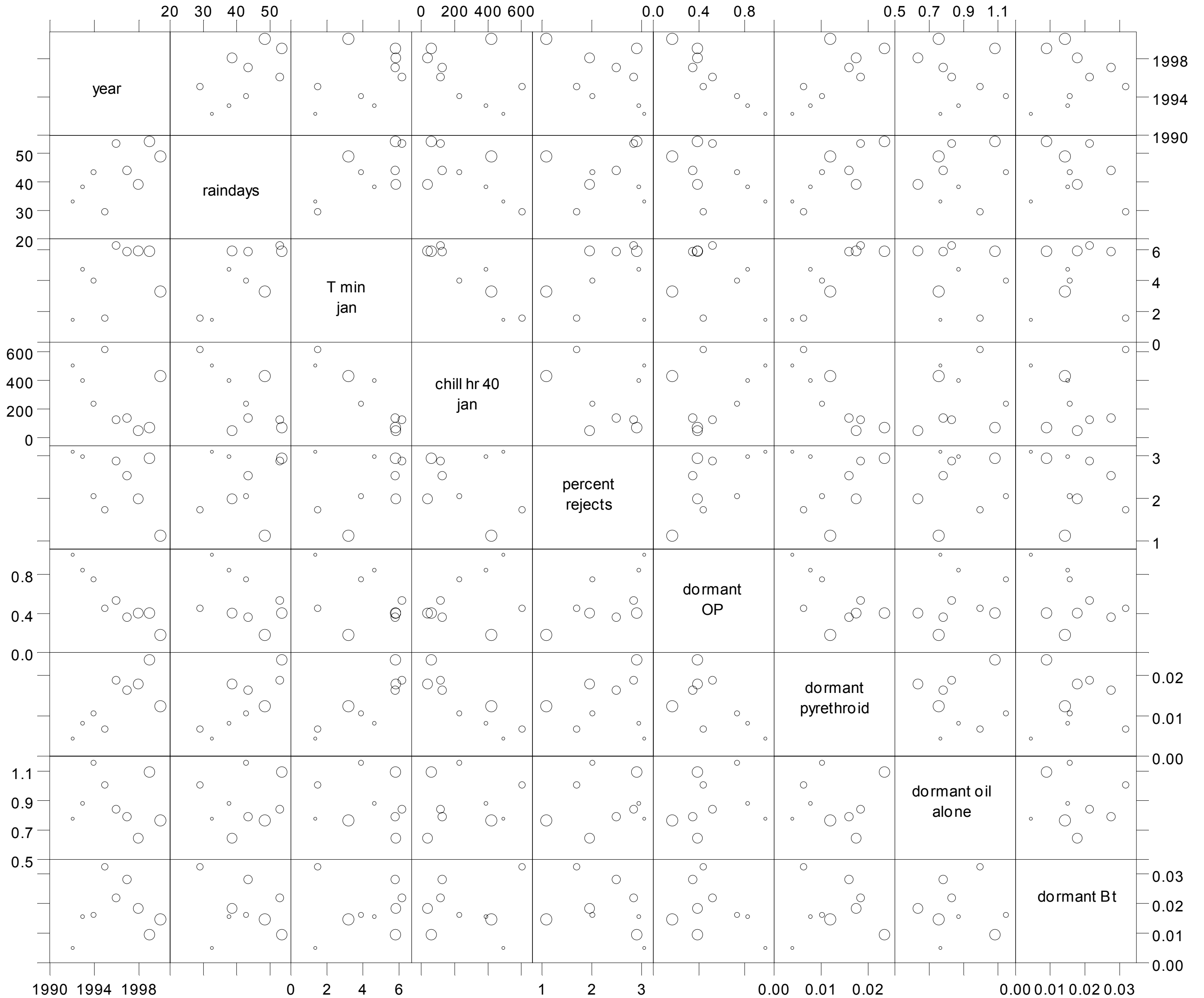

Figure 10. Relationships between dormant insecticide use and previous year's percent almond nut rejects and winter weather. The data represent the region that includes the 13 primary almond-growing counties from 1992 to 2000. Insecticides are classified as OPs, pyrethroids, oil with no other insecticide, and *Bacillus thuringiensis* (Bt). The weather data include the total number of days with rain between November 1 and March 20, the average of the minimum daily temperatures from January 15 to February 15, and the cumulative chilling hours below 40° F from January 15 to February 15.

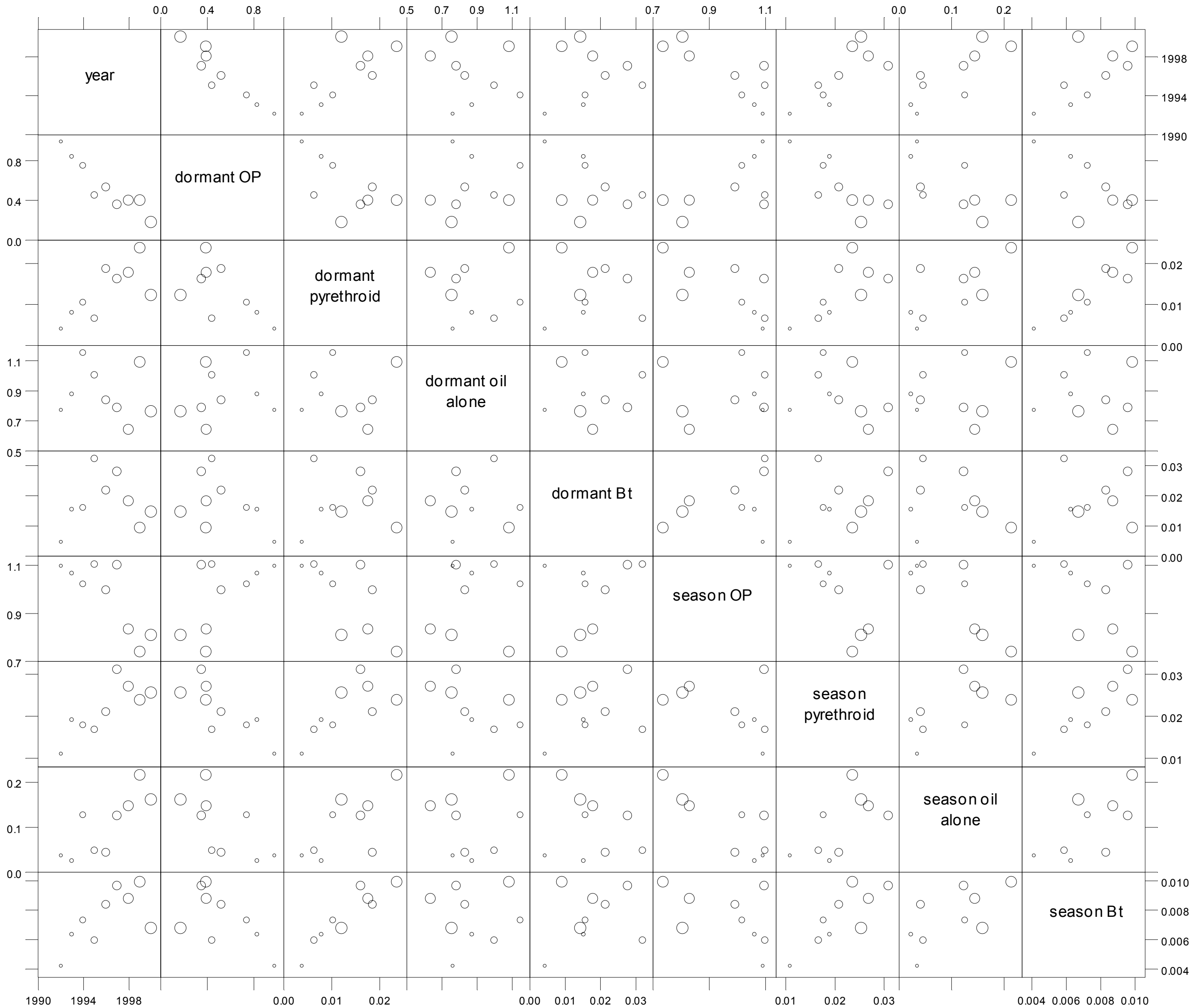

Figure 11. Relationships between dormant and in-season insecticide use. The data represent the region that includes the 13 primary almond-growing counties from 1992 to 2000. Insecticides are classified as OPs, pyrethroids, oil with no other insecticide, and *Bacillus thuringiensis* (Bt).

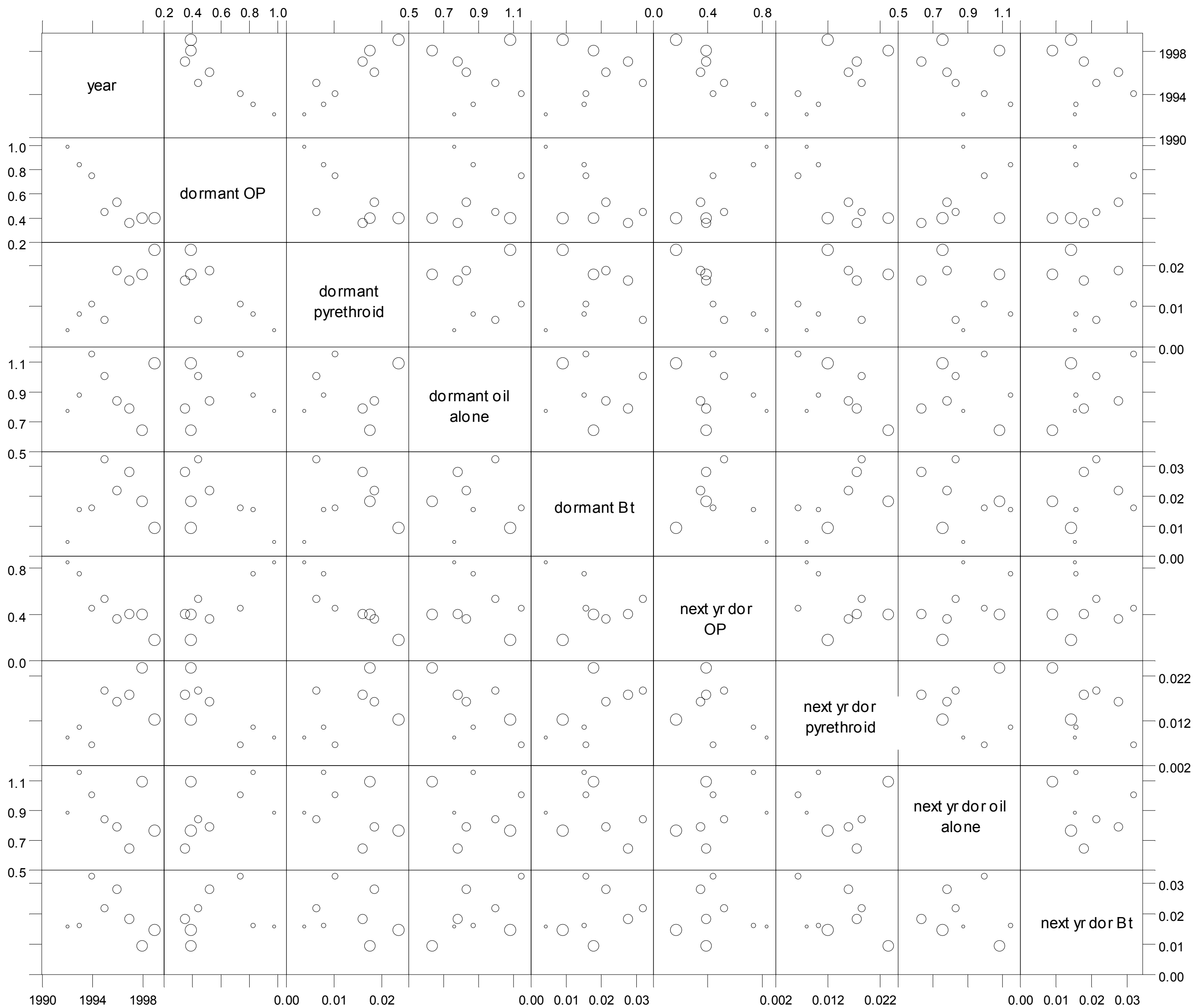

Figure 12. Relationships between dormant insecticide use in consecutive years. The data represent the region that includes the 13 primary almond-growing counties from 1992 to 2000. Insecticides are classified as OPs, pyrethroids, oil with no other insecticide, and *Bacillus thuringiensis* (Bt).

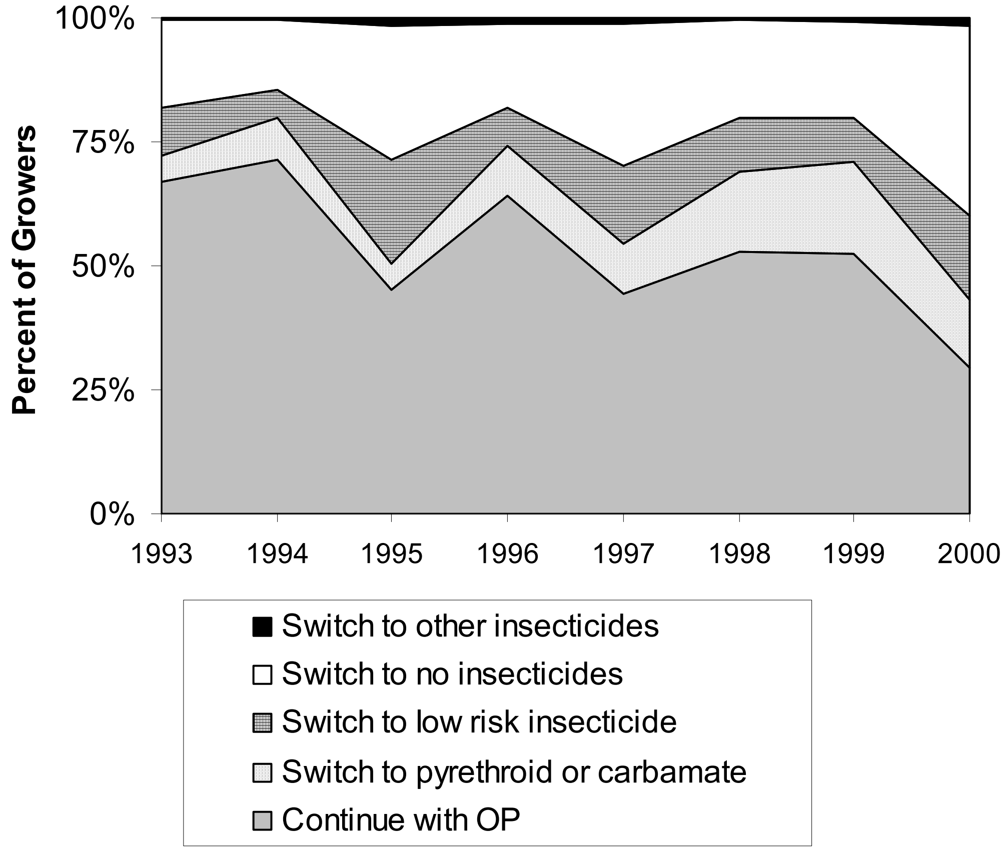

Figure 13. The percent of almond growers each year in California that used dormant OPs in the previous year and continued to use dorjmant OP in the current year; the percent that switched from dormant OP the previous year to a dormant pyrethroid or carbamate, a low risk pesticide (oil, Bt, or spinosad only), no dormant insecticide, or some other insecticide or combinations of insecticides.

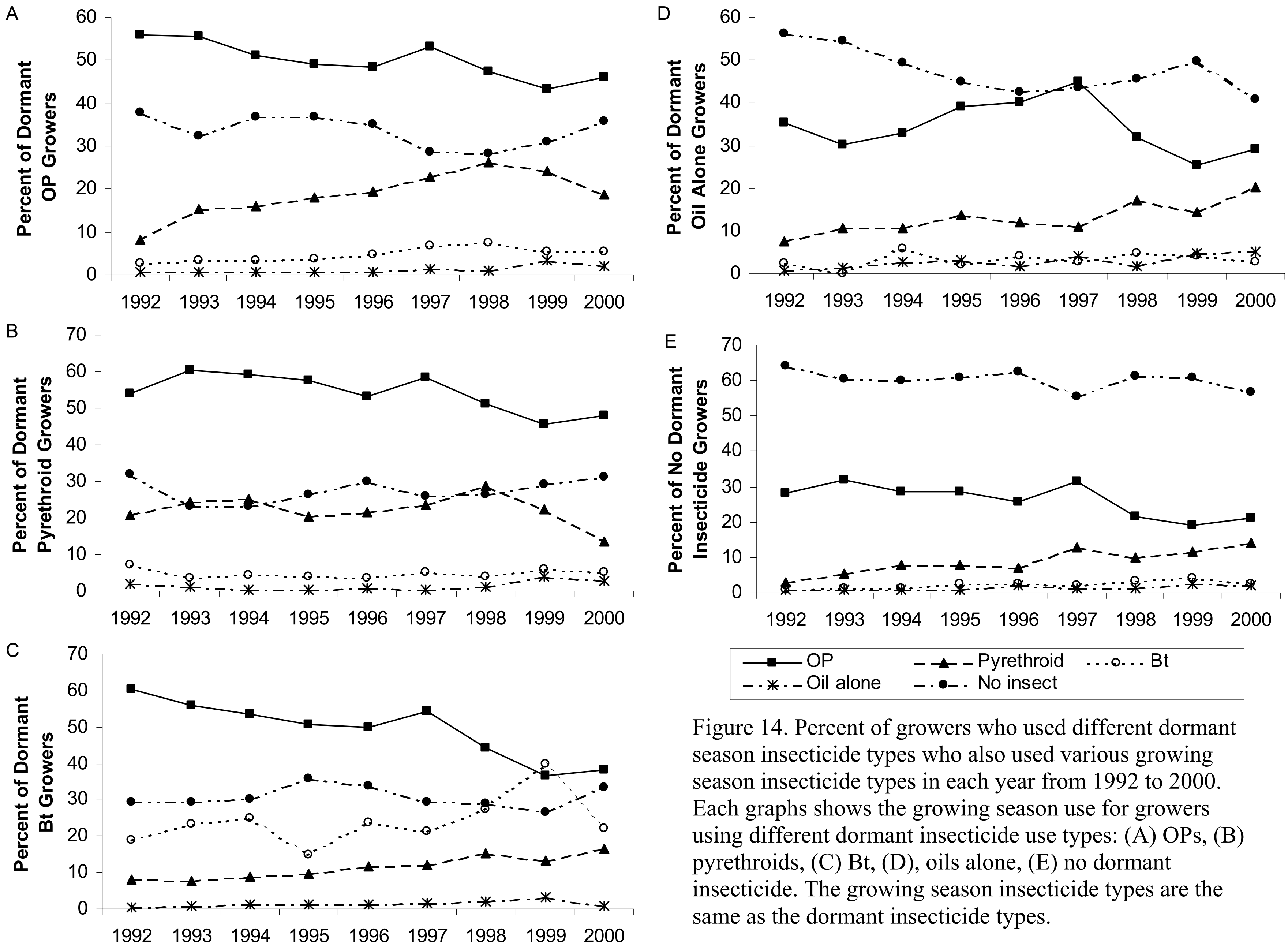

Figure 14. Percent of growers who used different dormant season insecticide types who also used various growing season insecticide types in each year from 1992 to 2000. Each graphs shows the growing season use for growers using different dormant insecticide use types: (A) OPs, (B) pyrethroids, (C) Bt, (D), oils alone, (E) no dormant insecticide. The growing season insecticide types are the same as the dormant insecticide types.

Appendix: Data Quality

Handling grower_id and site_loc_id errors.

To answer some of the questions addressed in this report we need to identify almond growers (by an identification code) and their fields. These data are used, for example, to determine the number of growers using different practices, the percent acres treated, and the acres planted. Although the PUR contains data on growers and fields, these data have problems that must be dealt with before they can reliably be used. We have developed several data cleaning procedures based partly on the work of Lynn Epstein (Epstein et al. 2001).

The grower and agricultural field are identified in the PUR by the data fields grower_id and site_loc_id. The site_loc_id identifies each grower's agricultural fields and in most counties it is an a string of letters and/or numbers that the operator chooses to identify each of his or her fields. The grower is identified by the last 7 characters of the grower_id which has been stripped out into another variable called operator_id. This is called the operator_id because it identifies not necessarily the grower or owner of a farm but the person responsible for managing the farm. In the operator_id, the first two characters identify the operator's home county and the last 5 characters should be a unique value that the county assigns to each operator.

Each county has its own method for assigning values to the grower_id. Some of these methods were documented through a survey sent to all County Agricultural Commission offices. Most counties assign sequential numbers to the last 5 characters of the operator_id to identify operators. However, some counties have different procedures. Based on the procedures used we developed methods to identify likely errors in operator_id and in some cases even determine likely correct values.

For example, in Butte county (county_cd = 04), operator_id values are assigned sequential numbers. In this case, although operator_ids = "04 0003", "0403   ", and "0400003" appear as different values in the database, they should all refer to the just one operator. This presumption is further supported by the fact that for these operator_ids, the site_loc_ids and acres planted reported were all the same. In this case fixing the problem is easy: convert the last 5 characters of the operator_ids to numbers padded with leading zeros for a total of 5 characters. Thus "04 0003", "0403   ", and "0400003" all become "0400003".

Another problem is that occasionally there will be a non-numeric value in the operator_id. One example is the value "040091B". In this case, there is another operator_id of "0400918" which has same site_loc_id and acres, so the "B" is probably an error and should have been an "8". Remember these values are often handwritten in reports and entered into the database by staff who do not necessarily know the rules for correct values. Again, these kinds of errors are easy to correct by converting certain letters to similar appearing numbers.

Here is the table of conversion used in our analyses:

1	2	4	5	6	7	8	9	0
I	Z	A	S	G	T	B	q	O
L		H				R	g	D

Some operator_ids may be impossible to decode, such as, "040133P" which does not seem to match any other valid operator_id. In those cases, we just left the values as they were even though they violated the apparent scheme for assigning values.

Some counties used letters in their grower_ids. For these counties we may not want to convert all letters to numbers. However, among some counties with almonds, the only other non-numeric values used were an ending value of "A", "N", "R", or "U". These letters are normally used to distinguish restricted use and non-restricted permits. In probably most counties one operator could receive two operator_ids which are identical except for the ending letter. So before any letters are converted to numbers, we first strip off an ending "A", "N", "R", or "U" and add a "0" in the 3rd position of the operator_id.

Errors can also occur in site_loc_id which contains a value to identify each agricultural field used by each operator. It is more difficult to correct values in the site_loc_id because the counties generally do not have any system for assigning values; in most cases growers can use whatever combination of letters and numbers they wish to identify their fields. They are not always consistent, for example, calling one field sometimes "1-A" and another time "1A" or for another field sometimes using "NBLOCK", other times "NBLCK" or "NORTHBLK", etc. We cannot develop an algorithm that will accurately find and fix all these kinds of problems. Since it is not necessary to know the correct name, just to know if two identifiers should refer to one field or two, we used the following scheme to reduce the number of incorrect values: remove all spaces and hyphens in the site_loc_id, remove leading "0", then change "0" to "O" and "1" to "I".

Handling MTRS and acres planted errors.

Another problem related to identifying fields is determining the most accurate values for location and acres planted for each field. The PUR contains two different measures of location: the county of the application and the Public Lands Survey coordinate which specifies the location to a square mile section. The Public Lands Survey coordinates are the baseline meridian, township, range, and section (MTRS). Different PUR records may report different values of MTRS, county, or acres planted for the same field as identified by operator_id and site_loc_id. The question is, which value is most likely correct.

Operator_id with site_loc_id (after undergoing the above fixes) should uniquely identify a geographic field, especially within a year. Between years, it is less likely because growers get a permit each year and each year assign some site_loc_id value to each of their fields. They do not necessarily assign the same site_loc_ids to each of their fields as they did in the previous year. However, for permanent crops such as almonds, the site_loc_ids mostly remain the same from year to year.

If the site_loc_ids do identify unique agricultural fields, then all reported values for MTRS and acres planted for each operator_id + site_loc_id should be the same within a year. Since fields do not move, the MTRS value should be same from year to year; however, the acres planted could change because of new plantings or tree removals.

When the reported MTRS does differ for different reported applications to the same field, the values reported in later years are more likely to be correct because improvements were made in checking MTRS values in the PUR system. So the program chooses the latest reported MTRS and county values for a field.

There are complications if the reported MTRS is not within the reported county boundary and if there are different reported MTRS values or counties reported for a field in the latest year. To handle these issues, the program carries out the following algorithm. It lists all MTRS and county combinations and number of PUR records reported for a given operator_id and site_loc_id in the latest year and orders these by the number of records. Starting with the MTRS and county with the most number of records, it chooses the first combination where MTRS is within the county boundaries. If none of the MTRS values were in the county, it chooses the county that had the most records and sets MTRS to NULL; the county is more likely to be correct than the MTRS.

Acres planted for a field could change from year to year, but within any given year, the acres should remain the same for all applications. In most counties, the acres planted value in the PUR actually comes from the permit database rather than from the application use report. The permit information, including field identification, location, area, is usually entered into the permit database in January of each year. These fields are the fields that growers expect to plant in the coming year. When planting time comes, the grower may decide to plant different area. If the actual acres planted is different than what was reported a permitting time, the growers is supposed to report the new value to their county offices and the permit database should be changed. However, this does not always happen or the value in the permit database may be changed after some use reports have been submitted for this field. Thus the acres planted that gets recorded in the PUR database may be incorrect and it may change during the season. Most likely, the latest reported value during the year is the correct value so that is what is used in our analyses.

Handling rate of use errors.

Some errors have a huge effect on rate of pesticide use (pounds of pesticide per area treated). Errors in units of measures (for example, gallons, quarts, pounds, ounces), pounds applied, or area treated affect rate of use. These errors can have significant effects on measures of use such as total pounds of pesticides applied and so must be dealt with. Unusually large rates are not necessarily errors, but if a rate is an extreme outlier compared to all other reported rates, it is almost certainly an error.

Before and after PUR data gets loaded into DPR's database, it is passed through a computer program that identifies unusually high rates of use based on several different criteria (Wilhoit 1998 and Wilhoit 2002). For most of our analyses we exclude rates of use that exceed values determined by three criteria:

1. 200 pounds of AI per acre treated,

2. the median pounds of product per acre for all uses of that product on a site or commodity, and

3. a value determined by a neural network.

The neural network is the most unusual technique. Basically, it is a computer programming technique to recognize patterns in a set of complex and noisy data. In this case, the distribution of rates have such unusual distributions that standard statistical techniques are of limited use.

In our analyses for this report, rather than exclude rates of use greater than one of these values, which means in effect setting the pounds of pesticide and area treated for that application to zero, we replaced each extreme rate with the median rate for all reported applications of the particular pesticide product on almonds. Specifically, we accepted the reported acres treated and set the pounds of pesticide equal to the median rate times the acres treated. Of course, an extremely high rate could have resulted by an incorrect low value for acres treated rather than an incorrect high value for pounds applied. However, an extremely low value has less effect on a sum than an extremely high value, so for our purposes an error in acres is of less concern than an error in pounds. Also, the calculation of the median rate for each product was based on all applications of that product on almonds for all years of the PUR.

Effect of data cleaning procedures

The data cleaning procedures changed the apparent number of growers in most years and counties by less than 0.1% (Table 1). The year 1991 had the largest number of errors and largely because of that we did not include 1991 (except for applications in December) in our analyses. Year 1992 had the second highest number of problems but the state wide difference in number of growers was only 0.68%. For all other years in all counties except for Stanislaus, Sutter, and Yolo Counties the data cleaning procedures had no effect on number of growers.

Table 1. Percent difference between the number of almond growers as calculated with and without data cleaning of grower_ids. Data are shown for each year from 1991 to 2000 and for each of the major almond growing counties where county is the home counties of each grower and for the entire state.

County	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Butte	8.72	3.54								
Colusa		1.35								
Fresno										
Glenn	9.38	3.30								
Kern										
Madera	1.00									
Merced	0.27									
San Joaquin	17.37	0.20								
Stanislaus	0.19		0.10	0.10	0.20	0.10	0.21	0.10	0.21	0.11
Sutter	4.08	9.26	2.13	1.79			1.79			
Tehama	10.42									
Tulare										
Yolo	6.15	4.35	3.51	1.67	1.61	1.72	1.89	1.92	1.92	2.17
Yuba		9.52								
California	3.90	0.68	0.11	0.08	0.08	0.05	0.11	0.05	0.08	0.05

In contrast, the data cleaning procedures had a fairly large effect on the apparent number of almond fields (Table 2). The years with the largest number of errors were from 1995 to 1999, with 7 to 14% change in the statewide number of fields. The years with the fewest number of errors were 1994 and 2000, with only 0.1% change in number of fields. These errors would found in all counties. The high number of errors in the later years (except for 2000) was surprising. However, most of these errors were from trailing or leading spaces in the site_loc_ids. In 2000, the program that loads the PUR data from the county had a procedure for removing these spaces and because of that the effects of data cleaning were much smaller then.

Table 2. Percent difference between the number of almond fields as calculated with and without data cleaning of site_loc_ids. Data for each of the major almond growing counties where county is the home counties of each grower and for the entire state. Almond fields were defined as the combination of grower_ids and site_loc_ids.

County	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Butte	1.41	2.58	2.65		2.98	2.33	10.06	14.96	13.62	0.16
Colusa	6.64		0.95		5.51	4.45	10.85		3.25	
Fresno		0.14			6.65	6.67	6.02	8.13	7.93	
Glenn	11.36	1.23			6.05	2.62	14.29	17.41	19.31	
Kern	0.52	0.55	0.14	0.13	14.00	14.62	8.75	18.71	14.10	
Madera					7.91	9.20	7.52	16.42	15.77	
Merced	0.07	0.21	0.29	0.35	13.90	9.54	9.61	15.85	13.99	0.34
San Joaquin	2.91		0.10	0.10	11.58	3.06	8.00	11.48	13.99	0.11
Stanislaus	0.16	0.11	0.05	0.05	12.55	6.06	6.63	15.97	14.90	0.05
Sutter	1.05	17.27			1.30	1.18	4.76	9.78	9.09	
Tehama	2.40	8.77				1.22	10.47	16.49	27.05	
Tulare	27.54	8.88			10.73	7.39	8.47	18.22	16.89	
Yolo	0.61	1.90	20.81		1.98	3.16	12.12	3.13	6.93	
Yuba		9.38			5.26	6.25	14.29	5.88	31.58	
California	1.97	1.05	1.06	0.10	10.51	7.14	8.31	14.32	13.53	0.09

The percent of almond fields that had different reported values for MTRS was fairly high. For all California the percent was 8.39 with about half of the counties greater than 10% (Table 3). The percent of almond fields with greater than one reported value for acres planted during each year was over 8% statewide in 1991 and 1992 and remained between 2 and 3% for each following year (Table 4). The percentages varied considerably from year to year for each county.

Table 3. Percent of almond fields that had inconsistent reported MTRS values during the period 1992 to 2000. Data are for each of the major almond growing counties where county is the home counties of each grower and for the entire state. Fields were defined as the combination of data cleaned grower_ids and site_loc_ids.

County	Percent Inconsistent
Butte	13.55
Colusa	5.91
Fresno	2.97
Glenn	7.13
Kern	4.31
Madera	3.38
Merced	11.08
San Joaquin	7.30
Stanislaus	13.88
Sutter	10.95
Tehama	11.83
Tulare	3.33
Yolo	13.45
Yuba	12.31
California	8.39

Table 4. Percent of almond fields that had inconsistently reported acres planted values during the period 1992 to 2000. Data are for each of the major almond growing counties (where county is the home county of each grower) and for the entire state. Fields were defined as the combination of data cleaned grower_ids and site_loc_ids.

County	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Butte	13.26	16.13	5.63	2.02	1.99	2.39	3.90	4.36	3.31	1.92
Colusa	0.47	0.47	2.87	2.51	1.25	1.27	2.17	1.83	1.12	2.07
Fresno	3.13	5.60	3.59	4.19	5.57	4.19	5.19	4.69	4.26	3.82
Glenn	6.20	1.86	2.40	1.60	2.97	5.38	2.25	5.37	3.42	4.55
Kern	3.39	3.19	0.42	1.56	1.84	1.59	1.63	1.83	2.18	0.76
Madera	0.65	1.93	1.90	2.38	0.55	1.72	3.39	2.62	0.73	0.58
Merced	2.29	2.29	3.15	2.08	2.71	1.24	1.33	2.96	3.28	2.05
San Joaquin	2.99	1.47	1.87	1.46	1.41	1.02	1.54	0.98	1.54	1.58
Stanislaus	22.09	19.99	2.79	2.42	0.93	4.11	3.91	1.91	2.59	2.12
Sutter	10.64	10.99	4.62	1.25	2.63	0.00	6.25	2.41	2.50	3.66
Tehama	19.67	12.50	2.90	8.33	4.88	7.41	2.60	6.17	7.87	2.06
Tulare	5.26	1.95	1.37	3.33	0.63	0.61	0.00	4.66	2.75	0.00
Yolo	6.71	6.45	3.65	0.00	1.01	0.00	1.15	2.15	0.00	2.33
Yuba	10.71	10.34	20.00	0.00	0.00	13.33	11.11	0.00	7.69	16.67
California	8.18	8.43	2.90	2.29	2.08	2.48	2.85	2.68	2.67	2.08

These error-cleaning procedures had only a relatively small effect on the almond acres as calculated from the PUR, the statewide percent differences being about 1% or less each year (Table 5). The differences were also small for most of the major almond counties, less than 5% in most years (Table 6). The exceptions were differences between 8 and 27% in Madera, Stanislaus, Sutter, and Tehama in 1992, a 31% difference in Yolo County in 1993, and differences between 7 and 27% each year in Tehama County.

In several years (1995, 1996, 1999, and 2000), the acres calculated after the data cleaning process differed by less than 1% to those reported by CDFA (Table 5). The largest difference between the different acres was13.7% in 1992. These results suggest that the PUR includes most of the almond fields in California and provides fairly accurate acre values.

Table 5. Almond acres from 1992 to 2000 as calculated from the PUR (with and without data cleaning procedures) and from the California Agricultural Resource Directory 2001 (California Department of Food and Agriculture) and the percent difference between the cleaned and uncleaned acres and between cleaned and CDFA acres. Acreage includes both bearing and non-bearing orchards.

	1992	1993	1994	1995	1996	1997	1998	1999	2000
PUR cleaned	503,564	458,652	470,498	482,078	505,345	525,312	587,900	583,812	594,144
PUR no cleaning	501,765	459,991	464,965	480,418	505,050	525,078	580,605	581,641	594,632
% Diff	0.36	-0.29	1.18	0.34	0.06	0.04	1.24	0.37	-0.08
CASS	434,600	446,400	479,500	483,700	500,400	505,000	573,000	585,000	595,000
% Diff	13.70	2.67	-1.91	-0.34	0.98	3.87	2.53	-0.20	-0.14

Table 6. The percent differences in almond acres in each of the major almond growing counties from 1992 to 2000 as calculated from the PUR with and without date cleaning procedures.

County	1992	1993	1994	1995	1996	1997	1998	1999	2000
Butte	3	4	5	1	0	-1	1	0	1
Colusa	0	0	2	-1	0	1	0	-1	-3
Fresno	2	0	-1	2	0	1	2	0	-1
Glenn	4	2	5	2	3	1	-2	-2	-1
Kern	1	0	1	-1	0	-1	4	1	-1
Madera	13	0	1	0	0	0	0	2	2
Merced	2	0	2	1	-1	1	1	0	0
San Joaquin	2	1	1	1	0	0	0	0	0
Stanislaus	-9	0	1	0	1	-1	0	0	0
Sutter	-12	0	3	0	0	-3	1	2	-2
Tehama	-27	-8	-7	-11	-18	-16	-22	-14	-14
Tulare	-2	1	-2	0	1	0	2	0	-1
Yolo	-5	-31	-2	6	0	0	1	-4	4

The percent of PUR records the had an extremely high rate of use (that exceeded at least one of our outlier criteria) was less than 0.55% statewide for each year from 1992 to 2000 (Table 7). This percentage was less than 1% for all years and counties of interest except in three situations, the highest being 3.5% error rate in Tehama in 1999. As described in the methods section, whenever the program found a rate exceeding one of the outlier criteria, the pounds of AI for that use was adjusted so that the rate would equal the median rate for that pesticide product on almonds. This resulted in lower values for pounds of AI. The effect on total pounds of AI used statewide was less than 6.5% all years (Table 8). The percent difference in pounds of AI for most counties in most years was less than 10% and most of these were in 1992 and 1993. Only one extremely large error in reported pounds can have a large effect on the percent difference and most of the large error rates were due to a few errors in the pounds of methyl bromide.

Table 7. Number of application records and percent difference between number of records with extreme high rates of use and total number records. Data are shown for each year from 1992 to 2000 and for each of the major almond growing counties (where county is the home county of each grower) and for the entire state.

County		1992	1993	1994	1995	1996	1997	1998	1999	2000
BUTTE	# Rec	13,021	12,920	16,386	13,213	14,255	11,653	15,655	14,656	10,866
	% diff	0.31	0.20	0.34	0.36	0.22	0.61	0.18	0.49	0.39
COLUSA	# Rec	2,751	2,890	3,396	4,051	3,221	2,323	3,349	3,386	4,187
	% diff	0.36	0.14	0.35	0.17	0.34	0.04	0.24	0.32	0.69
FRESNO	# Rec	9,776	10,933	10,229	12,209	11,270	12,890	14,316	13,184	15,538
	% diff	0.66	0.81	0.68	0.70	0.40	0.38	0.31	0.69	0.64
GLENN	# Rec	2,881	3,379	3,866	4,223	4,596	4,720	5,909	5,663	4,869
	% diff	0.10	0.21	0.34	0.17	0.37	0.11	0.46	0.07	0.21
KERN	# Rec	18,267	20,322	19,123	22,460	21,491	24,565	23,294	20,216	21,117
	% diff	0.16	0.20	0.34	0.35	0.29	0.31	0.11	0.57	0.52
MADERA	# Rec	9,299	9,952	10,767	11,564	9,739	9,480	11,044	9,628	9,993
	% diff	0.35	0.50	0.65	0.45	0.37	0.74	0.37	0.44	0.44
MERCED	# Rec	23,168	26,953	27,491	30,789	32,169	29,699	31,339	25,120	22,398
	% diff	0.49	0.13	0.31	0.52	0.24	0.10	0.05	0.21	0.35
SAN JOAQUIN	# Rec	17,312	15,675	15,970	15,077	16,283	16,006	18,168	15,292	14,617
	% diff	0.64	0.41	0.61	0.56	0.37	0.31	0.57	0.41	0.22
STANISLAUS	# Rec	27,806	32,932	32,605	30,897	35,317	31,742	38,004	32,680	28,238
	% diff	1.06	0.36	0.43	0.27	0.26	0.31	0.37	0.29	0.25
SUTTER	# Rec	674	713	874	770	902	803	943	882	942
	% diff	0.30	0.56	0.11	0.00	0.44	0.12	0.74	0.34	0.64
TEHAMA	# Rec	1,294	1,204	1,078	1,385	1,314	1,331	1,357	739	1,375
	% diff	0.46	0.25	0.00	0.22	0.38	0.53	0.44	3.52	0.80
TULARE	# Rec	2,525	2,529	2,965	3,017	3,225	3,344	3,875	3,659	4,220
	% diff	0.12	0.20	0.24	0.07	0.34	0.78	0.15	0.44	0.47
YOLO	# Rec	1,090	1,002	1,098	1,210	1,120	749	913	675	717
	% diff	0.37	0.10	0.00	0.08	0.63	0.27	0.11	0.59	0.98
YUBA	# Rec	311	228	188	227	265	363	369	278	306
	% diff	0.00	0.00	1.60	0.00	0.00	0.28	0.00	0.72	0.00
CALIFORNIA	# Rec	131,177	142,267	146,853	151,836	156,007	150,584	169,640	147,282	140,548
	% diff	0.55	0.32	0.42	0.40	0.30	0.33	0.27	0.41	0.41

Table 8. Total pounds of active ingredients with high rates replaced with median rates and percent difference between pounds as calculated with reported rates and with median rates. Data are shown for each year from 1992 to 2000 and for each of the major almond growing counties (where county is the home county of each grower) and for the entire state.

County	**Data**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
BUTTE	Lbs AI	1,144,391	1,393,794	1,191,399	931,062	1,276,790	1,245,720	1,264,178	1,072,411	345,981
	% diff	1.55	1.16	2.35	1.17	0.86	4.70	1.86	1.54	0.67
COLUSA	Lbs AI	293,094	286,721	250,636	218,203	365,729	208,114	274,669	153,373	238,406
	% diff	4.86	1.36	4.69	1.99	1.14	0.18	0.79	1.21	0.55
FRESNO	Lbs AI	1,291,389	1,609,134	1,575,746	1,430,205	1,407,605	1,828,406	2,172,736	2,318,038	2,072,160
	% diff	15.27	3.14	2.70	0.79	2.26	2.07	1.21	3.32	0.52
GLENN	Lbs AI	392,314	517,315	383,941	282,059	431,499	454,460	486,009	489,536	279,204
	% diff	0.33	0.32	0.18	0.04	0.11	0.03	0.07	0.04	0.11
KERN	Lbs AI	3,060,490	2,579,476	2,591,826	2,390,829	2,649,697	4,050,056	3,587,034	3,249,950	3,705,080
	% diff	0.33	1.09	9.89	1.13	1.30	6.19	0.86	0.19	0.25
MADERA	Lbs AI	1,033,058	962,633	1,117,930	986,995	1,111,088	792,445	1,004,469	1,080,651	721,790
	% diff	41.31	2.54	6.51	2.41	1.49	7.39	2.29	1.48	0.51
MERCED	Lbs AI	1,786,382	1,840,337	1,872,944	1,608,872	2,023,976	1,772,613	1,968,262	1,891,407	1,164,417
	% diff	3.98	3.42	3.44	3.13	1.76	1.69	0.16	0.27	-0.27
SAN JOAQUIN	Lbs AI	1,516,118	1,443,696	1,449,167	1,136,515	1,230,541	1,158,815	1,324,619	1,263,541	779,294
	% diff	3.25	14.91	4.64	5.59	2.40	11.48	13.82	2.72	1.10
STANISLAUS	Lbs AI	2,180,263	2,724,558	2,693,935	2,061,730	2,785,092	2,098,615	2,997,505	2,440,397	1,589,396
	% diff	2.57	1.76	2.54	1.05	2.33	3.28	2.44	0.44	1.91
SUTTER	Lbs AI	74,119	143,958	133,987	115,092	124,656	168,180	217,171	134,563	57,999
	% diff	5.21	14.06	0.51	0.00	0.20	0.01	8.49	0.03	0.26
TEHAMA	Lbs AI	166,414	204,945	93,919	124,150	151,706	158,002	136,669	122,349	55,554
	% diff	12.44	0.53	0.00	34.41	0.32	1.08	0.38	0.22	0.64
TULARE	Lbs AI	273,638	295,582	244,339	223,723	380,276	372,475	441,186	402,737	386,228
	% diff	0.47	0.29	1.94	0.36	2.52	3.72	1.36	0.18	0.78
YOLO	Lbs AI	89,187	68,743	53,375	47,473	56,666	45,992	51,409	25,819	36,285
	% diff	0.21	0.01	0.00	6.15	0.85	0.38	0.08	0.10	0.90
YUBA	Lbs AI	76,618	68,905	37,350	65,532	61,336	66,933	73,419	30,288	42,722
	% diff	0.00	0.00	2.41	0.00	0.00	7.85	0.00	0.27	0.00
CALIFORNIA	Lbs AI	13,464,006	14,219,104	13,750,130	11,714,505	14,114,349	14,504,979	16,073,987	14,808,373	11,642,522
	% diff	6.46	3.36	4.50	2.21	1.70	4.86	2.43	1.14	0.60

References

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2. Wilhoit, L. R.. 1998. A computer program to identify outliers in the pesticide use report database. Pest Management Analysis and Planning Program, Department of Pesticide Regulation. Report PM 98-01. 69 p.