

Pesticide Use Analysis and Trends from 1991 to 1996

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INTRODUCTION

This is the second analysis of pesticide use in California by the Department of Pesticide Regulation (DPR). In addition to analyzing 1996 pesticide use data, this study significantly expands the detail and scope of DPR's *An Analysis of Pesticide Use 1991–1995*. Both analyses are based on California's full use reporting system, which requires users of agricultural pesticides and some other users to submit complete, site-specific documentation of every pesticide application. DPR has compiled these pesticide use reports in the nation's most comprehensive pesticide use database (PUR). DPR scientists, working with scientists at the California Department of Food and Agriculture (CDFA), then used the PUR data to study pest management practices and trends, since effective pesticide regulation requires an understanding of the factors that drive the use of pesticides.

California pesticide users face enormously complex pest problems. The state produces more than 350 commodities in nearly that many microclimates, each with its own unique pest complex. Regulatory and economic factors dictate that pest problems, agricultural or urban, must be solved expeditiously with a limited number of chemical and nonchemical strategies. An analysis of both the statistics and circumstances of pesticide use can help regulators arrive at realistic policy decisions that are both environmentally and economically sound.

SUMMARY OF FINDINGS

DPR and CDFA scientists used various criteria to identify major use pesticides and the crops to which they were applied. The analysis focused on use patterns in 1996 and trends from 1991 to 1996 and, when possible, provided a perspective on pest problems and pest management strategies that influenced pesticide applications. Some of the findings:

- ◆ Reported pesticide usage in California declined from 1995 to 1996. A total of 189 million pounds of pesticides were reported in 1996, compared to 196 million pounds in 1995. Agricultural pesticide use declined to 174 million pounds in 1996 from 179 million pounds in 1995. (These figures do not include adjuvants, although these also must be reported in California. Adjuvants are ingredients that cause a pesticide to stick, spread, or dissolve in the appropriate manner.)
- ◆ Pesticide use went down as measured by total pounds of active ingredient applied, cumulative number of acres treated, and number of applications. At the same time, DPR's analysis underscored the fact that one year of data does not signify a trend; pesticide use increased from 1991 to 1995. Overall pesticide use varies from year to year, depending upon pest problems, weather, crops, and other factors.
- ◆ From 1991 to 1996, the single most-used agricultural pesticide—in pounds used, applications, and cumulative acres treated—was sulfur, a natural fungicide favored by both conventional and organic growers. Sulfur accounted for 36 percent of all active ingredient pounds used, about 9 percent of applications, and 11 percent of acres treated. Due to sulfur's

irritant properties and extensive use, it is also the most frequently reported source of pesticide-related injury (primarily skin rashes).

- ◆ Four pesticides (sulfur, oil, metam-sodium, and methyl bromide) accounted for 68 percent of all pounds applied in production agriculture in 1996. Thirty one agricultural pesticides (out of approximately 800) accounted for 85 percent of all pounds applied. The same pesticides accounted for most of the increase from 1991 to 1996. While these 31 pesticides range widely in toxicity, a number are generally acknowledged as reduced-risk pesticides.
- ◆ DPR's analysis found that 19 crops accounted for 83 percent of all production agricultural pesticide use, 71 percent of all applications, and 82 percent of all acres treated in 1996.
- ◆ Ranked by pounds applied, crops with the highest pesticide use were grapes (wine, raisin, and table), followed by tomatoes, almonds, cotton, oranges, strawberry, carrots, rice, and sugar beets.
- ◆ Pesticide use patterns have changed in California for at least five different reasons: (1) changes in crop acres or number of structures treated; (2) changes in pest problems due to new pests or predators; (3) changes in pest biology, such as the development of resistance to certain pesticides; (4) changes in how pesticide users make decisions; and (5) changes in pest management options, due to factors such as regulatory decisions.

THE OPPORTUNITY FOR PESTICIDE USE ANALYSIS

Since 1971, DPR has published two reports on an annual basis summarizing pesticide use data.¹ One report is indexed by crop, the other by active ingredient. For each pesticide active ingredient and each crop or site treated, the tabular reports list pounds applied, number of applications, and acres or other units treated. Under full use reporting, each table contains more than 300 pages of statistics, without analysis.

Such a statistical format offered little insight into overall pesticide patterns and trends. Before 1995, DPR lacked sufficient data to analyze use patterns and the capability to detect errors in that data. With five years of use reports in hand, and the availability of powerful computer technology, DPR scientists developed data-checking procedures to eliminate gross errors from the PUR database. Beginning with the 1995 pesticide use data and continuing with the 1996 data, this provided an opportunity to analyze use trends and provided a context for understanding pesticide use in California. DPR's analysis identifies high-use pesticides, the crops to which

¹Partial reporting of agricultural pesticide use has been in force in California since at least the 1950s. Beginning in 1970, anyone who used restricted materials was required to file a pesticide use report with the county agricultural commissioner. In addition, the State required commercial pest control operators to report all pesticides used, restricted or nonrestricted. The reports were entered into a computerized database and summarized by chemical and crop in annual reports. Full use reporting began in 1990. We did not include the 1990 data in our analysis because several problems occurred in collecting data during that first year and because the site or commodity categories were different than in the later years.

those pesticides were applied, trends in usage, and the pesticides most responsible for changes in usage.

However, additional analysis was needed to more fully explain the reasons behind patterns and trends. Pesticide use may vary because of changes in the environment or pest populations. For example, if chlorpyrifos use increased in the San Joaquin Valley, it is plausible that growers planted more crops that required the use of chlorpyrifos. Other possible explanations include greater pest problems or the failure of other pest management methods.

Understanding the factors behind changes in pesticide use can be helpful in a variety of venues. Growers and commodity groups can use the information to evaluate possible impacts of new laws such as the federal Food Quality Protection Act of 1996. (Among other things, this law requires the U.S. Environmental Protection Agency (U.S. EPA) to characterize overall pesticide risk, using real world data to assess exposure and risk.) Information on how pest management decisions are made in the field helps researchers better identify emerging challenges and direct research attention to finding solutions. In the same way, the information can help agencies that have funded research to identify which projects have successfully reduced risk from pesticide use.

Understanding the factors behind changes in pesticide use can also help DPR and other regulatory agencies improve estimates of dietary risk, locate sites for monitoring pesticides in the environment, ensure compliance with clean air plans and ground water regulations, and identify reduced-risk pest management alternatives for specific crops grown in different regions of the state.

CHANGING PATTERNS OF PESTICIDE USE

Pesticides are not the only tools available to control pests. Integrated pest management (IPM) is an approach to managing pests that combines biological, cultural, physical, and chemical tools in a manner that minimizes economic, health, and environmental risks. IPM first determines whether pests are present in damaging numbers, and if so, what pests are present and what damage they are causing. IPM stresses an understanding of pest biology. The pest manager then uses this information to decide on a rational approach combining all control methods.

An increase in pesticide use does not necessarily imply IPM's failure. Pesticide use depends on many factors. Weather plays a significant role. For example, excessive moisture encourages weed growth and humid conditions promote some types of disease. Changes in pest population may affect pesticide use, as can changes in pest biology; for example, development of resistance to certain chemical tools can lead to increased use of alternatives. A significant pest infestation may overwhelm natural enemies. Pesticide use also depends on crop economics. Low-value crops are subject to minimal pesticide use, given the expense of treatment. More pesticides may be used on crops whose market value depends on an unblemished appearance. Cropping patterns also are linked to the weather, since farmers are less likely to plant crops that require large quantities of water during a drought.

Changes in acreage

California growers have increased acreage in a number of crops such as wine grapes, cotton, and rice, while acreage decreased for other crops such as sugar beets. Different crops have different pest management needs, thus explaining some changes in pesticide use. A growing urban population could also bring an increase in demand for structural pest control.

Changes in pest problems

A number of new pests have entered California in the 1990s. The silverleaf whitefly attacks many crops, and the giant whitefly attacks many subtropical trees and shrubs. On the other hand, some new organisms have been deliberately introduced to help control certain pest populations. This is a pest management strategy known as biological control with many advantages including long-term pest control without continuous human intervention.

Pest problems can change in other ways. Before 1990, the cotton aphid was often present in cotton fields but seldom caused a problem; it has since become a key cotton pest for reasons yet to be fully understood. In some cases, a pest may benefit from changes in the environment, such as crop cultural practices or general weather conditions. An increase of plant diseases on tomatoes has probably been caused by changes in weather and irrigation systems.

Changes in pest biology

Changes may also occur due to alterations in the biology of long-time pests. The development of pest resistance initially may increase use of the traditional pesticide to offset its reduced efficacy. As resistance builds, the pesticide may become so ineffective that users switch to other pesticides or control methods. Fungal resistance to fungicides that control grape diseases has led to increased reliance on sulfur. Resistance of mites and scales to many pesticides used in citrus and stone fruits led to increased use of oils.

Change in pest management decisions

Today, more growers are aware of dangers and risks in pesticide use. Applicators may monitor more carefully for the presence or number of pests before applying a pesticide, protect themselves better from pesticide exposure, use different formulations that reduce drift, or use less toxic pesticides. They may also switch to other non-chemical methods. In some cases, this awareness of risk has resulted in more pounds applied, such as when sulfur replaces the use of fungicides. However, sulfur is significantly less toxic than many fungicides. In situations where more toxic chemicals must be used, growers must employ technology specifically designed to protect applicators, workers, and the environment.

Changes in pest management options

Regulatory agencies may restrict or even ban the use of a pesticide due to problems such as increased worker illness or environmental contamination. One notable example involves the fumigant 1,3-dichloropropene (1,3-D), which is used to treat bare ground before planting. In April 1990, routine monitoring by the Air Resources Board for DPR found high levels of 1,3-D in ambient air in Merced County. DPR immediately suspended all permits for use of 1,3-D. Growers then turned to alternatives such as metam-sodium. In December 1994, DPR approved a limited reintroduction of 1,3-D under new use practices that resulted in reduced emissions.

Parathion, an organophosphate insecticide, provides another example. In September 1991, the U.S. EPA announced that most uses of ethyl parathion would be canceled because of its high toxicity. Many growers then switched to other organophosphate insecticides.

Clearly, pesticide use trends in California are affected by economics, environmental factors, and the independent decisions of thousands of farmers and professional pest managers throughout the state. In some cases, burgeoning pest problems and a shortage of alternatives may prompt farmers to increase their use of pesticides. In other cases, non-chemical methods allow pest control that is both economically sound and reduces risks to workers and the public. This trend is expected to grow as more farmers experience success with reduced-risk methods and gain confidence in those methods.

SCOPE OF ANALYSIS AND EVALUATION METHODS

Each year of the PUR contains more than 2.5 million individual records of pesticide use. It documents the application of more than 1,000 different active ingredients and adjuvants used from 1991 through 1996 on approximately 250 different crops or sites. The PUR database contains information on each agricultural application, including what pesticide product was used, the date it was applied, which field was treated, and location to a square-mile section. This information may be used to answer specific and complex questions. For example, the data may indicate whether the use of oils increased on almond in Merced County during the dormant season. DPR also has an extensive database on pesticide properties. These databases can be linked to the PUR to ascertain, for example, whether Napa Valley growers have switched from dust to wettable powder formulations of sulfur on wine grapes.

The PUR contains information on nearly all agricultural pesticide use and on some non-agricultural use. Production agricultural use includes applications to growing crops, agricultural fields, and most applications to forest trees and ornamental turf. For brevity, these uses will all be referred to as “agricultural uses.” Other pesticide uses reported to DPR include post-harvest commodity treatments, rights of ways, landscapes, structural use, and other non-agricultural uses by commercial applicators. These heterogeneous applications will be referred to as “non-agricultural use.” Note, that post-harvest treatment of crops is included in the non-agricultural category. Reporting is not required for residential and institutional uses and most applications to livestock. This analysis focuses primarily on agricultural uses involving crop production.

Measures of pesticide use

Pesticide use can be measured in many different ways, including

- ◆ pounds of active ingredient (AI), the component in the pesticide product that kills or otherwise controls the target pest,
- ◆ number of pesticide applications, and
- ◆ cumulative acres treated.

For this analysis, number of acres treated refers to cumulative acres, e.g., one acre treated five times counts as five treated acres.

This analysis examines all three measures, since each gauges a different aspect of use. Pounds used are easily understood and provide a direct measure of the amount used. However, it can be misleading to compare pesticides by pounds used because different pesticides are often used at very different rates. In California, most pesticides are applied at rates of around 1 to 2 pounds per acre. However, the fumigant methyl bromide is typically applied at a rate of 225 pounds per acre and the insecticide avermectin is applied at a rate of about 0.01 pounds per acre. Fumigants are applied at high rates, in part, because they usually treat a volume of space rather than a surface area such as the leaves and stems of plants. Number of applications and acres treated are not so greatly affected by the nature of a pesticide; therefore, these measures provide a better comparison between pesticides. However, one application could involve a small spot treatment or a 2,000-acre forest.

How pesticides and crops were chosen

The 1991–1996 PUR contains records of use for 1,027 different active ingredients and adjuvants on 251 different crops or sites. Many pesticides were not applied throughout this entire period, either because their use was discontinued or because new pesticides were introduced. About 800 pesticides were used each year. Since it was impractical to examine all uses in detail, state scientists focused on production agricultural uses involving major pesticides and crops.

State scientists also analyzed only those pesticides used as active ingredients. Adjuvants—the additives that help an active ingredient to do its work—were not considered. (The U.S. EPA does not classify adjuvants as pesticides, and no federal registration is required. California, however, requires registration and use reporting of adjuvants.) Using these criteria, the analysis was narrowed to 632 active ingredients.

To determine a final list of pesticides for detailed analysis, DPR employed each of the three measures of use (pounds, applications, acres) to identify the ten pesticides with the highest use in each measure in 1996, the ten pesticides with the greatest increases in use from 1991 to 1996, and the five pesticides with the greatest decreases in use from 1991 to 1996 (Figure 1). That created a potential “high use” list of up to 75 pesticides. However, many pesticides made the list in several

categories—for example, sulfur met six criteria. By all three measures, it ranked as the highest use pesticide and the pesticide with the greatest increase in use.

As a result, 31 major pesticides were selected. Even though these 31 pesticides included only 4.9 percent of all active ingredients in production agriculture, they accounted for 85 percent of the pounds used, 52 percent of all applications, and 50 percent of the acres treated in 1996. They also accounted for most of the increase in pesticide use from 1991 to 1996. Even fewer pesticides accounted for most of the pounds: the top four pesticides accounted for 68% of the pounds applied. Therefore, analyzing the use of these 31 pesticides should provide a good overall understanding of pesticide use in California.

	Pounds Applied	Number of Applications	Acres Treated
AIs with the Highest Use in 1996	SULFUR OILS METAM-SODIUM METHYL BROMIDE COPPER HYDROXIDE SODIUM CHLORATE COPPER SULFATE CHLOROPICRIN GLYPHOSATE CRYOLITE	SULFUR GLYPHOSATE PERMETHRIN CHLORPYRIFOS COPPER HYDROXIDE MANEB IMIDACLOPRID METHOMYL OXYFLUORFEN IPRODIONE	SULFUR GLYPHOSATE CHLORPYRIFOS PARAQUAT OXYFLUORFEN COPPER HYDROXIDE METHOMYL TRIFLURALIN IMIDACLOPRID PERMETHRIN
AIs with the Largest Increase in Use from 1991–1996	SULFUR METAM-SODIUM OILS 1,3-D COPPER SULFATE GLYPHOSATE METHYL BROMIDE MANEB COPPER HYDROXIDE CHLORPYRIFOS	SULFUR IMIDACLOPRID GLYPHOSATE MANEB PERMETHRIN AVERMECTIN OXYFLUORFEN MYCLOBUTANIL COPPER HYDROXIDE AZADIRACTIN	SULFUR GLYPHOSATE IMIDACLOPRID CHLORPYRIFOS AVERMECTIN PARAQUAT OXYFLUORFEN MANEB COPPER HYDROXIDE MYCLOBUTANIL
AIs with the Largest Decrease in Use from 1991–1996	TRIFLURALIN DIMETHOATE MEVINPHOS PARATHION ZIRAM	ENDOSULFAN TRIADIMEFON BENOMYL PARATHION MEVINPHOS	FENARIMOL TRIADIMEFON DIMETHOATE MEVINPHOS PARATHION

Figure 1. The pesticide active ingredients (AIs) in the top row had the highest agricultural use in 1996 as measured by pounds applied, number of applications, or cumulative acres treated. The pesticides in the middle row had the greatest increase in use from 1991 to 1996 by each measure. The pesticides in the bottom row had the greatest decrease in use from 1991 to 1996.

To determine why these pesticides were used, and why use changed, state scientists also analyzed major crops to which the selected pesticides were applied. The analysis identified 19 crops for analysis of their pesticide use and pest management practices. Pesticide use on these 19 crops accounted for 83 percent of all production agricultural use, 71 percent of all applications, and 82 percent of all acres treated.

Pesticide types

It is often useful to discuss pesticides in categories, since they control similar pests. For simplicity, this analysis placed each pesticide into one of four general types: insecticides, herbicides, fungicides, and fumigants. The insecticide category includes pesticides for controlling any invertebrate animal pest (not just insects); herbicides, those used against plant pests or for desiccating plants; fungicides for pathogens, and fumigants for a wide range of organisms. For example, copper sulfate is classified as an insecticide because it is used in rice primarily to control tadpole shrimp, a crustacean. (Copper sulfate also has uses as a fungicide and algicide not discussed in this analysis.) Sodium chlorate is classified as an herbicide because it is used as a cotton defoliant.

Some pesticides do not easily fit into one category; for example, sulfur is used both as a fungicide and miticide. For purposes of this study, each pesticide was categorized according to its primary use in California. Thus, sulfur is classified as a fungicide since it is used mostly to control plant diseases.

Pesticides are identified by their most widely used chemical or common name. (Table B1, in the appendix, lists the trade names of the ten most-used products for each of the major active ingredients discussed.) Since a number of chemically different active ingredients are essentially used in the same way, this report groups and treats them as one active ingredient. For example, the herbicide 2,4-D is available in 23 different esters and salts. Mineral oil, petroleum oil, petroleum distillates, and petroleum hydrocarbons generally are used in similar ways for agriculture.

Data quality control and special problems

To improve data quality, values that were considered probable errors (“outliers”) were excluded from the analysis. Errors occur, for example, when decimal points are inadvertently shifted during data entry. DPR specialists spent more than a year developing, testing, and implementing software to detect outliers. (See the Appendix for details of the criteria used and a discussion of the software development.) While the error checking removed less than 1 percent of the PUR records, some records had extremely high values that significantly affected total pounds applied of a pesticide. For example, the 1995 database reported one carbaryl application of 596,511 pounds on five acres of oranges. (The median rate of carbaryl use on oranges in 1995 was 12 pounds per acre).

A few other special problems arose during the analysis. The PUR contains two categories for tomatoes: “tomato” and “tomato, processing.” The implication is that the tomato category includes only fresh market tomatoes. However, in the early years of full use reporting, pesticide applications reported on processing tomatoes were extremely low, while use on tomatoes was extremely high. This pattern later was reversed. According to CDFA crop statistics, the proportion of fresh market tomatoes remained at close to 12 percent of the total tomato acreage each year. Thus, it appears that in the earlier years (when farmers were still becoming familiar with the use reporting system), many growers recorded applications to processing tomatoes in the fresh tomato category. For clarity, this analysis combines the two tomato categories.

The PUR also contains six different nursery categories, but it was not always clear what types of plants were included in each of these categories. The analysis summed uses on all six categories and described the site treated as nursery crops.

Sources of information

All statistics on pesticide use in this report were calculated from the PUR database with outliers excluded. To achieve a better understanding of the factors behind pesticide use increases, decreases, and magnitude, DPR and CDFA scientists interviewed many farm advisors and IPM specialists.

Crop acreage statistics for 1991–1996 were excerpted from the California Agricultural Resource Directory 1997, published by CDFA. Harvested acres (rather than planted acres) were used for field and vegetable crops; both bearing and non-bearing acres were summed for fruit and nut crops.

ORGANIZATION OF THE REPORT

The rest of this analysis is divided into three main sections. The first section summarizes pesticide use by pesticide and crop. Uses and trends involving the most prevalent pesticides based on each measure (pounds, applications, acres treated) are discussed. The section also describes uses and trends for all pesticides on the highest-use crops.

The second section describes in detail the individual pesticide use and pest management issues for the 19 major crops. Crops are listed in order of pesticide use. For each crop, the first paragraph provides a short overview of the crop. This is followed by a table of use of all pesticides on the crop and a pie chart that breaks down the use of insecticides, herbicides, fungicides, fumigants, and other pesticide types. Subsequent paragraphs, arranged by pest type (insects, weeds, disease, and soil fumigation), provide specific information about the major pests and the pesticides used to control the pests. These paragraphs explain why the main pesticides were used and, when possible, analyzes why use changed. Factors may include change in weather patterns, increased pest resistance, new regulations canceling a pesticide, and withdrawal of a product registration.

The third section describes in more detail the uses for each of the 31 major pesticides selected, as previously described. Pesticides are listed in order of greatest use. Each pesticide has two tables,

one giving the total use on all crops in 1996 and the other table giving use of the 10 crops with the highest use of the pesticide. These data are followed by a brief description of use trends for the pesticide from 1991 to 1996, why the pesticide was important, and why use changed for the principal crops.

PESTICIDE USE PATTERNS BY PESTICIDE AND BY CROP

Production agricultural use

In 1996, 174 million pounds of active ingredients were used in 1.63 million applications on 52.6 million cumulative acres in production agriculture (Tables B2–B4, in the appendix). Cumulative acres are calculated by adding the number of acres treated for each application, including those cases where a field is treated more than once, e.g., one acre treated five times counts as five treated acres. The total agricultural acres in California in 1997 was 27.7 million acres, 52% of which was in range and pastureland. Total agricultural pesticide use as measured by pounds of active ingredient, number of applications, and acres treated increased from 1991 to 1995 from 1995 to 1996. (Figures 2a–2c).

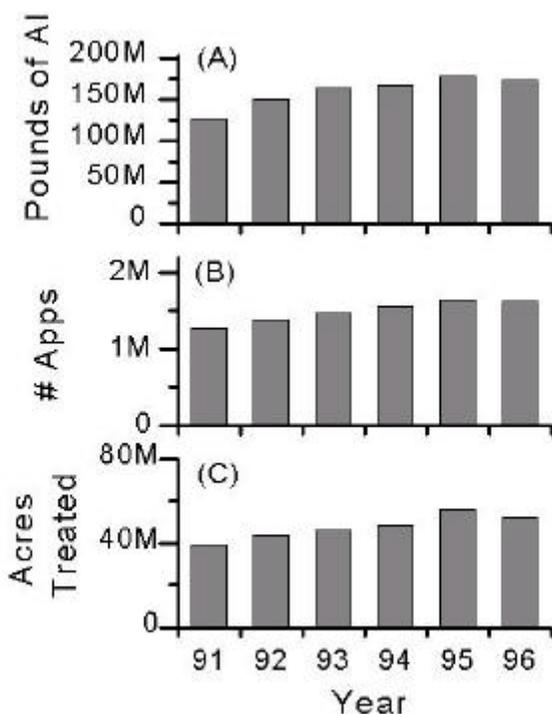


Figure 2. Production agriculture pesticide use in California from 1991 to 1996. Use was measured as (A) total pounds of all active ingredients; (B) number of applications; and (C) cumulative acres treated. Data from Department of Pesticide Regulation.

Use by pesticides – From 1991 to 1996, sulfur easily ranked as the top pesticide in production agriculture, whether measured by pounds used, applications, or acres treated (Tables B2–B4). The order of use for other pesticides depends on the measure. For pounds used, oils,

metam-sodium, and methyl bromide (all with high application rates per acre) had the next highest use. For number of applications and acres treated, the herbicide glyphosate was the second most-used pesticide. Other high-ranked pesticides for number of applications and acres treated included the insecticides permethrin and chlorpyrifos, and the herbicide paraquat dichloride.

From 1991 to 1996, pesticides with large proportional increases in use were 1,3 dichloropropene, maneb, captan, metam-sodium, imidacloprid, azadirachtin, and *Bacillus thuringiensis*, subsp. *aizawai*. (Pesticides showing the greatest decrease in use from 1991 and 1996, by all measures, were mevinphos and parathion, because they were canceled for most uses. Triadimefon and fenarimol also decreased, probably mostly due to development of resistance by some plant pathogens.)

Among use of the 31 major pesticides, fungicides (sulfur, copper hydroxide, maneb, iprodione, and myclobutanil) increased from 1991 to 1995. Use decreased from 1995 to 1996, with the exception of maneb. Most of the other fungicides (ziram, fenarimol, and triadimefon) generally decreased (Figures 3a and 3b). Fumigant use generally increased, due mostly to a substantial increase in metam-sodium (Figure 3c). Use of the fumigants methyl bromide and chloropicrin was nearly the same each year. Increased herbicide use was due primarily to glyphosate but also to paraquat and oxyfluorfen (Figure 3d). Use of several major insecticides increased (oils, chlorpyrifos, permethrin, imidacloprid, avermectin, copper sulfate and azadirachtin). Some insecticides decreased (endosulfan, mevinphos, and parathion). Other insecticide use remained fairly constant from year to year (Figures 3e and 3f).

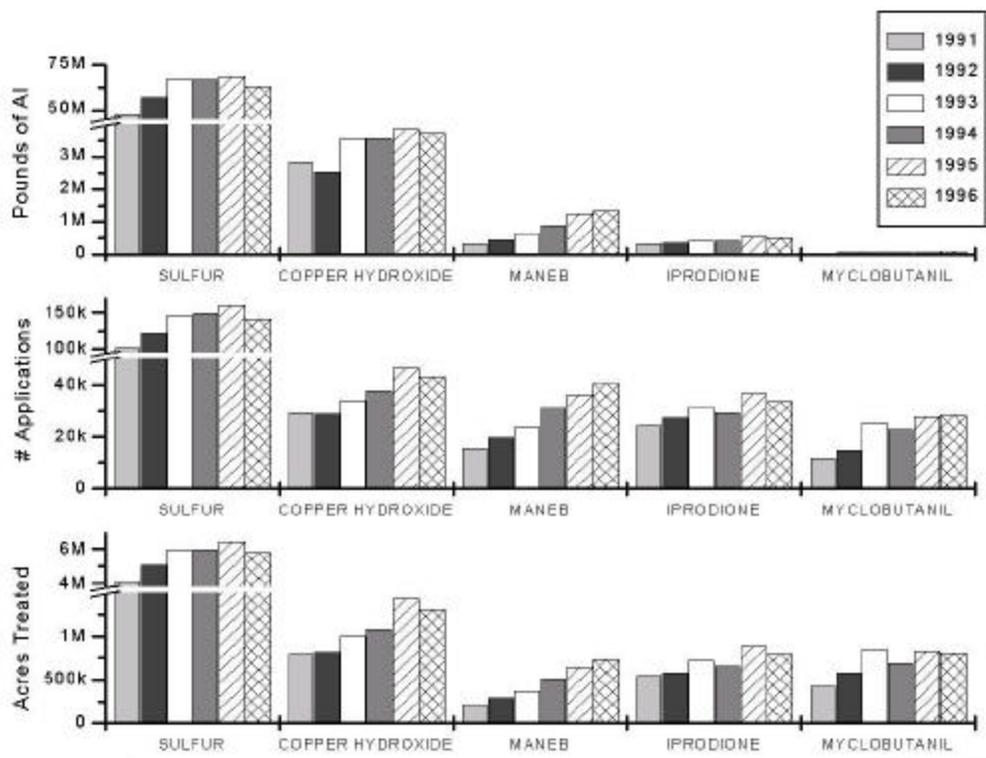


Figure 3a. Use of major fungicides in production agriculture in California from 1991 to 1996

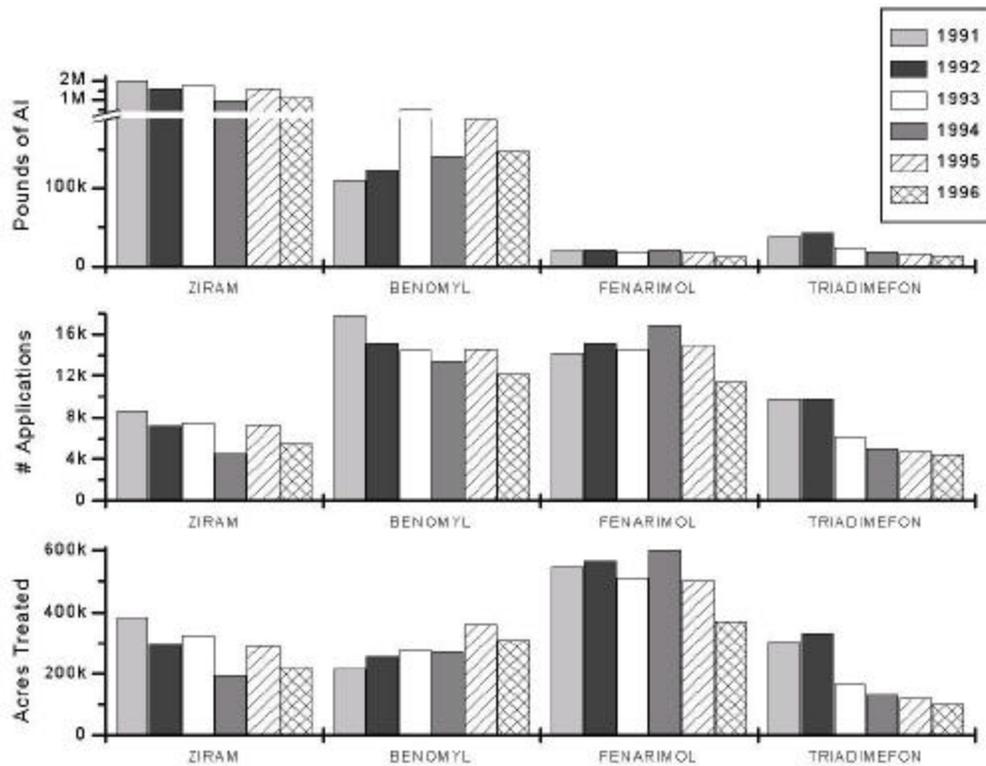


Figure 3b. Use of major fungicides in production agriculture in California from 1991 to 1996

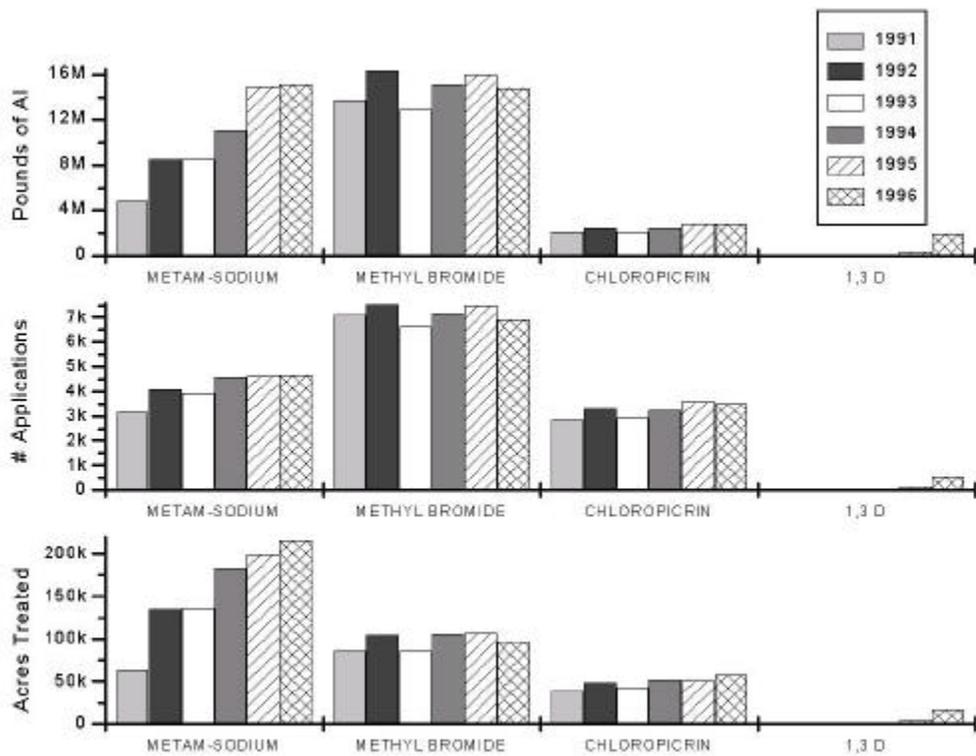


Figure 3c. Use of major fumigants in production agriculture in California from 1991 to 1996

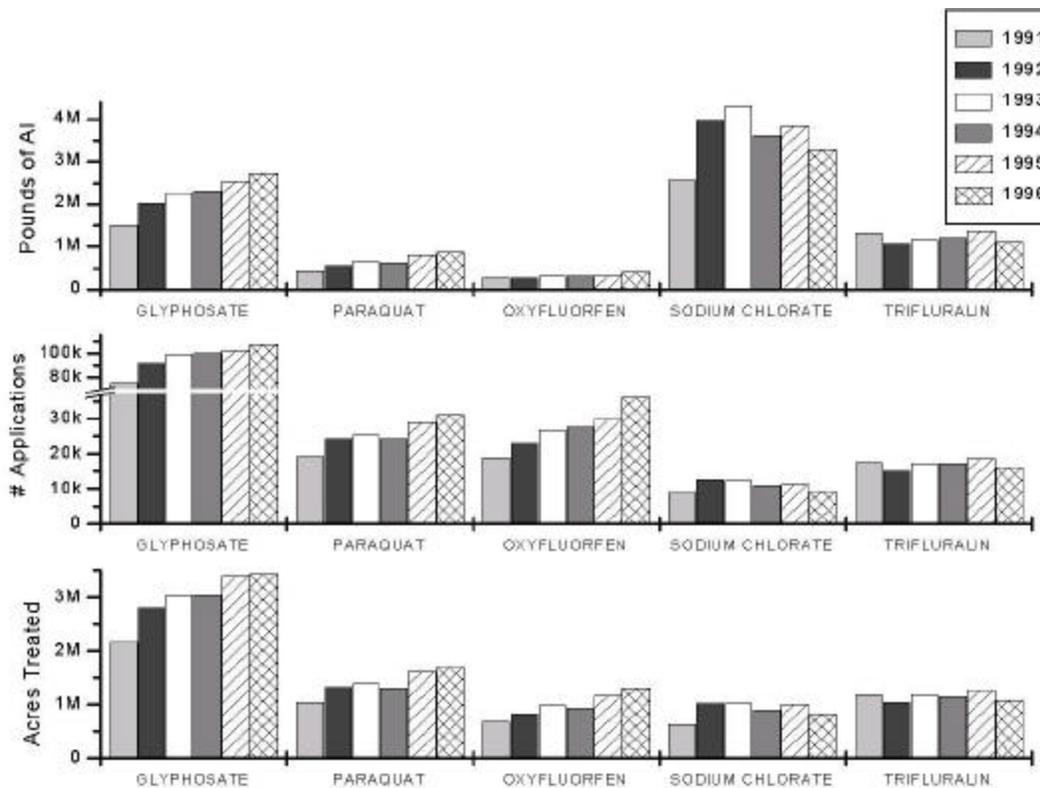


Figure 3d. Use of major herbicides in production agriculture in California from 1991 to 1996

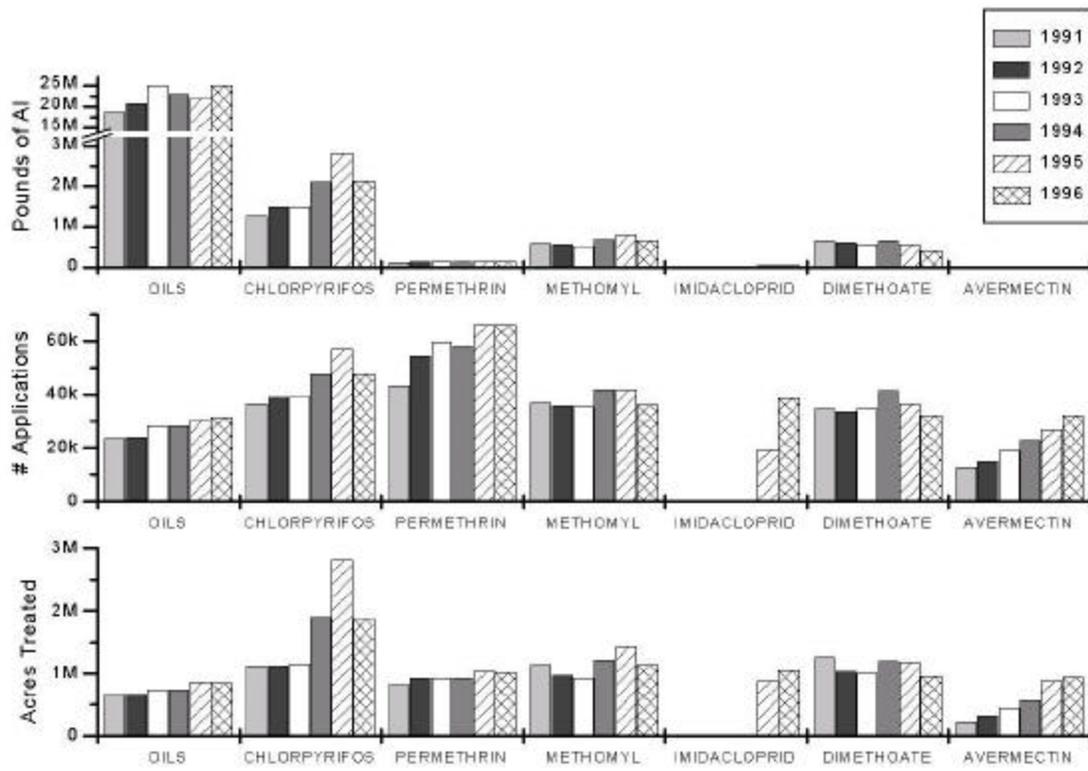


Figure 3e. Use of major insecticides in production agriculture in California from 1991 to 1996

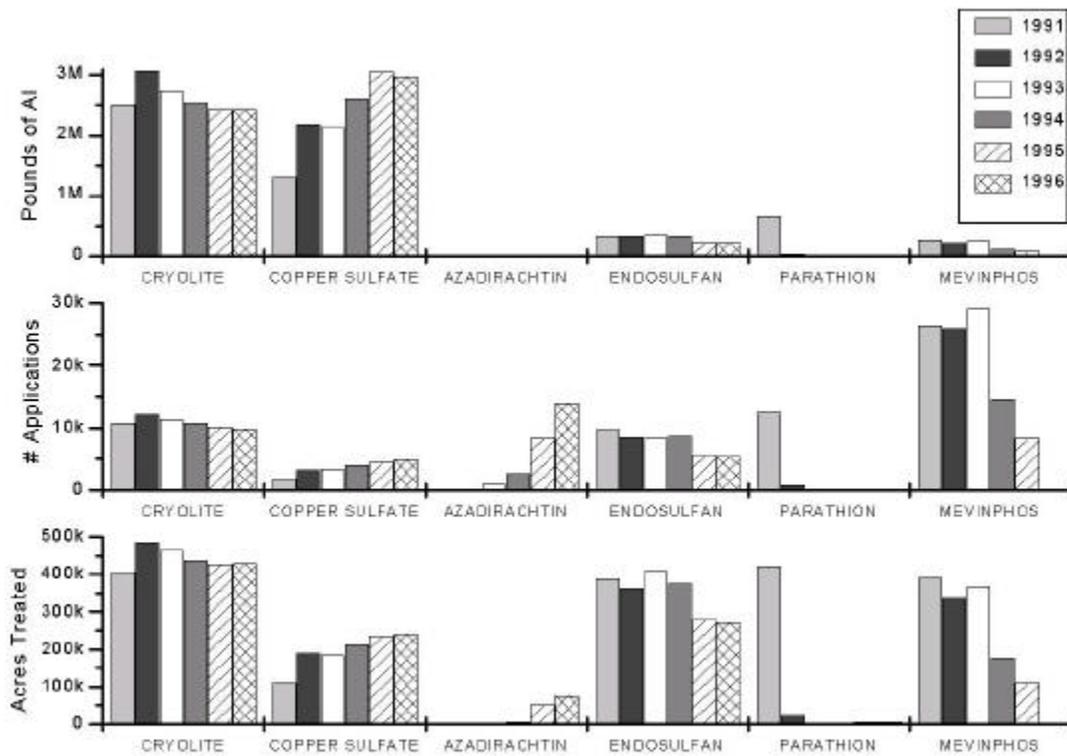


Figure 3f. Use of major insecticides in production agriculture in California from 1991 to 1996

Use by crops – Wine, raisin and table grapes showed the highest pesticide use in pounds applied. They were followed by tomatoes, almond, cotton, orange, strawberry, carrot, rice, and sugar beet (Table B5, in the appendix). Ranked by number of applications, primary crops were, in order: nursery crops, raisin and table grapes, cotton, head lettuce, wine grapes, almonds, leaf lettuce, orange, peach, and alfalfa (Table B6). For acres treated, cotton ranked first, followed by raisin and table grapes, almond, wine grapes, alfalfa, tomatoes, head lettuce, rice, orange, and walnut (Table B7). It is to be expected that these crops would rank high since they have the greatest planted acreage in California.

By all measures, pesticide use generally increased from 1991 to 1995 on wine, raisin and table grapes, as well as cotton, tomatoes, leaf lettuce, carrot, rice, and walnut. In 1996, use decreased for most of these crops. Number of applications on nursery crops and head lettuce increased from 1991 to 1996. Pesticide use on stone fruit, alfalfa, strawberry, lemon, and apple remained fairly constant from year to year, except for small increases in use by some measures on some of these crops. Use by all measures generally decreased on sugar beet and decreased slightly on pear. Pounds of pesticide increased on orange, although the number of applications and acres treated remained fairly constant.

Comparing total pesticide use for different crops provides an overview of *where* most chemicals were used, but few insights into *why* they were used. Variations in crop acreage may also affect the amounts of pesticide used. Finally, different categories of pesticides used at very different rates may be applied on different crops, affecting the total pounds used. A more detailed analysis of pesticide use and pest management systems in the 19 major crops is provided later in this report.

Non-agricultural use

Only a limited number of non-agricultural uses must be reported. These include commercial applications for post-harvest commodity treatments, rights of way, landscapes, structural use, and a few others. No obvious trend emerged on total pounds of non-agricultural use from 1991 to 1996 (Figure 4). The number of non-agricultural applications are not included in this analysis because some uses do not have to be reported and therefore are not consistently reported in the database. Acres treated are also not included since most non-agricultural application sites cannot be measured in acres.

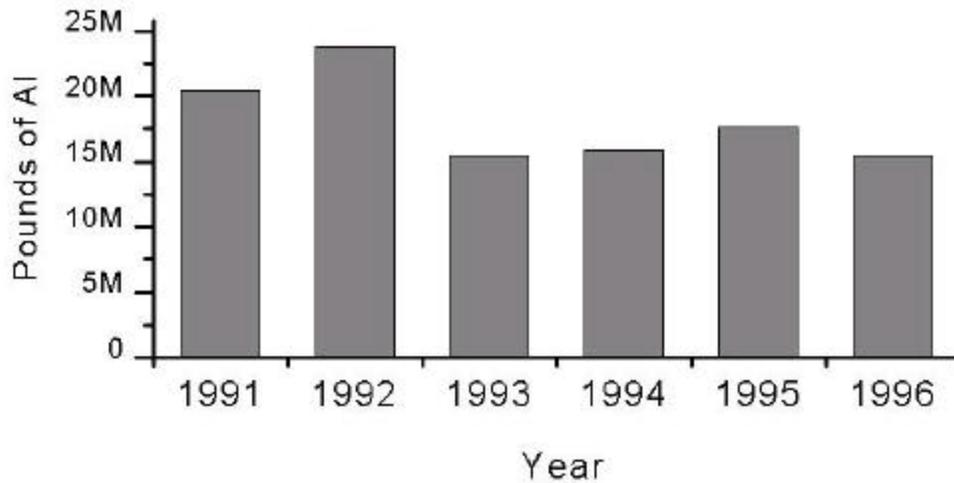


Figure 4. Reported non-agricultural pesticide use in California from 1991 to 1996, measured as total pounds of all active ingredients. Reported uses do not include all non-agricultural uses. Data are from Department of Pesticide Regulation.

Based on pounds applied, major pesticides used in non-agricultural sites in 1996 included sulfuryl fluoride, oils, glyphosate, and methyl bromide (Table B8). Most high-use pesticides fluctuated from year to year with no clear, overall trend. However, use of sulfuryl fluoride gradually increased. (In April 1992, DPR imposed major restrictions on the use of methyl bromide in structural fumigations, greatly increasing the time structures had to be ventilated after treatment. According to industry sources, this made sulfuryl fluoride more cost-effective than methyl bromide for many fumigations.) Oil use increased from 1991 to 1993, then generally decreased from 1993 to 1996. In non-agricultural settings, oils are used primarily for public health mosquito control. Glyphosate use generally increased. In terms of percentage change, pesticides with the greatest increase in use included the insecticide esfenvalerate, the insecticide/fungicides disodium octaborate tetrahydrate and borax, the bactericide calcium hypochlorite, and the fumigant carbon dioxide. Many pesticides had decreasing use, including methyl isothiocyanate, PCP, copper sulfate, zinc naphthenate, sodium hypochlorite, rotenone, sodium hydroxide, and carbaryl.

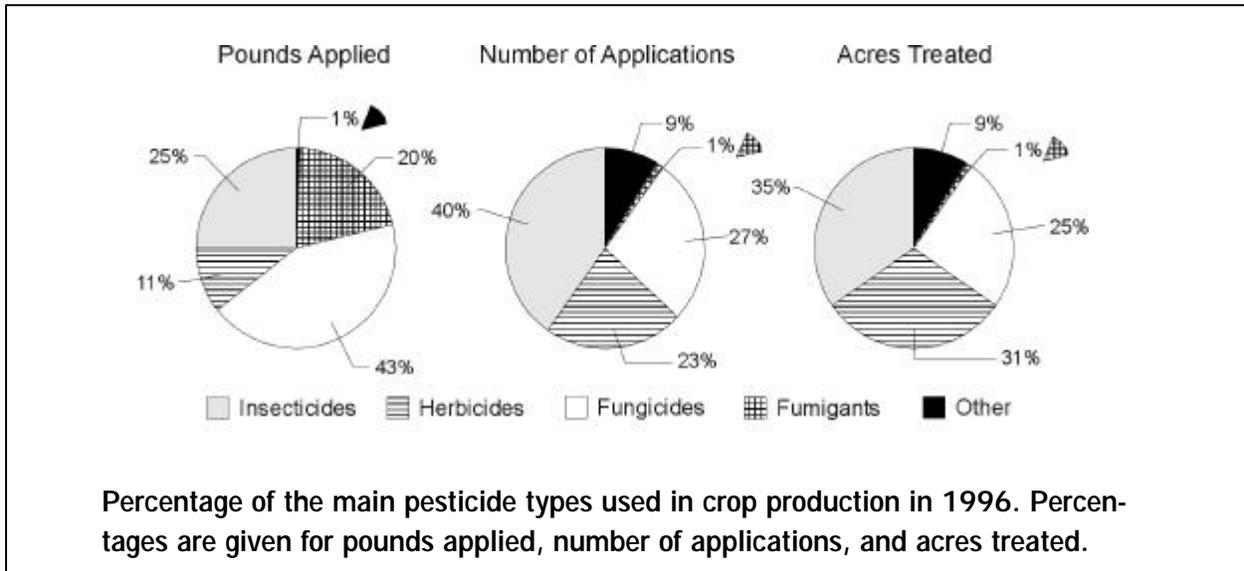
The highest reported uses of non-agriculture pesticides included (in order): commercial structural pest control, rights of way, public health pest control, wood protection, and landscape maintenance (Table B9). Structural and public health use generally decreased; rights-of-way use generally increased, and landscape use remained relatively constant.

PESTICIDE USE PATTERNS AND TRENDS ON THE MAJOR CROPS

The 31 pesticides we chose to analyze further accounted for 85% of the pounds of all pesticides applied in production agriculture, and the 19 major crops accounted for 83% of all pounds applied in 1996 (Tables B10–B12, in the appendix). These pesticides and crops also accounted for over half of the number of applications and acres treated. The number of applications and acres treated were fairly evenly divided between insecticides, herbicides, and fungicides.

Pesticide use for all crops in 1996.

Measures of pesticide use	Total for all crops
Pounds applied	174,024,906
Number of applications	1,629,591
Acres treated (cumulative)	52,553,956

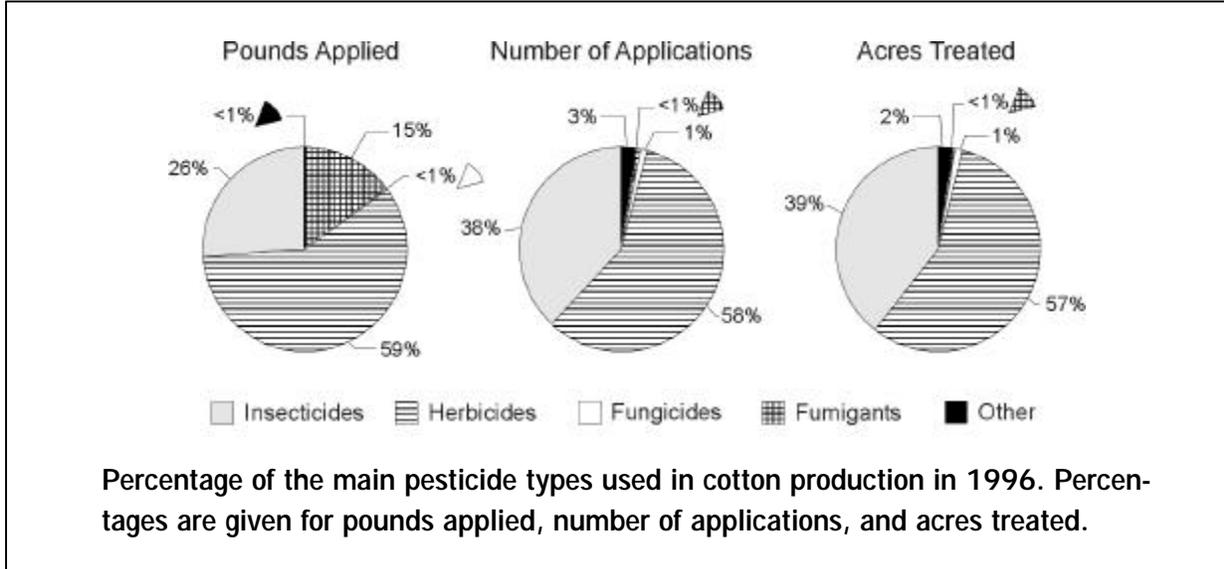


Cotton Production

Cotton is grown for fiber, oil, and animal feed. Approximately 1.2 million acres of cotton were grown in California in 1996. Nearly 13.5% of the total cropland in California was devoted to cotton, more than any other crop in the state. Most cotton is grown in the southern San Joaquin Valley, but a small percentage is grown in the Imperial and Sacramento valleys.

Pesticide use for cotton in 1996.

Measures of pesticide use	Total for cotton	Percentage for all crops
Pounds applied	1,464,941	0.84%
Number of applications	18,612	1.14%
Acres treated (cumulative)	490,835	0.93%



Cotton has a long history of integrated pest management in California. In the 1960s, high insecticide applications to control lygus bugs resulted in secondary outbreaks of other pests. Concern about high pesticide use led researchers to develop better measures for deciding when specific pests needed to be controlled. When growers began to follow the new guidelines, fewer pesticides were used to keep pests below damaging levels. In addition, growers began using pesticides that were less disruptive to beneficial insects, and maintaining these populations also helped reduce pest populations. However, during the 1990s, aphid and mite pressure on cotton led to higher pesticide use.

Pest problems began increasing yearly in 1991, culminating in severe outbreaks of aphids and lygus bugs in 1995. This situation stimulated a cotton industry meeting in November 1995, in which growers discussed changing their pest management practices. Following the meeting, growers began to avoid early-season use of broad-spectrum pesticides (especially pyrethroids),

and began developing a resistance management program for key pests. By 1996, growers had reduced the use of many broad-spectrum insecticides.

Insect and Mite Management – Cotton aphids, lygus bugs, and spider mites are the most serious pests in cotton.

Cotton aphid – The cotton aphid is the most common aphid on cotton in the state. It can damage the plant, reducing the production of cotton lint. Honeydew produced by the aphid falls on open bolls, causing the lint to become contaminated with sticky sugars. Because sticky cotton is difficult to process, many gins do not accept it or pay the grower a lower price.

Chlorpyrifos, the most commonly used cotton insecticide, is used to control cotton aphid. During the 1980s and early 1990s, cotton aphids were a minor pest of cotton; since 1992, and especially in 1995, this aphid caused serious problems. The dramatic increase in chlorpyrifos use (from 57,000 pounds in 1991 to 1.3 million pounds in 1995) reflects the increasing cotton aphid problem. Chlorpyrifos use decreased in 1996, but its use on cotton still accounted for 28% of all agricultural use. Probably 90% to 99% of all chlorpyrifos applied to cotton targets cotton aphid.

Aldicarb, the second most widely used insecticide on cotton, is applied to control cotton aphid, thrips, lygus bugs, and nematodes. It is often applied when cotton is planted, before pests appear. Aldicarb use increased in 1996, possibly because more growers used it preventively. Also, University of California Cooperative Extension advisors recommended aldicarb applications along the crop row because this type of application is less disruptive to beneficial insects.

Lygus bug – Lygus bug is another key insect pest in cotton, feeding primarily on small cotton flower buds (squares). Growers use chlorpyrifos, aldicarb, and imidacloprid to control it.

Spider mites – Four species of spider mite are common in cotton; they cause the leaves to turn yellow or red, and drop. Avermectin is used to control mites, and was the third most widely used insecticide on cotton in 1996. Dicofol and propargite are also used for mite control, but their use dropped in 1996, probably because of mite resistance problems.

Weed Management – Perennial weeds such as nutsedges, field bindweed, bermudagrass, and johnsongrass are common in cotton. Black and hairy nightshade are the most difficult annual weeds to control, and most herbicides are only partially effective against them. Because herbicide efficacy depends upon the weed species, the soil type, and the season of application, growers use different herbicides for weed control.

Trifluralin and cyanazine are the most commonly used herbicides in cotton, at least, herbicides not also used as defoliants (see *Cotton Defoliation* below). Trifluralin has been used in cotton for many years and is applied before planting or in the fall and winter to fallow fields that will be planted to cotton. Trifluralin controls pigweed, lambsquarters, and most annual grasses, such as barnyard grass, but is not as effective on mustards, thistles, morningglory, and nightshade. Cyanazine and oxyfluorfen are used to control weeds that are not controlled by trifluralin.

Metam-sodium is used before planting to control nightshade; pyriithiobac sodium can also effectively control black and hairy nightshade. Before 1990, nightshade was controlled mostly by

hand hoeing. When metam-sodium was shown to control nightshade effectively and more economically, this product replaced hand hoeing. This may explain the large increase in metam-sodium use from 1991 to 1992. Metam-sodium was the second most widely used pesticide in cotton (measured by pounds), but measured by number of applications and acres treated, its use was very low (see *Disease Management*).

Growers use glyphosate to control regrowth of late-season cotton, and to control field bindweed, johnsongrass, morningglory, and nightshade. Fallow beds are treated with glyphosate in early February. With the planting of Roundup Ready (glyphosate-resistant) cotton, it is expected the use of glyphosate will increase.

Cotton Defoliation and Plant Growth Regulation – Defoliants and desiccants are applied to remove cotton leaves just before harvest. Leaf removal enables growers to mechanically harvest clean cotton. Defoliants are slow-acting herbicides that cause cotton leaves to drop from the plant, while desiccants act as contact herbicides that cause leaves to dry out quickly.

Growers use various defoliants and desiccants depending upon the plant and environmental conditions. Sodium chlorate is used at relatively low application rates to defoliate cotton plants, but it acts as a desiccant at higher rates. It is less effective than most other defoliants, but it is used extensively because it is inexpensive. Because of its poor efficacy, it is used at higher rates than other defoliants and requires repeated use; thus it was one of the most commonly used pesticides on cotton in 1996. Use of sodium chlorate on cotton accounted for 97% of its use in California (measured by pounds and acres treated).

Paraquat was the most commonly used defoliant/desiccant in 1996 in terms of acres treated, and the second most commonly applied cotton pesticide in 1996. Applications to cotton accounted for 53% of all paraquat use in California agriculture. Paraquat is used to cause cotton bolls to open, or to control regrowth of late-season cotton, and is often used in combination with other defoliants.

Mepiquat chloride is a plant growth regulator that is used to manage the development and maturity of cotton plants; its use enables growers to produce maximum yields at the best time for harvest. Mepiquat chloride was the most commonly applied cotton pesticide in 1996.

Disease and Nematode Management – Verticillium and Fusarium wilt are the two most destructive diseases of cotton. Verticillium wilt is controlled through cultural practices such as resistant varieties and rotation with other crops not susceptible to it. Fusarium wilt is controlled by managing nematodes, which increase the susceptibility of cotton to wilt. Pesticides are generally not used to control these wilts in cotton. However, some pesticides, such as the fumigant metam-sodium, are used to control seedling diseases such as damping-off, soreshin, and black root rot.

Root knot nematode is a microscopic roundworm that damages cotton by attacking the young tap and secondary roots. Aldicarb and metam-sodium are used to control nematodes, although metam-sodium is relatively ineffective as a nematicide.

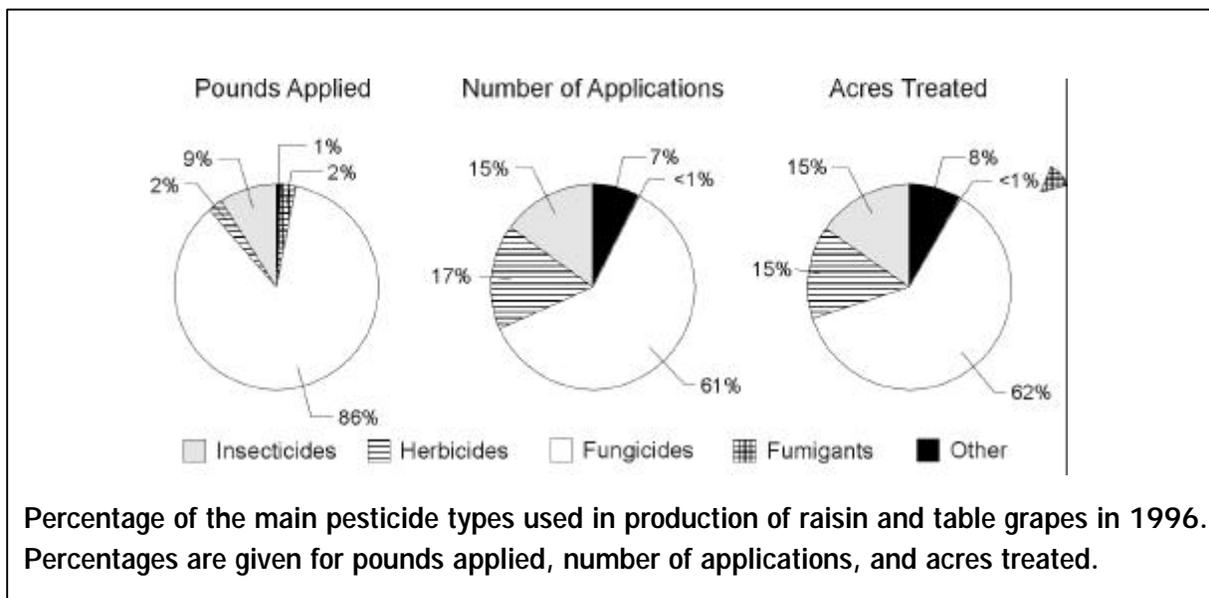
Raisin and Table Grape Production

California produces 90% of all grapes grown in the United States. Grapes are the leading commodity for nine counties in California and within the top ten for 17 other counties. In 1996, California had 270,000 acres of raisin grapes and 74,500 acres of table grapes, amounting to 41% and 11%, respectively, of total grape production for the state. Combined with wine grapes, which make up the remaining 48% of grape acreage, the entire grape crop comprises nearly 8% of total crop acreage in California. Most raisin and table grapes are grown in the San Joaquin Valley counties of Fresno, Kern, Madera, San Joaquin, and Tulare.

Because they are grown for fresh consumption, table grapes—and to some extent grapes dried for raisins—must be more cosmetically appealing than wine grapes. Any sign of pests or pest damage might reduce the value of the harvested fruit. As a result, growers use proportionally more pesticide on raisin and table grapes than on wine grapes.

Pesticide use for raisin and table grapes in 1996.

Measures of pesticide use	Total for raisin/table	Percentage for all crops
Pounds applied	24,447,132	14.05%
Number of applications	135,590	8.32%
Acres treated (cumulative)	5,490,039	10.45%



Insect and Mite Management – Major arthropod pests of grapes include spider mites, leafhoppers, phylloxera, and several lepidopteran species such as cutworm, grape leaf folder, omnivorous leafroller, orange tortrix, and western grapeleaf skeletonizer. Growers use cryolite to control many of these pests. Most cryolite used in California is used on raisin and table grapes. In 1996, more than 75% of all applications of cryolite were made to this crop. Use of cryolite

decreased from 1991 through 1996, possibly due to reduced pest pressure from the western grapeleaf skeletonizer.

The decreased use of the miticide propargite in 1996 may have resulted from the growing popularity of imidacloprid, first registered in 1995 for leafhoppers, which have become resistant to other chemicals. Many raisin and table grape growers have found that imidacloprid's mild impact on beneficial insects has reduced the need to use propargite for mite control. Also, DPR greatly extended the restricted-entry interval for propargite to protect workers from dermatitis.

Weed Management – Soil characteristics of the vineyard influence the weed profile and in turn, the persistence of herbicides. A number of persistent weed species invade vineyards, including johnsongrass, bermudagrass, field bindweed, and nutsedge. In 1996, the main herbicides used in raisin and table grape vineyards were glyphosate, simazine, and paraquat. Weed control in vineyards tends to be prophylactic, although growers now substitute contact herbicides (glyphosate and paraquat) for pre-emergent herbicides (simazine) and plant cover crops.

Use of glyphosate and paraquat generally increased in 1996. Glyphosate, used as a preplant or postplant postemergence herbicide, kills a variety of weeds. Growers extend its killing power by tank mixing it with oxyfluorfen, oryzalin, napropamide, or simazine. Paraquat is applied as a postemergence herbicide for most annual weeds. Simazine use was fairly constant from 1992 through 1996. Simazine was not labeled for use in vineyards less than three years old, an important factor given the doubling of nonbearing acreage from 1991 to 1996.

Disease Management – The most important fungal and bacterial diseases affecting California grapes are powdery mildew, bunch rot (*Botrytis*), cane diseases (including *Phomopsis*), and Pierce's disease. Powdery mildew was the most important grape pathogen in 1996. Many other fungal diseases were fairly consistent in severity, although *phomopsis* in particular was an increasing problem during the 1990s.

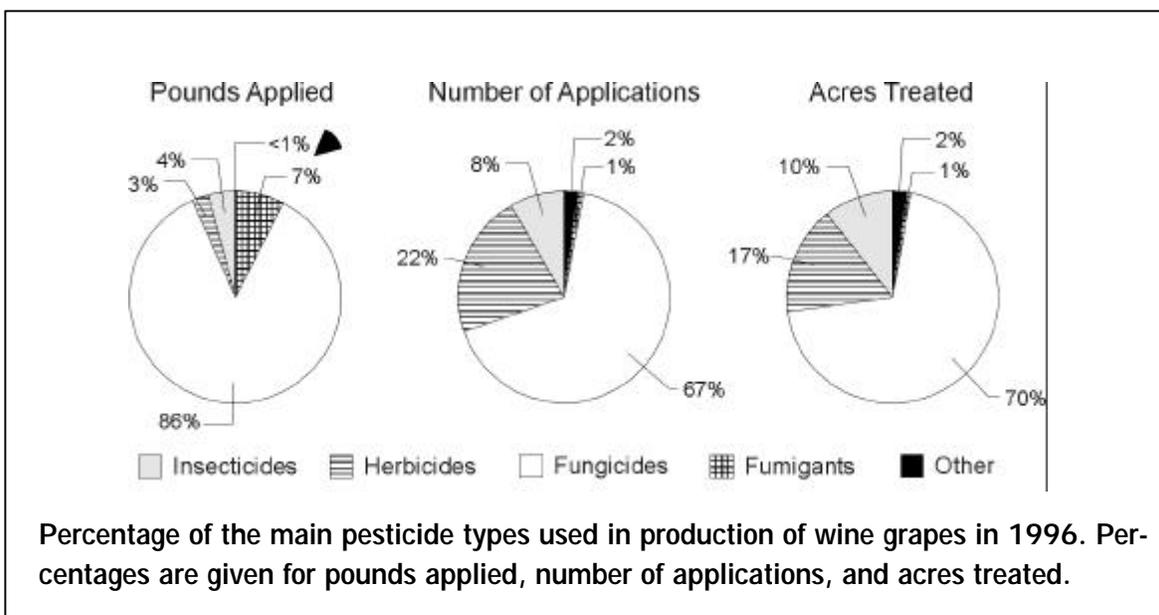
The main fungicides used in 1996 were sulfur, myclobutanil, copper hydroxide, and fenarimol. Sulfur, fenarimol, myclobutanil, and triadimefon are all rotated for powdery mildew control. Sulfur use increased in 1996 because of greater powdery mildew problems. Triadimefon, introduced in the mid-1980s, belongs to a class of compounds known as sterol biosynthesis inhibitors (SBIs) or dimethylation inhibitors (DMIs). Within a few years, powdery mildew resistance to triadimefon developed and use of triadimefon decreased dramatically during the 1990s. Beginning in the early 1990s, powdery mildew began showing resistance to the newer SBIs, fenarimol and myclobutanil. Sulfur was used against powdery mildew either alone (especially in raisin grapes) or combined with fenarimol and myclobutanil (standard practice in table grapes).

Wine Grape Production

In 1996, California produced 311,000 acres of wine grapes, or 48% of the total grape acreage for the state. (Raisin and table grapes account for the remaining 52% of the grape acreage.) Wine grapes are grown throughout California, in coastal regions from San Diego County in the south to Mendocino County in the north, and the Central Valley and other inland areas.

Pesticide use for wine grapes in 1996.

Measures of pesticide use	Total for wine grapes	Percentage for all crops
Pounds applied	25,266,817	14.52%
Number of applications	109,475	6.72%
Acres treated (cumulative)	4,338,403	8.26%



Insect and Mite Management – Wine grapes are attacked by the same complex of arthropod pests found on raisin and table grapes. Cryolite, the insecticide with the highest use in 1996, was used to control leafhoppers, spider mites, phylloxera, and young larvae of grape leaf folder, omnivorous leafroller, orange tortrix, and western grapeleaf skeletonizer. Cryolite is especially important in controlling leafhoppers, which vector Pierce’s disease, a bacterial disease that has recently developed into a serious problem for the wine grape industry in Napa and Sonoma counties.

Use of cryolite increased in 1996, possibly because of its effectiveness against the western grapeleaf skeletonizer. Growers use more cryolite on raisin and table grapes; of the total acreage

treated, they treat 28% of all wine grapes with cryolite as contrasted to 70% of raisin and table grapes. Mined cryolite is approved for organic production.

Weed Management – As with raisin and table grapes, the weed complex depends primarily on soil characteristics. In 1996, glyphosate and oxyfluorfen use generally increased, especially from 1995 to 1996. Oxyfluorfen kills cheeseweed, nettle, and filaree, which glyphosate misses. Drip irrigators prefer oxyfluorfen because of its persistence and safety to nontarget plants and like to combine it with glyphosate.

Disease Management – The most important fungal diseases of wine grapes are powdery mildew, bunch rot (*Botrytis*), cane diseases (including *Phomopsis*), and *Eutypa* dieback. Powdery mildew is the most important grape disease; the leaves and fruit become covered with white mycelia. Growers treat preventively with sulfur alone or combined with other fungicides such as myclobutanil or fenarimol. Use of sulfur has generally increased from 1992 through 1996.

Botrytis bunch rot, a fungal disease that directly affects the ripe fruit, is often treated with benomyl. Use of benomyl generally decreased from 1991 through 1996, possibly because more growers used cultural practices such as leaf removal to avoid the disease.

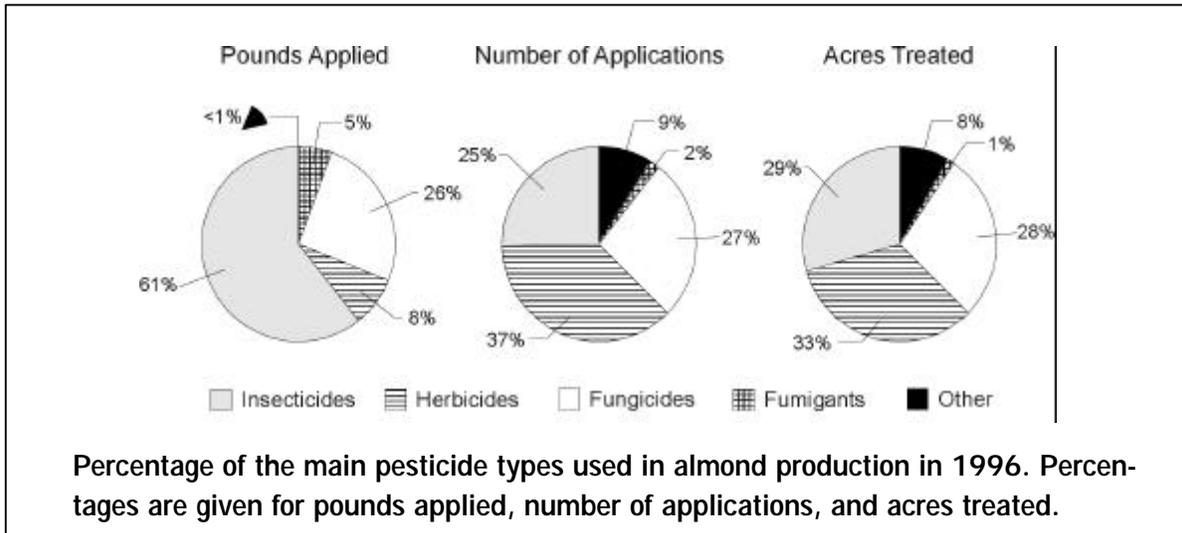
Soil Management – Just before growers replant vineyards with phylloxera-resistant rootstocks they use methyl bromide to control nematode and soil-borne pathogens and to prophylactically manage noxious weeds. During the 1990s, methyl bromide was used on less than 1% of treated acres of wine grapes. Still, almost all of California's vineyards have been fumigated with methyl bromide. From 1993 through 1996, use of methyl bromide increased slightly.

Almond Production

Seventy-five percent of the world’s almonds are grown in California’s Central Valley. Almonds are one of California’s largest crops by area; in 1996, 405,000 acres of almond were harvested, or 4.7% of the state’s cropland. Nearly all of the nation’s almonds are grown in California because of the ideal climate—the hot summer temperatures and lack of rain are required for a disease-free crop.

Pesticide use for almond in 1996.

Measures of pesticide use	Total for almond	Percentage for all crops
Pounds applied	13,538,436	7.78%
Number of applications	87,744	5.38%
Acres treated (cumulative)	4,407,851	8.39%



Insect and Mite Management – The major arthropod pests of almonds are navel orangeworm, peach twig borer, ants, mites, and San Jose scale. Historically, almond trees were sprayed with an organophosphate (OP) pesticide with a narrow range oil during the dormant season (from about November through February). Until recently this was the recommended practice because (1) it controlled several important pests (peach twig borer, overwintering mites, and San Jose scale); (2) it was less harmful to beneficial insects than applications performed during the growing season; (3) it conflicted less with other farming practices; and (4) it provided better coverage of the trees because the leaves were not present. However, in order to protect surface water from possible contamination by OPs, there has been an effort to change this practice.

Navel Orangeworm—The navel orangeworm is the most significant insect pest in almond orchards. Navel orangeworms overwinter as larvae inside nuts left on the tree after harvest and

on the ground. The larvae of this moth feed on the almond kernels inside the shell and destroy the kernel. The larvae are also associated with the fungi responsible for aflatoxins. Navel orangeworm can best be controlled by harvesting the nuts as early as possible, and removing and destroying nuts on the trees and ground. This will remove the pests' overwintering sites and reduce pest populations the following year.

Azinphos methyl is the pesticide most frequently used to control navel orangeworm, although its use decreased from 1991 to 1996. Azinphos methyl is applied after almond bloom, and is popular because it is effective and remains on the trees for a long period of time. Esfenvalerate and permethrin are also used to control navel orangeworm, but because they kill the natural enemies of mites, these pesticides can cause mite outbreaks. Navel orangeworm eggs and larvae are also controlled with aluminum phosphide, which is applied as an on-farm fumigant to harvested nuts under tarpaulins before hulling and processing. However, the most effective methods of controlling navel orangeworm do not involve pesticides. Harvesting the nuts as early as possible and destroying nuts from the trees and ground will remove the pests' overwintering sites and result in much lower pest populations the following year.

Peach Twig Borer—Peach twig borer is another major insect pest in almond orchards. The moth's larvae feed on the almond nuts, damage growing shoots and almond shells, making it easier for navel orangeworms to enter the nuts. Peach twig borers overwinter as larvae primarily under the bark in limb crotches. Spraying the trees during the dormant season is the easiest and most effective way to control this insect.

In the past, growers used dormant sprays consisting of an oil–OP mixture (chlorpyrifos, diazinon, or methidathion) to control peach twig borer, San Jose scale and other scales, and mites that overwintered as eggs, thus reducing the need for more disruptive applications during the growing season. Use of several OPs increased in the early 1990s, probably as a result of the 1992 cancellation of parathion, which had been an important dormant material. Subsequent decreases in the use of OPs were probably associated with some growers using only oils during the dormant season, and the increased popularity of synthetic pyrethroids such as permethrin (Figure 5). The synthetic pyrethroids became popular because of their relatively low cost, and because San Jose scale and peach twig borer began to develop resistance to OPs.

Although a dormant spray with oil alone is effective for scales and mites, it will not adequately control peach twig borer. However, peach twig borer can be controlled by applications of *Bacillus thuringiensis* in the spring, or applications of azinphos methyl and other OPs during the course of the season.

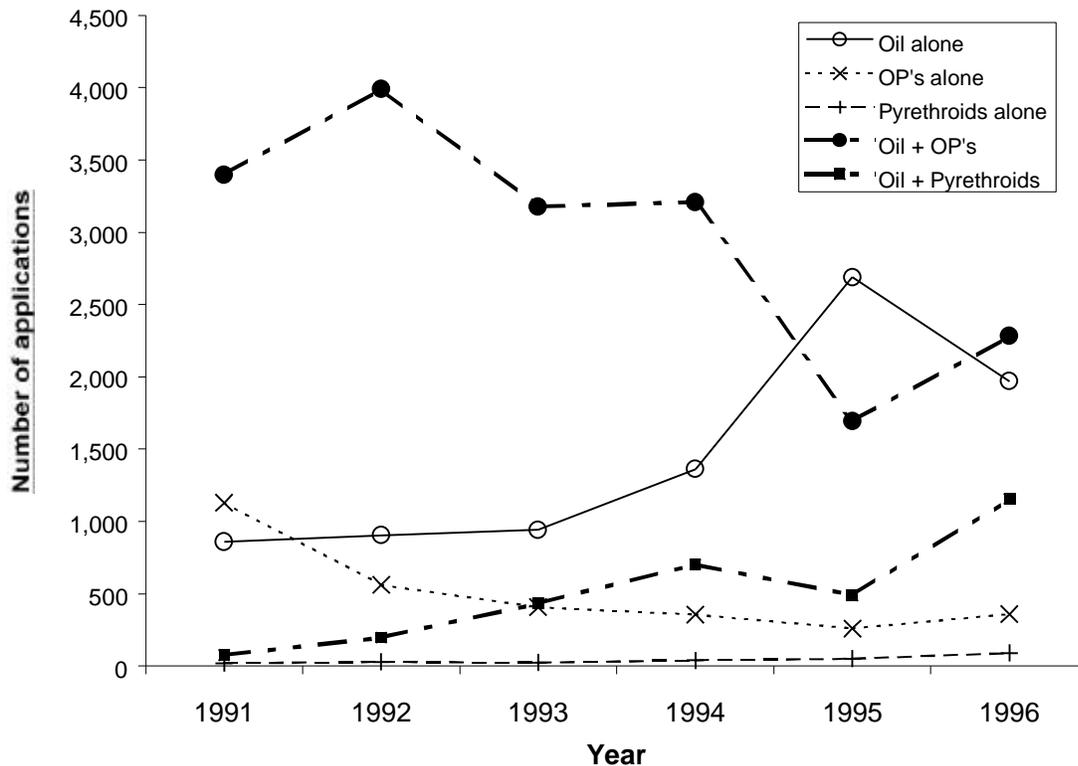


Figure 5. Number of applications in almonds in California during the dormant season (Dec 1 of previous year to March 1 of current year) for different combinations of insecticides: applications with only dormant oils, with oils combined with organophosphates (OP), oils combined with pyrethroids, with only an organophosphate, or with only a pyrethroid.

Ants—Ants are a significant insect pest in almond, particularly in the central and southern areas of the San Joaquin Valley. The pavement and southern fire ants cause the majority of damage in almond orchards. Ants are principally a problem after almonds fall from the trees, and damage increases the longer the nuts remain on the ground. Ants can completely hollow out the nuts. Ant problems have increased in many orchards since the early 1990s because of the trends toward low volume irrigation systems. The previous practice of flood irrigation would drown out the ant nests. The low-volume irrigation provided optimal soil moisture for the ants. Growers have switched to low-volume irrigation to save water and reduce cost. Ant problems may have also increased because of the reduction in the navel orangeworm spray programs, which incidentally controlled ants.

Chlorpyrifos is the only pesticide registered for almond that provides effective ant control. While the use of chlorpyrifos as a broad-spectrum dormant season spray has decreased, its overall use during the remainder of the season (specifically for the control of ants) has increased; thus its annual use has remained relatively constant.

Weed Management – Almost all almond orchards are no-till, meaning tractors are not used to cultivate the land surface within the orchard for the purpose of weed control. Herbicide applications and/or mowing must be done to control weeds in no-till orchards. Growers have adopted no-till practices to reduce soil compaction, which can damage roots. Tilling requires heavier equipment than applying herbicides. Also, applying herbicides is faster than tilling.

Preemergence and postemergence herbicides or combinations of pre- and postemergence herbicides are often used between tree rows in no-till orchards. Preemergence herbicides are generally used only in the tree row, that is between trees along the rows. This reduces the total amount of these herbicides, which are generally more expensive than postemergence herbicides, and prevents the surface roots in the tree row from being damaged by cultivation equipment. By treating the tree row, only 25–33% of the total acreage within the orchard is treated.

In the early- to mid-1990s, the use of postemergence herbicides increased. This reflected a distinct shift in weed management practices. Earlier practices relied upon one or two applications of various combinations of preemergence materials in combination with disking or mowing. Many growers shifted to cheaper postemergence herbicides, such as glyphosate, applied at low rates to the entire orchard floor. This practice also replaced mechanical mowing of weeds or cover crops. Growers switched to these systems because it was possible to use small, inexpensive equipment coupled with the additional benefits of easier field access in muddy conditions, and less soil compaction. These methods were also faster than mowing, and postemergence herbicides tended to be cheaper than preemergence herbicides.

Glyphosate, oxyfluorfen, and paraquat are the herbicides most commonly used in almond orchards; use of all three increased from 1991 to 1996. Glyphosate is applied during the dormant, pre- and/or post-bloom season by ground. It is often applied at low rates several times during the season. It is a nonselective systemic herbicide used for a broad range of weed species. It is effective anytime on emerged, irrigated, rapidly growing, non-stressed weeds and is the best material available for most perennial weeds. However, it is not effective against older cheeseweed plants and some weeds can develop tolerance to glyphosate when it is used for long periods.

Oxyfluorfen is applied anytime following almond harvest through mid-February. It is a selective broadleaf herbicide and is effective as a pre- and postemergence material. It is particularly useful when combined with glyphosate; the combination increases efficacy on various broadleaf weed species and slows the development of tolerance to glyphosate. Oxyfluorfen is the only material effective on cheeseweed and related species.

Paraquat is a nonselective postemergence material used for quick burn-down of most weed species. It is less effective against perennials that will regrow with vigor (e.g., bermudagrass, dallisgrass, johnsongrass, and field bindweed). It is most effective when used on early spring or winter growth of annual grass species in combination with preemergence herbicides.

Cultural Methods of Weed Control—Almond orchards may benefit from plant cover on the orchard floor if the cover is carefully managed. Orchard floor management is of particular importance because the crop is picked up from the soil surface after being knocked from the

trees. Whether an orchard is tilled, nontilled, herbicide treated, or cover cropped, the grower must ensure that the orchard floor is in the best possible condition for harvesting. In addition, a well-maintained ground cover can help increase water infiltration, reduce soil compaction, maintain soil organic matter content, cool the orchard, and provide habitat for beneficial insects.

However, maintaining bare or closely mown orchard floors can also be beneficial. Because almonds begin blooming in mid-February before the danger of frost has passed, and because bare ground absorbs more heat and can reduce the threat of frost damage, early season frost protection can be achieved by close mowing or herbicide treatment.

Disease Management – Almond trees are attacked by many diseases that affect the roots, crowns, trunk, branches, vascular tissues, leaves, and fruits. Unfortunately, once the orchard is planted chemicals can effectively control only leaf and fruit diseases. The most important leaf and fruit diseases found in almond orchards include brown rot, anthracnose, and shot hole, which are controlled with fungicides.

Increased use of fungicides was responsible for a large proportion of the total increase in pesticide use for almond. Use increased for almost all of the important fungicides between 1991 and 1996, except for ziram, which experienced a use decrease of almost 50%. Between 1991 and 1996, captan and maneb each increased from less than 100,000 pounds to over 500,000 pounds per year; sulfur use increased from about 40,000 to almost 290,000 pounds per year.

Increased fungicide use for almond was generally correlated with the end of the drought years in 1993, and with high precipitation in 1995 and 1996. Wet weather is particularly conducive to disease development. Thus, in the late 1990s growers had to contend with a number of diseases that had not been a problem since the mid-1980s. For example, anthracnose problems had been relatively unknown, but in 1995 and 1996 growers scrambled to deal with outbreaks of this disease. Ziram use probably decreased because, although it was effective against shot hole (and scab later in the season), growers found that other fungicides could protect their orchards against a wider range of disease organisms.

Brown Rot—Brown rot is a fungal disease that affects almond flowers and twigs. It can be found in most almond-producing areas in California; rain or fog during bloom aids the growth of the disease. Since complete crop loss can occur on susceptible cultivars when rain persists during bloom, flowers must be protected from infection if brown rot is to be controlled. The fungus overwinters in cankers on twig or in dead blossom parts; it grows from the blossom into fruiting spurs or twigs to form cankers. Brown rot causes the nearby leaves or the entire twig beyond the site of infection to die. The economic effect of infected spurs does not appear until several years later when fruit production from these spurs is reduced. Pesticides used to control brown rot include benomyl, iprodione, myclobutanil, maneb, and copper hydroxide.

Anthracnose—Anthracnose is a disease affecting the blossoms, leaves, and fruit of almonds. It was not a problem in California until the early 1990s, but the fungus is now found in all major almond-growing regions from Butte to Kern County. It is considered a major threat to the industry in the state. This is an extremely serious disease, which requires multiple pesticide applications. Myclobutanil and captan are moderately effective against anthracnose; newer

materials, such as propiconazole and tebuconazole, which were registered for use in almonds after 1996, are more effective.

Shot Hole—Shot hole affects both the leaves and young fruit of almonds. Infection of young fruit can cause the fruit to drop, but infection of older fruit does not develop deep into the hull. Shot hole can cause losses in yield and tree defoliation, thus weakening the trees. Captan, iprodione, ziram, and maneb are used to control shot hole.

Soil Management – Methyl bromide, aluminum phosphide, and 1,3-dichloropropene (1,3-D) are the fumigants most often used in almond orchards; methyl bromide and 1,3-D are injected into the soil before planting new trees. Target pests of these fumigants included a variety of nematodes, gophers, and fungal diseases such as *Armillaria* root rot. The number of acres treated with methyl bromide are generally in the range of the acreage of new plantings, suggesting that most growers fumigate before they establish an orchard.

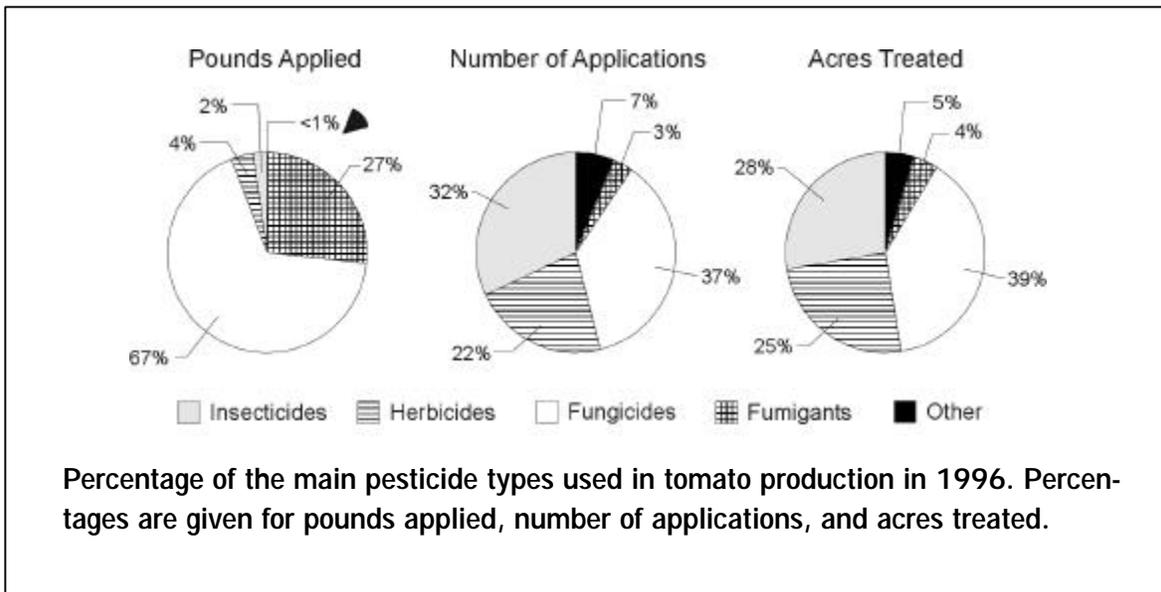
Nematodes—Because there are no effective post-plant nematicides (and no rootstocks known to be resistant to root lesion nematode), growers make a critical decision when they decide whether or not to fumigate for nematodes. Methyl bromide, or an effective alternative (such as 1,3-D) are used for nematode-targeted fumigations on ground to be planted to almonds. Nematode damage can become severe enough in almond orchards that if a fumigant is not used, orchard trees will experience a reduction in root mass and will be weakened. This root system reduction will also mean that insect or disease damage from above ground will impact the trees more severely. While 1,3-D can replace methyl bromide for this particular use, this pesticide was suspended from use in California from 1990 to 1994. In December 1994, DPR approved a limited reintroduction of 1,3-D under new use practices that resulted in reduced emissions. Serious acreage restrictions and application limits were placed on 1,3-D use.

Tomato Production

California grows 28% of all fresh market tomatoes and 90% of all processing tomatoes in the United States. In 1996, growers harvested approximately 38,000 acres of fresh market tomatoes and 285,000 acres of processing tomatoes. Together, fresh market and processing tomato acreage makes up 4% of all cropland in California. Sixty percent of all processing tomatoes are grown in Yolo County; 40% are produced in the southern San Joaquin Valley. Half of all fresh market tomatoes are grown in San Joaquin, Stanislaus, and Merced counties; approximately 25% come from the southern San Joaquin Valley. The remaining 25% are grown in the Central and South coasts and the Imperial Valley.

Pesticide use for tomato in 1996.

Measures of pesticide use	Total for tomato	Percentage for all crops
Pounds applied	16,158,300	9.29%
Number of applications	41,200	2.53%
Acres treated (cumulative)	2,520,843	4.8%



Insect and Mite Management – Tomato fruitworm, tomato pinworm, and beet armyworm are major tomato pests that directly attack fruit. Tomato fruitworm feeds primarily in the fruit, causing premature ripening and decay. Tomato pinworm, mainly a pest of summer and fall fresh market tomatoes, bores into the fruit, causing contamination and decay. Feeding of the beet armyworm is often superficial, and each larva can damage several tomatoes. Growers rely on several insecticides to control these pests, including esfenvalerate, methomyl, carbaryl, diazinon, and *Bacillus thuringiensis*. Use of esfenvalerate rose from 1991 through 1995, falling slightly in 1996. The decline may be due to increasing fruitworm resistance to this material. Also, extensive

use causes flare-ups of leafminers. Use of methomyl from 1991 through 1996 increased slightly. Methomyl effectively controls lepidopteran pests, but its control spectrum is smaller than that of esfenvalerate. Methomyl's increase in use can be attributed to its short preharvest interval, relative low cost, and more prevalent insect resistance to it which results in growers using more.

Stink bugs feed directly on fruit, causing spotting and internal scarring. Growers treat stink bugs with dimethoate, methamidophos, and endosulfan. Use of dimethoate fluctuated from 1991 through 1996 in response to variations in pest pressure. Along with endosulfan, dimethoate also controls potato aphid, formerly a minor pest that has recently become a major problem in some areas.

The tomato russet mite can quickly defoliate plants in hot weather. A single application of sulfur effectively controls these mites. Use of sulfur steadily increased from 1991 through 1996, possibly due to increased mite pressure and a higher incidence of powdery mildew (see *Disease Management*).

Disease Management – Powdery mildew appears in most tomato-growing regions in California. Outbreaks result from environmental stresses such as hot weather combined with irregular watering. Sulfur, also used for tomato russet mite, controls powdery mildew. The increase in sulfur use from 1991 through 1996 may be explained by a higher incidence of disease resulting from spring rains.

Late blight is probably the most serious disease of fresh market tomatoes. In 1996, growers primarily used chlorothalonil and mancozeb as preventive treatments. They also rotated metalaxyl with other materials to avoid resistance problems since metalaxyl-resistant strains of late blight have become more widespread. Use of all three fungicides peaked in 1995, but fell off slightly in 1996.

Bacterial speck infects tomato plants during cool, moist weather, causing small, dark specks on unripe fruit. Growers who must plant early crops use copper hydroxide often combined with mancozeb when the disease seems likely to develop. Copper hydroxide functions protectively and must be used before infection; mancozeb increases the effectiveness of copper hydroxide. Use of both peaked in 1995 and decreased in 1996, probably as a response to lower disease pressure.

Weed Management – Major weed species in tomato fields include nightshades, field bindweed, nutsedges, and dodder. Trifluralin provides cost-effective season-long control of many annual grass and broadleaf weeds. Trifluralin is applied before weeds emerge, often after thinning or transplanting. Use of trifluralin generally increased from 1991 through 1996. Of all the trifluralin used on California acreage in 1996, 18% was used for tomatoes.

Metam sodium, primarily used to control nightshades, is incorporated into the soil at least 14 days before tomato plants go in. Acreage treated with metam sodium peaked in 1996 due to prevalent nightshade.

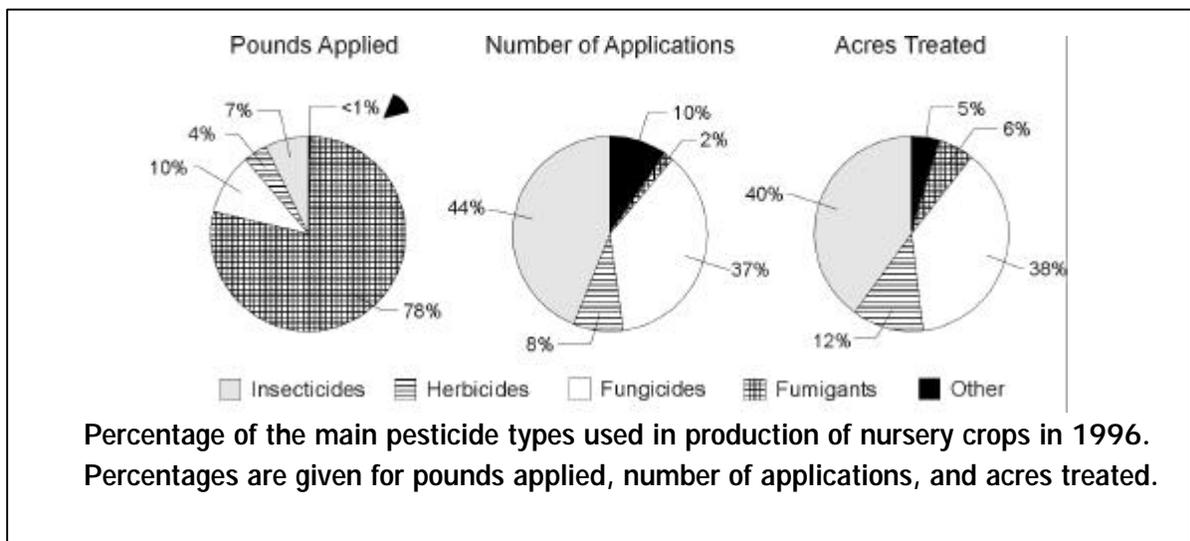
Nursery Crop Production

Nursery crops form a diverse group of ornamental and crop plants grown for the wholesale and retail market. This summary combines greenhouse- and outdoor-grown ornamentals, stock for on-farm planting, and cut flowers. Pest management practices vary substantially for the hundreds of plant species grown by nurseries.

In 1996, approximately 33,000 acres of nursery plants were grown in California, accounting for over 20% of all nursery plants grown in the United States. In California, nursery plants are grown indoors (primarily in greenhouses) and outdoors. Nurseries often grow indoor or outdoor plants in containers or flats; some outdoor plants such as fruit and landscape trees are grown in fields. Another broad category separates on-farm from ornamental (landscaping) stock, although some overlap exists. For example, apple trees grown for orchards may also be purchased for backyard plantings.

Pesticide use for nursery crops in 1996.

Measures of pesticide use	Total for nursery	Percentage for all crops
Pounds applied	3,347,547	1.92%
Number of applications	193,741	11.89%
Acres treated (cumulative)	564,780	1.07%



Most outdoor nursery plants are grown in San Diego, Los Angeles, Orange, San Mateo, and Ventura counties. The counties of San Diego, Santa Barbara, San Mateo, Monterey, and Santa Cruz are the leading producers of outdoor flowers and foliage plants. Most fruit and nut tree stock is grown in the Central Valley, grapevines in the Central Valley and coastal wine-growing regions, and strawberry transplants in Shasta and Lassen counties.

Ornamental nursery stock must be free of quarantined pests and relatively free of common pests such as spider mites and greenhouse whiteflies. Nurseries usually steam sterilize the soil for container-grown ornamentals to rid them of soil-borne pests. Pests on cut flowers are not regulated, but growers are mindful that consumers generally do not tolerate pests or pest damage. The nursery industry maintains stringent sanitary practices for on-farm stock. Not only must plants in this category meet the same pest-cleanliness standards as those for ornamental stock, but the soil in which these plants are grown must be completely free of nematodes. As a result, nurseries often fumigate the soil in which on-farm stock is grown. If they do not fumigate, the soil is sampled for nematodes when the plants are sold.

On-farm nursery crops may require higher amounts of pesticide than other crops to keep soil free of nematodes. Also, because nurseries try to sell cosmetically attractive plants, some pesticides may be used on a calendar basis rather than when actually needed. Because many nursery crops are not included on product labels, special-permit pesticides must sometimes be used.

Insect and Mite Management – A number of arthropod pests attack nursery plants, including mites, aphids, scale insects, leafminers, and caterpillars. Avermectin is registered for many nursery crops to control mites, leafminers, and tomato pinworm. In 1996, 37% of all avermectin applications were made to nursery plants. Use of avermectin increased in 1996, possibly because of its low toxicity to natural enemies. Azadirachtin (neem oil), a reduced-risk material, controls aphids, whiteflies, thrips, leafminers, and caterpillars. In 1996, azadirachtin was used on less acreage than other insecticides—notably avermectin, acephate, tau-fluvalinate, chlorpyrifos, and dinotol. However, use of azadirachtin, first registered in California in 1992, rose dramatically from 1994 through 1996. Both avermectin and azadirachtin are used primarily on cut flowers in greenhouses and container plants grown in greenhouses or outdoors.

Disease Management – A wide range of plant diseases affect nursery plants. Thiophanate-methyl, a broad-spectrum systemic fungicide, was used on more nursery acreage than any other fungicide. Also used widely were metalaxyl, mancozeb, chlorothalonil, iprodione, copper hydroxide, sulfur, fosetyl-al, and vinclozolin. Iprodione is used to control various diseases affecting roots and leaves, primarily on cut flower crops grown in the greenhouse or outdoors. Use of iprodione increased from 1991 through 1996. Nearly 25% of all iprodione applications in 1996 were to nursery plants. Two other fungicides, copper sulfate and triadimefon, are important because a high proportion of applications made to all crops (27% and 36%, respectively) are made to nursery plants. Copper sulfate controls many bacterial and fungal diseases, while triadimefon controls powdery mildew and rust fungi on most nursery crops. Use of both materials declined somewhat after 1993. Triadimefon, first introduced in the mid-1980s, gained popularity until the early 1990s when powdery mildew began to develop resistance to it.

Soil Management – Methyl bromide is the main soil-sterilizing fumigant used by nurseries to control soil pathogens such as *Verticillium* and *Fusarium* wilts, plant parasitic nematode pests such as rootknot nematode or nematode vectors of plant disease. Methyl bromide also destroys most weed seeds and soil-dwelling arthropods. Nurseries rely heavily on methyl bromide for on-farm stock (such as strawberry), cut flowers, new tree and vine plantings, and field-grown nursery stock plantings. Chloropicrin, also a soil fumigant, is used together with methyl bromide

at low rates as a warning agent or at higher rates to control some soil-borne pests and diseases. It can be used alone for some crops to sterilize container potting soil before potting plants and to control Verticillium wilt.

In 1996, acreage treated with methyl bromide and chloropicrin increased. Nursery acreage accounted for more than 17% of treatments with methyl bromide and nearly 25% of those with chloropicrin. During 1996, three times more methyl bromide than metam sodium was used on nursery acreage. Metam-sodium, another soil fumigant, controls weed seeds and soil fungi. Although cheaper than methyl bromide, metam sodium is less effective and its supplies were sometimes limited in 1996.

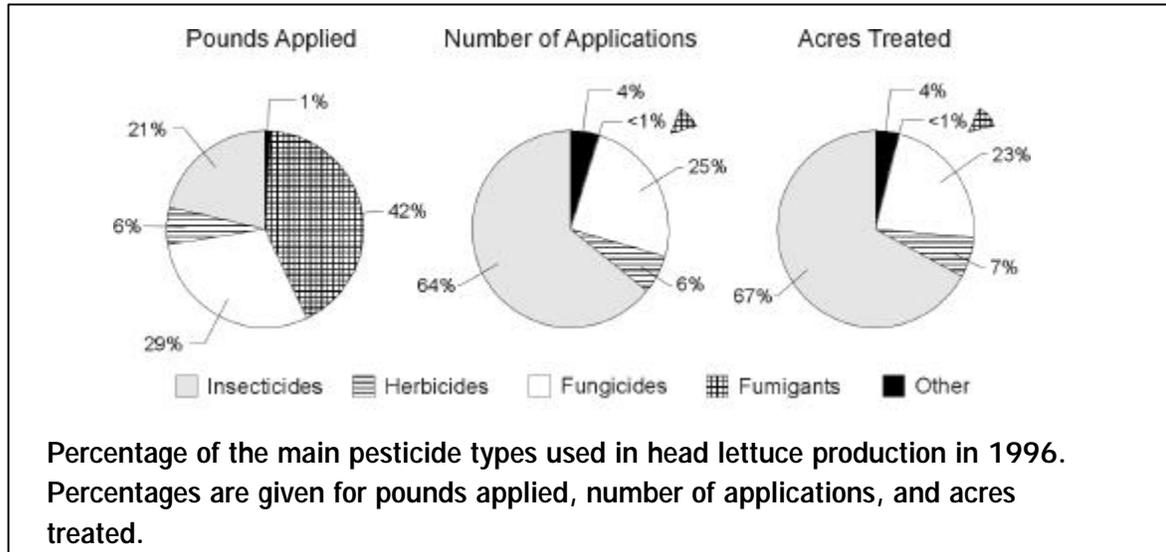
Head (Iceberg) Lettuce Production

In 1996, California grew 72% of the head or iceberg lettuce produced in the United States. Lettuce is grown in four regions of the state: 1) the central coastal area (Monterey, San Benito, Santa Cruz and Santa Clara counties); 2) the southern coastal area (Ventura, Santa Barbara, and San Luis Obispo counties); 3) the San Joaquin Valley (Fresno and Kern counties); and 4) the southern desert regions (Imperial and Riverside counties). Harvested acres decreased from 152,000 acres in 1991 to 135,500 acres in 1996, making up 1.6% of all harvested acreage in California.

Growers must control a wide variety of pests to produce a marketable head lettuce crop. Pest pressures are complex and related to the types of crops and crop residues present in adjacent fields, specific growing regions, and seasonal weather patterns.

Pesticide use for head lettuce in 1996.

Measures of pesticide use	Total for head lettuce	Percentage for all crops
Pounds applied	2,241,579	1.29%
Number of applications	120,051	7.37%
Acres treated (cumulative)	2,172,108	4.13%



Insect Management – Leafminers, green peach aphid, beet armyworm, cabbage looper, and lygus bug are the dominant insect pests in the coastal regions of California. Beet armyworm, cabbage looper, corn earworm, silverleaf whiteflies, and thrips are the most serious pests in the desert region. Leafminers, beet armyworm, cabbage looper, corn earworm, and thrips are the most serious pests in the Central Valley.

Certain insects are primarily pests of seedling lettuce, although some pests also cause damage in later stages of lettuce growth. Because lettuce is normally directly seeded in the field, insects can rapidly attack and consume tender emerging lettuce seedlings. However, seedling pests such as cutworms and leafminers are only intermittent pests.

Head lettuce is particularly vulnerable to insect attack when the lettuce heads are forming. Pesticide applications are recommended after certain insect counts have been reached, so growers must pay careful attention to the timing of infestations. Growers must carefully select insecticides to avoid harming beneficial insects and to prevent the development of resistance by pests.

In 1996, cypermethrin was the most widely used insecticide on head lettuce (by number of applications and acres treated); use increased steadily from 1991 to 1996. Permethrin use was second. Applications to head lettuce accounted for 24% of all permethrin use in 1996. Cypermethrin and permethrin are synthetic pyrethroids used to control caterpillars; however, these pesticides can also be used for adult leafminers.

Methomyl is used to control the beet armyworm and other caterpillars and silverleaf whitefly. Dimethoate is used for aphids. Use of dimethoate declined from 1994 through 1996, possibly due to environmental concerns and resistance of aphids. Imidacloprid is used to control silverleaf whitefly and aphids, and was first used in 1994. Its use increased dramatically from 1994 to 1996. Avermectin is used to control the larval stages of leafminers; its use has increased dramatically from 1991 to 1996, probably because problems with leafminers have been increasing. Endosulfan is used for cabbage looper, corn earworm and aphids.

In the early 1990s mevinphos was one of the most widely used insecticides. However, its use was cancelled after December 1, 1995.

Weed Management – Weed management is an essential component of lettuce production because most lettuce is direct seeded, and is typically accomplished through the use of a combination of herbicides, cultivation, and hand weeding. Young emerged lettuce plants must compete with weeds for water, nutrients, and sunlight, necessitating weed control from planting time through stand establishment. A wide variety of weeds—annuals and perennials, broadleaf weeds and grasses—can cause economic loss, but annual broadleaf weeds present the biggest problem in lettuce. Propyzamide is by far the predominant herbicide used in all production areas, and is used to control annual broadleaf weeds. Other herbicides applied to lettuce fields include bensulide, benefin, and glyphosate. Growers apply metam-sodium before planting, primarily to kill weed seeds.

Disease Management – Lettuce is susceptible to several diseases including anthracnose, bacterial leaf spot, bottom rot, corky root, downy mildew, and lettuce drop (Sclerotinia drop). Downy mildew is present in all production areas of California, and is the most serious foliar disease in the coastal areas. Lettuce drop is a fungal disease that wilts the entire lettuce head when it is close to maturity. Both lettuce drop and downy mildew are promoted by cool, moist weather. All disease damage is dependent on weather, cultural practices, and variety of lettuce.

Maneb is the dominant fungicide used in head lettuce production, primarily to control downy mildew and prevent anthracnose. In 1996, 44% of all maneb applications were to head lettuce. Maneb's use has steadily increased each year from 1991 to 1996 because of increased disease pressure and because it partly replaced metalaxyl, which became less effective.

Fosetyl-al is the second most widely used fungicide in head lettuce, also controlling downy mildew. Iprodione is used for bottom rot, but this fungicide seldom provides adequate control. Iprodione is used for lettuce drop, but application timing is critical. Several fungicides are applied preventively for lettuce drop, including maneb, iprodione, and vinclozolin.

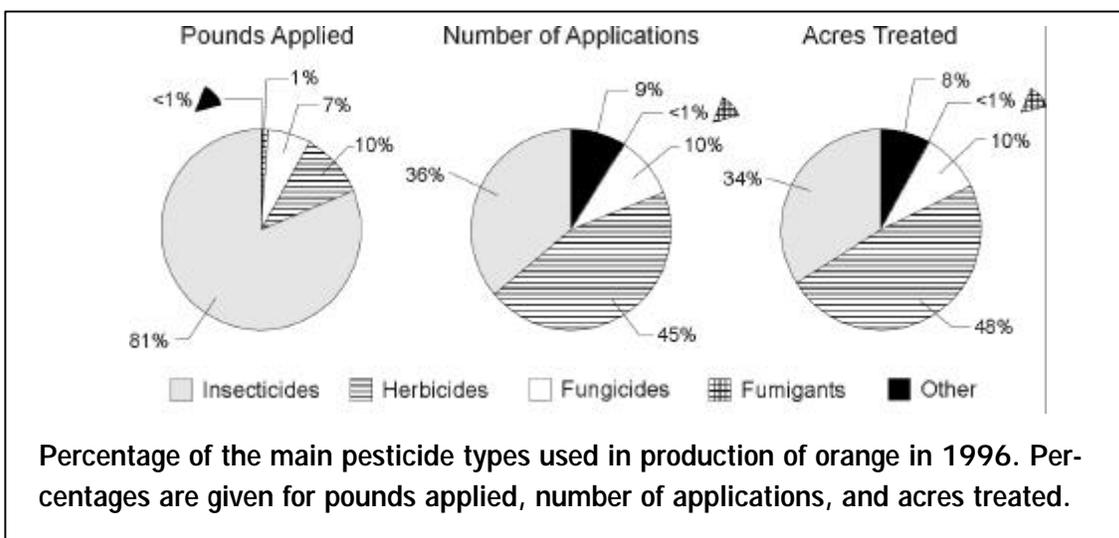
Soil Management – Methyl bromide was used for root-knot nematode and soil pathogens such as corky root. (See *Weed Management* for metam-sodium use.) However, fumigants were not commonly applied, accounting for less than 0.15% of the both number of applications and acres treated of all pesticide use in head lettuce.

Orange Production

California's primary orange production areas are the San Joaquin Valley, the coastal intermediate district from southern Santa Barbara through San Diego counties, eastern Riverside County, and the desert valleys. From 1991 through 1996, orange acreage increased from roughly 178,400 to 196,000, or 2.3% of all bearing acreage in California, and second among all states nationwide. Navel orange acreage increased while valencia orange acreage decreased. Pest problems differ for navel and valencia oranges, as for the different orange-growing regions.

Pesticide use for orange in 1996.

Measures of pesticide use	Total for orange	Percentage for all crops
Pounds applied	7,537,200	4.33%
Number of applications	59,027	3.62%
Acres treated (cumulative)	1,556,433	2.96%



Insect and Mite Management – California red scale and citrus thrips cause substantial damage to San Joaquin Valley orange crops, as do citrus cutworm, fruittree leafroller, and citrus red mite. California red scale, citrus rust mite, and snails are the main pests in the coastal intermediate district and in eastern Riverside County. Citrus thrips and California red scale are important pests in the desert valleys. Mites and snails are more of a problem of lemon (see *Lemon Production* for more on these pests).

Oils are the most common insecticides used for orange, and their use increased by about sixfold from 1991 through 1996. Oils are primarily used to control greenhouse thrips and California red, citricola, and black scales. Their use increased for two main reasons: 1) scales have developed resistance to carbamates and organophosphates pesticides, but oils have remained effective; and

2) more growers are adopting reduced-risk pest management practices and oils are important because they do not disrupt the natural enemies of scale.

Scale Insects—California red scale causes serious damage to orange crops in California, sucking fluids from tree branches, leaves, and fruit. Heavily infested fruit may be downgraded in the packinghouse, and trees can be seriously damaged. Other scale insects that can cause problems for orange include citricola scale and black scale. Other pesticides besides oils used for scales include chlorpyrifos, carbaryl, and methidathion. These pesticides are often rotated in an attempt to minimize scale resistance. For 1996 the orange crop, chlorpyrifos was used as much as oils in terms of number of applications and acres treated, but previously it was main insecticide. It is commonly used because of its high selectivity (which is better than carbaryl's), fast kill, compatibility with IPM programs, and effectiveness for citricola scale.

Citrus Thrips—Citrus thrips cause major damage to orange fruit in the San Joaquin Valley, puncturing the epidermal cells of the fruit, and leaving scabby scars on the rind. Citrus growers used cyfluthrin, dimethoate, formetanate hydrochloride, and avermectin to control citrus thrips. Cyfluthrin and avermectin use is increasing, but dimethoate and formetanate uses are decreasing, probably because thrips began developing resistance to dimethoate and formetanate, and cyfluthrin and avermectin are still effective. Also, avermectin is more selective than formetanate hydrochloride and dimethoate, meaning it does not impact non-target insects to the same degree.

Weed Management – Weed management is important for orange not only because weeds compete with the orange trees for nutrients and water, but also because a weed-free orchard floor makes irrigation and other cultural practices easier and reduces the possibility of freezing in the winter. However, more growers are planting cover crops, especially in northern California and in hilly areas. A cover crop prevents soil erosion and improves the soil structure. However, cover crops do need to be managed by mowing and they require additional water.

Herbicides are relied on to manage weeds because cultivation creates several problems for orange. Cultivation damages the feeder roots, which are critical for absorbing nutrients, water, and oxygen from the soil. Damaged roots also provide entry points for disease. If the soil is dry, cultivating creates dust, which can disrupt the biological control of pests by natural enemies.

Glyphosate is by far the most widely used pesticide in orange groves as measured by number of applications and acres treated. It is applied to winter and summer annual weeds after they have emerged. Diuron is the second most used herbicide followed closely by simazine. Diuron and simazine are preemergence or residual soil-active herbicides, which means they are applied to the soil before weeds emerge. They are effective for long periods against weeds that emerge after the soil treatment. The number of pounds increased for all three herbicides from 1991 through 1996, possibly because California experienced more weed problems in 1995 and 1996.

Glyphosate is more commonly used because the soil-residual herbicides cannot be used if a cover crop is to be planted and glyphosate allows for more flexibility.

Disease Management – In California, orange diseases are caused by several different viruses, some fungi, and one bacterium. Tristeza, a viral disease transmitted by aphids, is widespread in southern California. Stubborn disease, a mycoplasma or virus-like organism transmitted by

leafhoppers, is a problem in the interior valleys. Both tristeza and stubborn disease affect tree growth and yield but do not have other distinctive symptoms. Citrus blast, a bacterial disease, is limited to the Sacramento Valley because it thrives best in wet and cool conditions. It affects leaves and twigs, getting its start through injuries caused for example by insect damage. Fungal diseases of primary concern affect the roots and trunk of citrus trees and these occur in all production areas. These include several root rots and gummosis, which affect the trunk. The most important disease of the fruit is brown rot, followed by Alternaria spot and Septoria spot.

Copper hydroxide and copper sulfate (basic) are commonly applied to prevent brown rot, gummosis, citrus blast, and Septoria spot. Applications of both of these fungicides increased during 1995 and 1996 as a result of the unusually high rainfall, and an increase in orange acreage. Metalaxyl and fosetyl-al were other commonly used fungicides. Tristeza and stubborn disease are controlled by controlling the insects that transmit the diseases and by planting stock certified to be disease-free. Root rots are generally controlled by fumigants and cultural practices such as using planting in areas that are disease free, resistant rootstocks, providing adequate soil drainage, and avoiding over-irrigation.

Soil Management – Methyl bromide and metam-sodium are fumigants usually applied before orchards are planted to control nematodes and soil-borne diseases such as gummosis and root rots. In 1996, metam-sodium was the primary fumigant used in orange groves; however only 0.02 percent of all orange acres were treated with metam-sodium. Methyl bromide use declined due to regulatory constraints and an increasing reliance on a combination of metalaxyl (or fosetyl-al) and fenamiphos (for nematode control) as a post-plant treatment.

Alfalfa Production

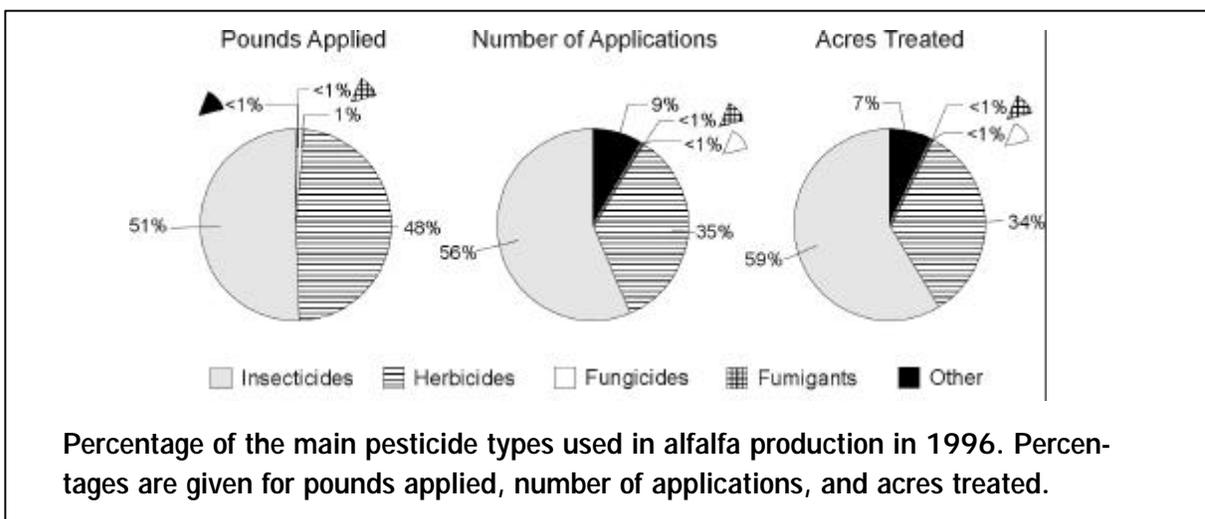
Alfalfa is grown in most California counties. From 1991 through 1996, the total alfalfa acreage in California decreased slightly from 1.05 to 0.94 million acres. California ranks second in the nation for alfalfa production; 10.9% of all production acreage in the state is devoted to alfalfa. Both alfalfa hay and seed are produced commercially; hay production is concentrated in the Central and Imperial valleys, alfalfa seed is produced mainly in the lower Central Valley. Alfalfa is a perennial crop; plants remain in the field for three or four years. Six or more cuttings are harvested annually in regions that are warm enough to support new growth.

Alfalfa provides habitat for a variety of natural enemies that attack pests in alfalfa and neighboring crops. Conservation of these natural enemies is important. Research has shown that cultural practices such as strip cutting (harvesting alfalfa by cutting alternate strips) can maintain populations of predators and parasitoids within the alfalfa field. Crop rotation and the planting of pest-resistant alfalfa species are also options that can limit pesticide applications and preserve natural enemies.

The production of high-quality hay is important to commercial alfalfa growers. Livestock owners demand quality hay because several weed species found in alfalfa fields are poisonous to livestock. When these weeds are baled together with the hay at harvest, the value of the hay declines.

Pesticide use for alfalfa in 1996.

Measures of pesticide use	Total for alfalfa	Percentage for all crops
Pounds applied	2,843,351	1.63%
Number of applications	48,031	2.95%
Acres treated (cumulative)	3,054,015	5.81%



Insect Management – Some of alfalfa’s most important insect pests include the alfalfa caterpillar, alfalfa weevil, beet armyworm, blue aphid, pea aphid, and Egyptian alfalfa weevil. Lygus bugs are significant pests only on alfalfa grown for seed production.

Chlorpyrifos was the most widely used insecticide on alfalfa in 1996 (measured by the number of applications and acres treated); this pesticide’s use generally increased from 1991 to 1996. For southern desert alfalfa hay, chlorpyrifos is used to control Egyptian alfalfa weevil and various aphids during the spring, and beet armyworm during the summer months. Chlorpyrifos is a selective pesticide; beneficial insects can be preserved when it is applied.

Methomyl is used as an alternative to chlorpyrifos; its use also increased. Dimethoate is used to control aphids and leafhoppers on alfalfa.

Weed Management – In most cases, properly prepared young alfalfa stands grow vigorously and out-compete weeds during their first and second year. Alfalfa fields remain in production until areas of the stand die out and noxious weeds begin to fill in and decrease market value.

Herbicide use has special significance for alfalfa production since several California weeds are poisonous to livestock; fiddleneck, yellow starthistle, and common groundsel all present a danger. Other weeds, and even some crop plants, accumulate nitrates, which pose a danger to cattle and hogs, but not to horses or sheep.

Trifluralin is the most widely used herbicide in alfalfa; applications accounted for nearly half of all trifluralin use in 1996. Growers use this postemergence herbicide in the spring to control summer annual grasses in established fields, and in the late dormant season to manage summer grasses such as yellow foxtail and cub grass. Trifluralin also eradicates dodder, a parasitic plant. It is not legal for growers to sell or ship contaminated alfalfa seed.

EPTC, diuron, hexazinone, and paraquat are also used in alfalfa. Paraquat is used to control broadleaf weeds and small grasses, but it is not as effective as diuron. However, paraquat can be applied during wet years when fields are too wet to apply diuron or hexazinone. Each of these herbicides was used about half as much or less than trifluralin.

Disease Management – Several viral, bacterial, and fungal diseases attack alfalfa, but chemical control is rarely used. The fungicide and bactericide copper hydroxide is used occasionally; its use increased from 1991 through 1996. Sulfur was used on relatively few acres; it was probably used as a soil amendment with winter herbicide tank mixes, but its use in the herbicide mixture is reported as a pesticide.

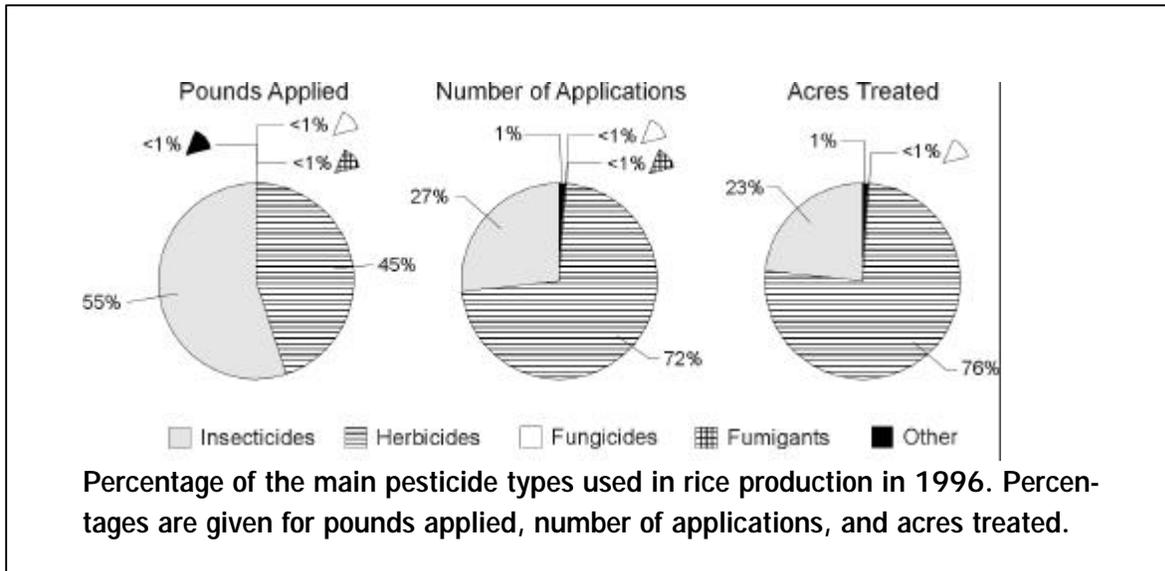
Soil Management – Metam-sodium is the pre-plant fumigant most often used to control nematodes in alfalfa. Although nematode pests can reach levels high enough to damage seedlings, growers often avoid fumigation by planting resistant cultivars or other crops. Therefore, little metam-sodium is used.

Rice Production

In 1996, California grew less than 1% of the world’s rice, but ranked second in the United States, producing 22% of the nation’s rice crop. From 1991 to 1996, harvested rice acreage expanded 43%—from 350,000 to 500,000 acres, making up 5.8% of the total acreage for all harvested crops in California. Most rice is grown in the northern Sacramento Valley in the counties of Colusa, Butte, Glenn, and Sutter.

Pesticide use for rice in 1996.

Measures of pesticide use	Total for rice	Percentage for all crops
Pounds applied	5,110,306	2.94%
Number of applications	24,119	1.48%
Acres treated (cumulative)	1,612,910	3.07%



Arthropod Management – The rice water weevil is the major arthropod pest of rice. Its larvae damage rice by pruning the roots of developing rice seedlings. Carbofuran was the only registered pesticide for its control. Use of carbofuran peaked in 1993 and declined from 1993 through 1996. Use of carbofuran for rice water weevil control is scheduled to be phased out due to the Food Quality Protection Act and potential wildlife toxicity concerns.

The tadpole shrimp, a widespread pest related to marine shrimp, chews on rice seedlings and uproots them while digging. Copper sulfate (pentahydrate) controls tadpole shrimp and algae, although opinions of scientists vary as to which use is more common. In 1996, over 94% of the copper sulfate used on all crops was used on rice (as measured by acres treated). From 1991 through 1996, use of copper sulfate generally increased.

From 1991 through 1996, rice growers applied less methyl parathion to control tadpole shrimp, due in part to restricted permit conditions required by DPR's Rice Pesticides Program, based on aquatic toxicity concerns.

Weed Management – Several species of annual and perennial weeds infest rice fields. The most problematic weeds are grasses—barnyardgrass and the watergrasses. Because rice is a member of the grass family, herbicides that target grasses can also slow growth of rice, contributing to yield loss.

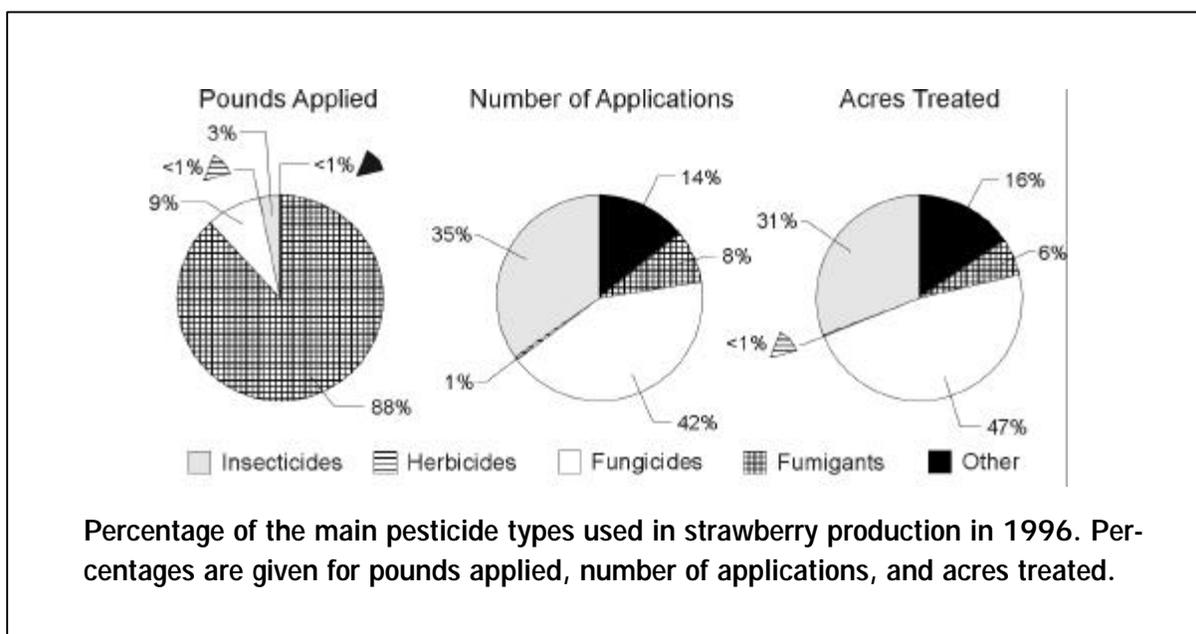
Molinate controls the grass weeds, but its use from 1993 through 1996 declined because it provides no control of broadleaves or sedges, which are controlled by bensulfuron methyl. Weed resistance to bensulfuron methyl led to its decreased use from 1994 through 1996 and an increase in use of several alternative herbicides for broadleaves or sedges, such as thiobencarb, propanil, and the phenoxyes, MCPA and 2,4-D.

Strawberry Production

Strawberry crops are grown in California's central and southern coastal areas. Although strawberries are perennial plants, they are primarily grown as an annual crop for the fresh market. In 1996, strawberry acreage was 25,200 or 0.3% of all bearing cropland in California. About 84% of the nation's strawberries are grown in California.

Pesticide use for strawberry in 1996.

Measures of pesticide use	Total for strawberry	Percentage for all crops
Pounds applied	7,241,584	4.16%
Number of applications	24,822	1.52%
Acres treated (cumulative)	594,549	1.13%



Insect and Mite Management – Lygus bugs and two-spotted spider mites are the most serious arthropod pest of strawberry. Cyclamen mites, aphids, corn earworm, and root weevils are pests only in some areas.

Malathion was the most commonly used insecticide on strawberry, effectively controlling lygus bug with only moderate toxicity to beneficial insects. Alternative compounds such as naled and methomyl, which are disruptive to beneficial insects, are less commonly used. Growers use naled and methomyl only when malathion fails to control lygus bug, or when large numbers of the bugs suddenly infest fields.

Avermectin and oil are used primarily during the winter for two-spotted spider mite control. Avermectin use has increased, probably because resistance to the miticides dicofol and fenbutatin-oxide have increased.

Weed Management – Because strawberry plants are sensitive to most herbicides, growers depend upon pre-plant soil fumigation for weed control, primarily methyl bromide combined with chloropicrin. However, some growers use metam-sodium in rotation with methyl bromide/chloropicrin formulations to control weeds. Metam-sodium is applied before planting to control weeds that germinate under clear plastic mulch.

Disease Management – One of the limiting factors in strawberry fruit and nursery production is the replant problem, a disorder which is still not clearly understood but which is thought to be a complex of fungal disease and nematodes. Gray mold (*Botrytis* fruit rot) is the major disease of strawberry fruit in all production areas of the state. *Phytophthora* spp., *Verticillium dahliae*, and *Rhizoctonia* spp. are the major soil-borne diseases of strawberry. Other major strawberry diseases include powdery mildew, common leaf spot, and anthracnose.

Growers apply a mixture of methyl bromide and chloropicrin once each year before planting to control the replant disorder, soil-borne diseases, weeds, and nematodes. Mixtures of these two fumigants combine the greater soil penetration of methyl bromide and higher fungal toxicity of chloropicrin. For most soil fumigation in other crops, chloropicrin is used primarily as a warning agent with methyl bromide and accounts for only 1–5% of the total fumigant. For strawberry, a high ratio of chloropicrin controls soil diseases, so strawberry fumigations usually contain 20 to 50% chloropicrin. In 1996, 30% of methyl bromide and 71% of chloropicrin applied to California crops (as measured in pounds) were to strawberries.

Gray mold penetrates strawberry flowers and invades the fruit later in the season. Captan is used to prevent gray mold; its use increased dramatically each year from 1991 to 1996, probably because the frequent rains in 1995 promoted gray mold growth along California's coast and in the San Joaquin Valley. In addition, in 1994 the U.S. EPA reduced the interval between application of captan and harvest, thereby allowing captan to better fit into production schedules. Iprodione and vinclozolin are used as a last resort to control gray mold because of label restrictions and gray mold resistance to these compounds. To date, no fungal resistance has been reported for captan. Rotating use of different pesticides is important in slowing resistance.

Powdery mildew infects strawberry flowers and fruit; sulfur and myclobutanil are commonly used to combat this fungal disease. Use of sulfur declined after 1991 when myclobutanil was introduced, and because sulfur is phytotoxic above 75°F. Use of myclobutanil on strawberry was permitted from 1992 through 1996 by Section 18 emergency exemption; increased use of myclobutanil in 1995 and 1996 may have been due to weather conditions that promoted the development of powdery mildew. However, sulfur is currently rotated with myclobutanil to prevent powdery mildew resistance to myclobutanil.

Anthracnose and *Mucor* fruit rot are controlled by preventive treatments of captan and benomyl.

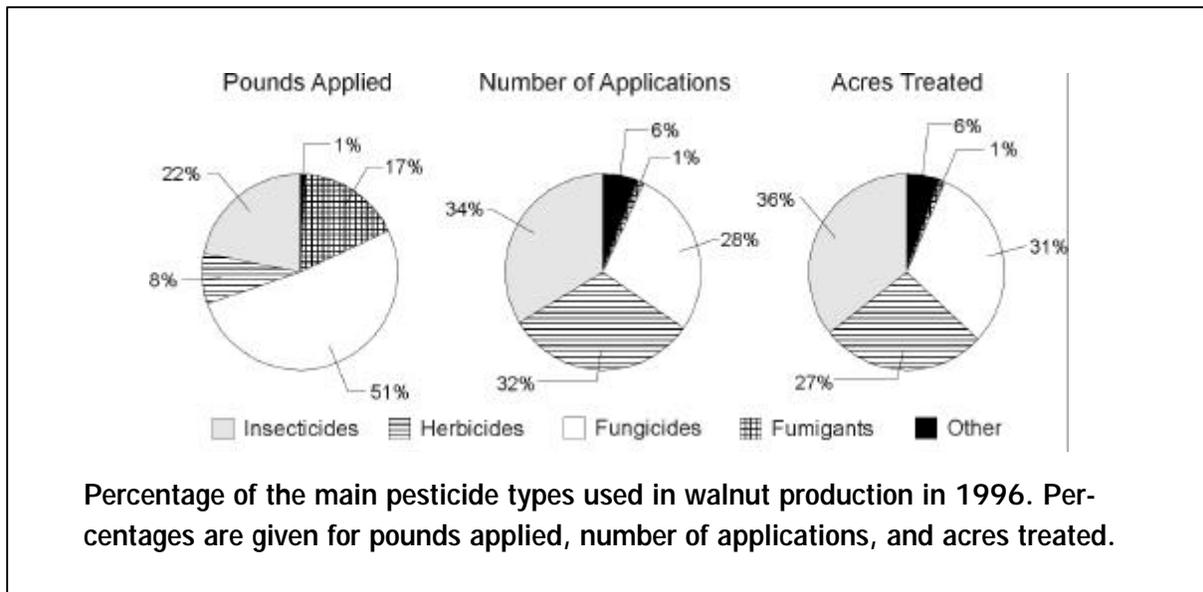
Walnut Production

California produces 99% of the walnuts grown in the United States and 38% worldwide. In 1996 there were 169,000 acres of bearing walnut trees in California, or 2% of the total acreage for all crops harvested in California. The walnut industry began in Southern California in the late 1800s, but one hundred years later, 88% of the walnut acreage stretches through the Sacramento and San Joaquin valleys. The remaining 12% of the acreage is located in the coastal valleys and Sierra Foothills.

Over 15 varieties of walnut are grown commercially in California, ranging in susceptibility to major pests. Thirty-five percent of all walnuts are sold in the shell, increasing the need for unstained shells with light-colored kernels.

Pesticide use for walnut in 1996.

Measures of pesticide use	Total for walnut	Percentage for all crops
Pounds applied	2,958,342	1.70%
Number of applications	36,682	2.25%
Acres treated (cumulative)	1,220,195	2.32%



Insect Management – Codling moth is the key insect pest, requiring one to three treatments annually on susceptible varieties. The larvae bore into nuts and destroy the kernels. Infested nuts also encourage infestation of navel orange worm. If left uncontrolled, damage by codling moth can exceed 40%.

Growers use pheromone traps to monitor codling moth populations to better time treatments. Chlorpyrifos and azinphos methyl are the most commonly used insecticides. Chlorpyrifos is also

applied later in the season for scale and walnut husk fly, and effectively controls azinphos methyl-resistant codling moth. Use of chlorpyrifos peaked in 1992 and 1993, then generally decreased from 1993 to 1996, possibly because use of phosmet and esfenvalerate increased. Phosmet first became registered on walnut in 1996 and was widely used. Esfenvalerate disrupts mite predators and is consequently used late in the season, when outbreaks of mites are better tolerated.

Diflubenzuron, a new insect growth regulator that targets codling moth, was first registered for walnut in 1994. Another reduced-risk material, tebufenozide, is a selective insecticide for codling moth registered in 1995. Both were widely used in 1995, but use fell in 1996, possibly due to cost. Both materials require good coverage for adequate control, which is often impractical with big trees. Also, many growers may have turned to phosmet once it became available in 1996.

Weed Management – Glyphosate and oxyfluorfen are the main herbicides used in walnut orchards. Glyphosate is a broad-spectrum, inexpensive herbicide that controls all annual grasses, most annual broadleaves, and some perennial grasses—bermudagrass, dallisgrass, and johnsongrass—that other herbicides do not control. Oxyfluorfen complements glyphosate by controlling cheeseweed, clovers, filaree, and knotweed as they germinate. Use of glyphosate and oxyfluorfen generally increased from 1991 to 1996.

Disease Management – Walnut blight, a bacterial disease, can seriously damage leaves and walnut kernels. Late spring rains promote the spread of walnut blight in humid coastal areas and parts of the Sacramento Valley. Growers primarily use copper-based fungicides such as copper hydroxide for control. From 1991 to 1996 use of copper hydroxide generally increased, and by 1996 more than 30% of copper hydroxide applied to all crops (as measured in pounds) was used on walnut. In areas of copper-resistant blight bacteria, maneb has gained favor. Use of maneb, first registered for walnut in 1994, rose every year since. In 1996, nearly 16% of the maneb applied to all crops (as measured in pounds) was used on walnut.

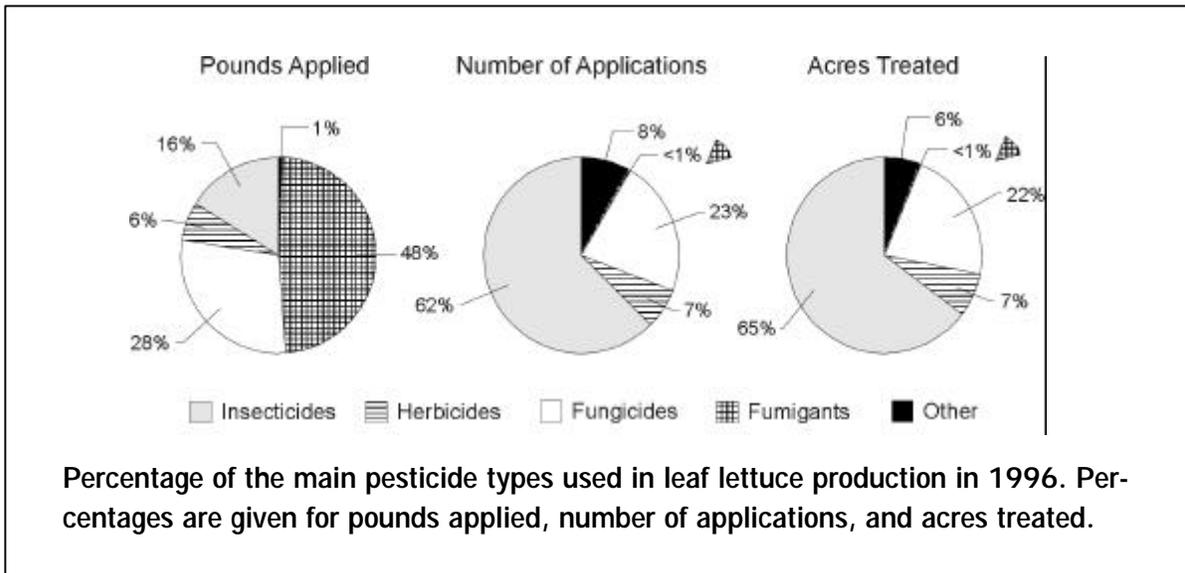
Leaf Lettuce Production

Leaf lettuce varieties grown in California include romaine (cos), greenleaf, redleaf, and butter lettuce. Romaine, greenleaf and redleaf lettuce grow in an upright bunching form, with the leaves folded around the outside of the plant. Romaine tends to be sweeter than other types of leaf lettuce and is the predominant leaf type grown. Butter lettuce varieties form loose heads with their leaves folded on top of each other. Leaf lettuce is grown in the same regions as head lettuce except that leaf lettuce is not usually grown in the San Joaquin Valley.

The pest management problems and practices associated with the cultivation of both head (iceberg) and leaf lettuce varieties are nearly the same (see *Head Lettuce Production*).

Pesticide use for leaf lettuce in 1996.

Measures of pesticide use	Total for leaf lettuce	Percentage for all crops
Pounds applied	764,345	0.44%
Number of applications	74,259	4.56%
Acres treated (cumulative)	663,400	1.26%



Insect Management – Green peach aphid, potato aphid, leafminers, beet armyworm, cabbage looper, corn earworm, cutworms, and silverleaf whiteflies are the insect pests most likely to impact lettuce production.

Cypermethrin, the dominant insecticide used in head lettuce production, is not registered for use on leaf lettuce. Permethrin is the dominant insecticide used in leaf lettuce and was applied for nearly the same purposes as cypermethrin and permethrin in head lettuce— primarily to control

the larvae of moths and butterflies and adult leafminers. Permethrin use in leaf lettuce increased from 1991 to 1996.

Imidacloprid was used more in leaf than in head lettuce production, and its use increased more for leaf than head lettuce. It was used primarily for silverleaf whitefly and aphid control. Methomyl and dimethoate use patterns were similar for both head and leaf lettuce.

Weed Management – Growers manage weeds in leaf lettuce fields through the use of a combination of herbicides, cultivation, and hand weeding. The patterns of herbicide use were about the same for both types of lettuce. A wide variety of weeds—annuals and perennials, broadleaf weeds and grasses—can cause economic loss to lettuce growers, but annual broadleaf weeds present the biggest problem. Propyzamide is by far the main herbicide used in all production areas. Other herbicides applied to lettuce fields include bensulide, benefin, and glyphosate. Metam-sodium is primarily used to kill weed seeds.

Disease Management – Lettuce is susceptible to several diseases including anthracnose, bacterial leaf spot, bottom rot, corky root, downy mildew, and lettuce drop. Downy mildew is present throughout California. The patterns of fungicide use were nearly the same for both leaf and head lettuce. Maneb was the dominant fungicide used in 1996 for lettuce, followed by use of fosetyl-al. Maneb, fosetyl-al, and metalaxyl are used for downy mildew control.

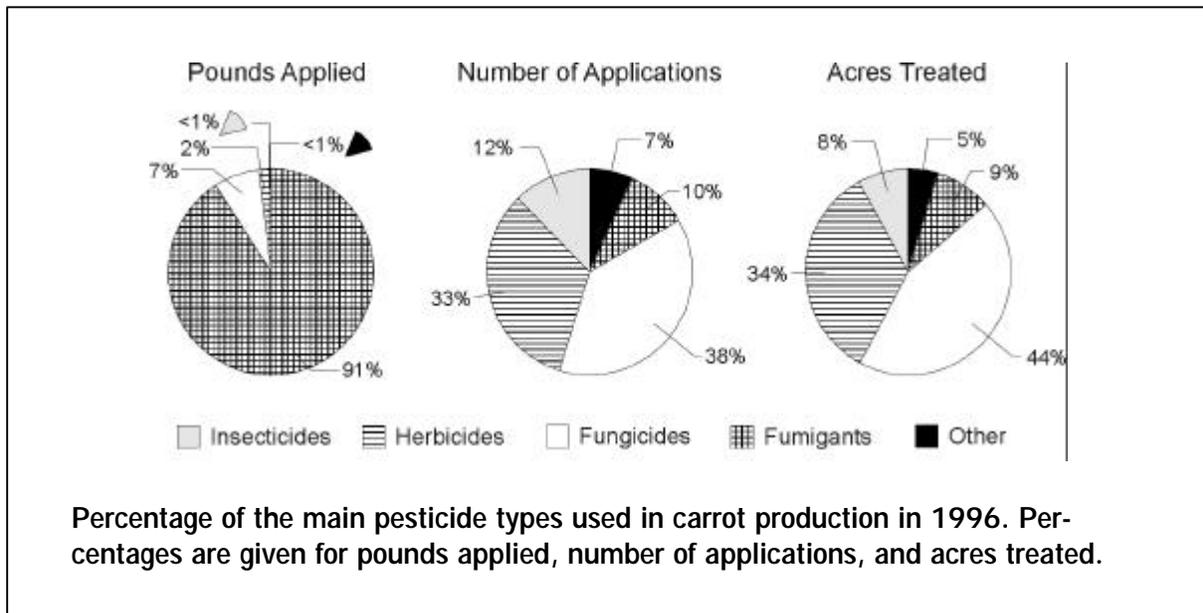
Soil Management – Methyl bromide was used for root-knot nematode and soil pathogens such as corky root.

Carrot Production

In 1996, California ranked first in carrot production in the United States, producing 59% of the nation's carrot crop. From 1991 to 1996, harvested carrot acreage rose from 56,000 to 70,300 acres, a 26% increase. In 1996, carrot acreage made up 0.8% of all productive acreage in California. Carrots are grown primarily in Kern, Imperial, and Monterey counties.

Pesticide use for carrot in 1996.

Measures of pesticide use	Total for carrot	Percentage for all crops
Pounds applied	6,309,200	3.63%
Number of applications	7,551	0.46%
Acres treated (cumulative)	405,665	0.77%



Insect management – Insects are generally not a major problem in carrot production and consequently little insecticide is used. Growers manage most of the insect pests using cultural and biological practices.

The green peach aphid, the most difficult insect to control in carrot production, vectors more plant viruses than any other aphid, transmitting over 100 different viral diseases. The cotton/melon aphid, also a vector of viral diseases, can build up in carrot fields adjacent to cotton or melon fields. Natural enemies often keep aphid populations from exploding, but growers also use the insecticides esfenvalerate, diazinon, methomyl, and malathion. Some or all of these insecticides may be used to control other occasional pests such as whiteflies or the pale-striped flea beetle. Use of esfenvalerate increased from 1991 through 1996.

Weed management – A number of weed species compete with carrot plants, especially during the seedling stage. The principal weeds include broadleaves, small grasses, and yellow nutsedge. Linuron, a postemergence herbicide, provides good control of many of these. Use of linuron increased dramatically from 1992 to 1993, and then fell to previous levels from 1994 through 1996. Trifluralin is mainly effective against grasses and a few broadleaf weeds, and was used by carrot growers to complement linuron. Use of trifluralin remained fairly steady from 1991 through 1996.

Disease management – The two most serious diseases of carrot are *Alternaria* leaf blight and carrot cavity spot. *Alternaria* leaf blight potentially weakens leaves so that they break off when gripped by a mechanical harvester, leaving the roots (the portion of economic importance) in the ground. Iprodione effectively controls *Alternaria* leaf blight, although many growers use cultural controls instead. Use of iprodione steadily increased from 1991 through 1995, and increased sharply in 1996. This was a rainy year in many areas, which may have intensified disease pressure.

Carrot cavity spot causes lesions on the root. Metalaxyl is the only effective fungicide that manages carrot cavity spot. Its use gradually increased from 1991 through 1996.

Soil management – Root-knot nematodes are the major soil-borne pest in all carrot-growing areas of California. Sandy loam soils that are ideal for carrot production are also ideal for root-knot nematodes. Besides causing stubbing and forking, numerous galls form on the taproot and feeder roots. Stubby root nematodes and the needle nematode also cause forking and stubbing of roots. The galling and dieback result in unmarketable carrot roots. *Pythium* spp. and *Rhizoctonia solani* are the most common soil-borne fungi that infect carrots. These fungi may also reduce marketability of carrots.

The main fumigants used are metam-sodium and 1,3-dichloropropene (1,3-D). In 1990, DPR suspended the use of 1,3-D in California, but reinstated limited use in December 1994. Use of metam-sodium increased from 1991 through 1996. In 1996, use of metam-sodium (as measured in pounds) made up 80% of all fumigant use, and almost 60% of all pesticide use on carrot. Although 1,3-D is a more effective nematicide than metam-sodium, its use has not yet returned to pre-suspension levels, although approximately one-third of all 1,3-D used on all crops is used to fumigate carrot fields.

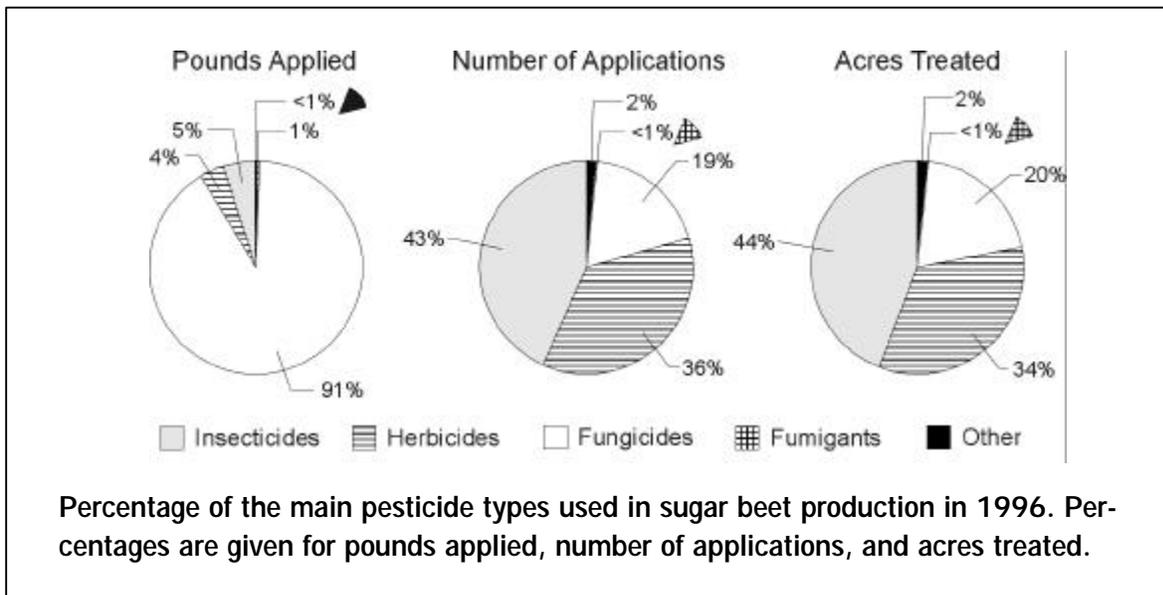
Sugar Beet Production

The roots of sugar beets provide a source of sucrose, which is processed into sugar. About 40% of the world’s sugar comes from sugar beets and the remaining 60% from sugarcane.

California’s sugar beet acreage has declined since the late 1980s due to urbanization, conversion of open land to trees and vines, low sugar prices, crop disease, and the increasing popularity of high fructose corn syrup as a sweetener. Acreage planted to sugar beets dropped from about 200,000 acres to about 96,000 acres in 1996. Only four of the eight sugar processing facilities of the 1980s are still in operation.

Pesticide use for sugar beet in 1996.

Measures of pesticide use	Total for sugar beet	Percentage for all crops
Pounds applied	16,158,300	9.29%
Number of applications	41,200	2.53%
Acres treated (cumulative)	2,520,843	4.8%



Pesticide use on sugar beets declined steadily from 1991 to 1996, primarily due to the drop in acreage. From 1991 to 1996, pesticide use decreased 46%, from 8.3 million to 4.5 million pounds, and acres treated declined by 48%, from about 158,000 to 82,000, or less than 1% of the total crop acreage in California.

Sugar beets are grown in various locations throughout California, mainly the Imperial, Sacramento and San Joaquin valleys, the Klamath Basin, and the Hollister–Gilroy area of San Benito County. Sugar beets are planted in nearly every month somewhere in the state. Harvest occurs from late March until the rains and wet soil finally stop harvest, usually in November.

The diversity of planting and harvest dates directly impacts the types of pests and severity of diseases that affect the crop.

Insect and Mite Management – The primary pests of sugar beet are aphids, armyworms, leafhoppers, and spider mites.

Aphids—Two species of aphid commonly infest sugar beets—the green peach and black bean aphid. The green peach aphid has caused damage to sugar beets in California for over 50 years; the black bean aphid is a relatively new pest of sugar beets in the state. These aphids transmit damaging viral diseases that can cause up to 75% reduction in yield.

Armyworms—Beet armyworm can severely defoliate the sugar beet plant and reduce crop yield. Efforts to reduce armyworm populations can result in spider mite and leafhopper outbreaks, because armyworm control efforts can eliminate beneficial insects. Armyworm outbreaks are most severe in the San Joaquin Valley in July and August. The cost of armyworm control can comprise as much as 10% of overall crop production cost.

Leafhoppers—Empoasca leafhoppers are small, wedge-shaped insects that cause sugar beet yield losses when their populations are high. These insects feed on the plant sap and inject a toxin that causes yellowing. Insect feeding causes a symptom called hopperburn that can progress from mild stippling of leaves to leaf loss. The beet leafhopper is another leafhopper species that usually does not have as high population levels. However, beet leafhopper does carry the disease curly top, which infects sugar beets. The beet leafhopper lives during the winter on weeds in the foothills. When the weeds start to die in the spring, the leafhoppers move to sugar beet fields and infect young plants. The beet leafhopper can be managed by spraying foothill weeds that harbor the insects with malathion. Also, phorate is applied at sugar beet planting for beet leafhopper control.

Mites—Spider mites caused serious problems in sugar beets in 1995 and 1996, but are not normally major pests of this crop. Mites feed on the plant leaves and cause defoliation. Sulfur is used to control mites as they have become resistant to most other miticides.

Chlorpyrifos and methomyl are the primary insecticides used in sugar beets. Chlorpyrifos use dropped at rates about equal to the decline in sugar beet acres. Most chlorpyrifos use (90%) is directed at armyworm control, although this pesticide also controls aphids and leafhoppers. Chlorpyrifos and methomyl are used interchangeably to control armyworm. Growers report variable success with the use of chlorpyrifos for armyworm control from year to year, and its effectiveness is believed to be declining. Whether this decline is due to a change in the habits of the larvae, or a build-up of insect resistance is not known. Methomyl use remained fairly constant; the areas of methomyl use did not experience a decline in sugar beet acreage. Methomyl is primarily used for armyworm control.

Weed Management – The sugar beet plant is a poor competitor against weeds. Uncontrolled weeds that emerge with the crop typically cause from 50 to 90 percent yield loss. High levels of weed control are essential for profitable sugar beet production. Sugar beets are a relatively long-

duration crop in comparison with many other row crops. This means that weeds must be controlled for relatively long periods, which may span two or three seasons.

Desmedipham, phenmedipham, ethofumesate, EPTC, and sethoxydim are commonly used herbicides in sugar beet fields. Glyphosate, less commonly used, kills emerged weeds before sugar beets are planted.

Disease Management – Powdery mildew is one of the primary diseases of sugar beets. If powdery mildew is not controlled, sugar yield may decrease by as much as 40%. Sulfur is the primary pesticide used throughout the state to control powdery mildew on sugar beets. Sulfur is used not only because it is effective against powdery mildew and mites, but also because it is inexpensive. Sulfur use declined with the drop in sugar beet acreage.

Curly top is another widespread disease of sugar beets that can cause yield reductions. It is caused by a virus that is carried from plant to plant by the beet leafhopper. The disease is controlled by controlling this leafhopper (see *Insect Management* above).

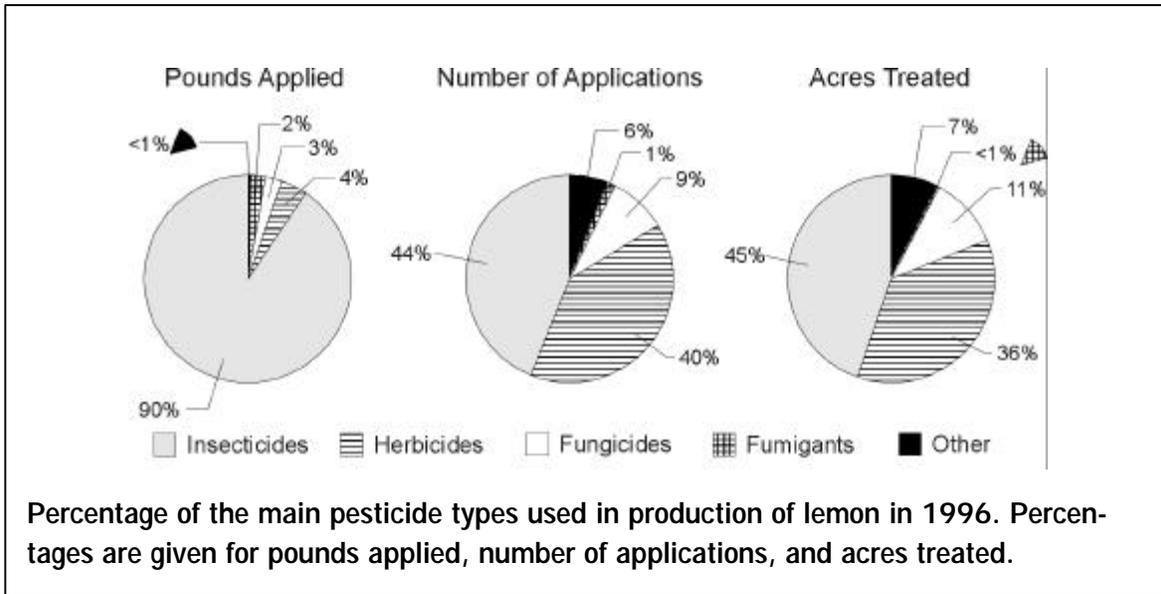
Chlorpyrifos is used to control the aphids that spread the viral diseases western beet yellows luteovirus, and beet yellows closterovirus. These diseases, along with others, are known as the yellows complex. Infection with the yellows complex early in the growth of the beet can result in a 50 to 75% reduction in yield.

Lemon Production

Lemons are grown in four major areas of California: the San Joaquin Valley, the coastal intermediate district from southern Santa Barbara through San Diego counties, eastern Riverside county, and the desert valleys of southern California. California grows 80% of the nation's lemons. In 1996, more than 46,000 acres of bearing lemons were grown, or 0.5% of all bearing acreage in California. Pests, and pest management practices, are similar for lemon and orange production.

Pesticide use for lemon in 1996.

Measures of pesticide use	Total for lemon	Percentage for all crops
Pounds applied	2,478,655	1.42%
Number of applications	12,060	0.74%
Acres treated (cumulative)	514,891	0.98%



Insect, Mite, and Snail Management – In most areas, California red scale and citrus thrips are the primary insect pests of lemon and are described in the Orange Production, page 39. Lemon and orange crops share the same pests in most areas of the state. However, in the coastal intermediate district and eastern Riverside county where lemon acreage is greater than orange acreage, the pest complexes differ slightly. Here, other pests of concern are citrus bud mite, silver mite, broad mite, and the brown garden snail.

Mites—Citrus bud mite is the primary pest for lemon in the coastal region, but other mite species, such as the silver mite and bud mite, occasionally cause problems as well. Citrus bud mites feed inside flower buds, which can distort fruit or reduce yield.

Oils are the primary insecticide used for lemon. Probably most of the use is for California red scale, but oils are also used to control mites. Use of oils increased, especially in number of applications and acres treated, but not as dramatically as for orange. The increased use of oils is probably because other pesticides are becoming less effective due to pest resistance, and oils are less disruptive to natural enemies. Avermectin and sulfur are also used for mite control for lemon; their use was higher for lemon than for orange possibly because of greater mite problems on lemon.

Snails—The brown garden snail is primarily a pest in Southern California where most lemons are grown. Snails feed on ripening fruit and young tree leaves. The primary pesticides used for snails are metaldehyde and basic copper sulfate. Metaldehyde is the third most used pesticide for lemon by number of applications and acres treated. Copper sulfate is used as a paste applied as bands around the tree trunk, which prevents snails from reaching the tree canopy when they try to crawl up.

Weed Management – Weed problems and herbicide use are similar in lemon and orange groves (see *Weed Management* for orange, page 40). Glyphosate is the most widely used herbicide, controlling winter and summer annual weeds. Diuron and simazine are used when growers require more long-term weed control.

Disease Management – Disease problems differ in the various lemon-growing regions, but the fungicides used in all areas are similar. Copper hydroxide and copper sulfate (basic) are commonly applied to prevent brown rot, gummosis, citrus blast, and Septoria spot. Applications of both fungicides increased during 1995 and 1996 as a result of unusually high rainfall.

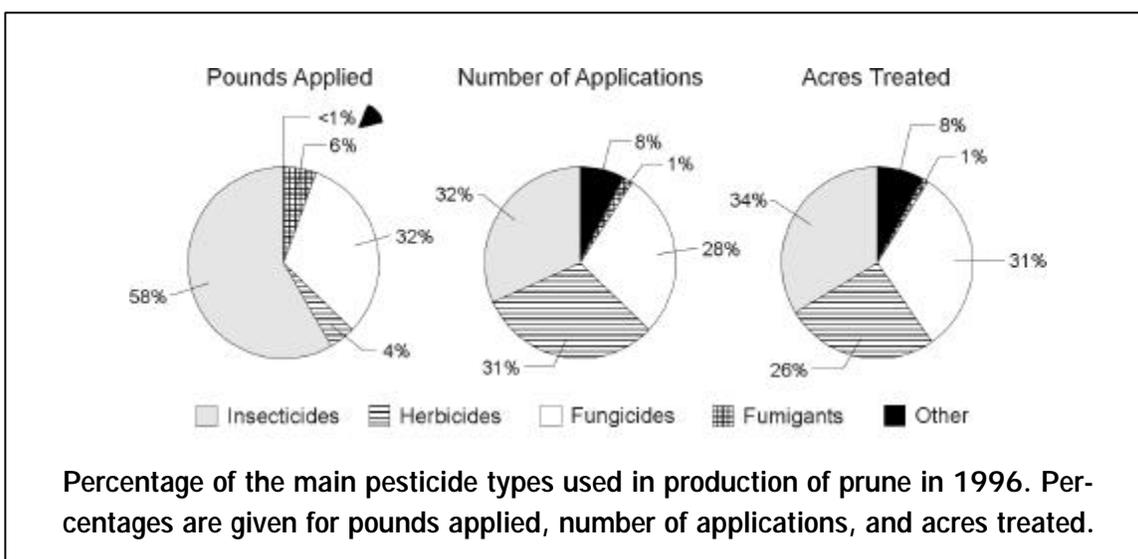
Both methyl bromide and metam-sodium are used in lemon groves; metam-sodium was applied more times and to more acres for lemon. When growers replant old citrus groves, they fumigate the soil with methyl bromide before planting. Fumigation kills Armillaria root rot and prevents the replant problem, which is a set of unknown soil problems that cause orchards to decline in vigor soon after they are planted. Increased use of methyl bromide and metam-sodium from 1993 through 1996 corresponds with the replanting of citrus groves following a severe frost in 1992.

Prune Production

The majority of the state's prunes are grown in the Sacramento Valley. Other production areas include the San Joaquin Valley (primarily Tulare and Fresno counties), and the coastal areas. Prune acreage increased every year in California from 1991 to 1996; by 1996 there were 80,200 acres of prunes harvested in the state, making up 0.9% of all harvested acreage in California.

Pesticide use for prune in 1996.

Measures of pesticide use	Total for prune	Percentage for all crops
Pounds applied	2,478,655	1.42%
Number of applications	12,060	0.74%
Acres treated (cumulative)	514,891	0.98%



Insect and Mite Management – The most serious pests of prune include the peach twig borer, leafrollers, San Jose scale, mealy plum aphid, leaf curl plum aphid, and mites. The peach twig borer and leafrollers damage the fruit, while San Jose scale kills limbs or the entire tree. Both aphid species retard tree growth and reduce sugar content of the fruit. Honeydew secreted by the aphids drops onto the fruit and causes it to split. Mites reduce fruit yield and quality. Historically, prune trees have been sprayed with an organophosphate (OP) pesticide combined with a narrow range oil during the dormant season (from about November through February). The dormant application controls most of the major insect pests. However, in order to protect surface water from possible contamination by OPs, there has been an effort to change this practice. The use of dormant oils for prune is nearly the same as for almond. (For more on dormant sprays see the *Almond Production*, page 25).

Peach twig borer is a key pest for prune. Dormant application of oils and OPs, especially diazinon, have been the primary means of controlling peach twig borer. Oils are the dominant insecticides for prune, followed by diazinon. Other controls for peach twig borer include pyrethroids, primarily esfenvalerate in the dormant season, in-season OP and pyrethroid pesticide applications, and applications of *Bacillus thuringiensis* in the spring. However, pyrethroids, especially when used in season, may disrupt biological control of mites.

Traditionally, aphids have not been considered serious pests of prune because dormant organophosphate sprays destroy overwintering eggs. However, under reduced risk programs where dormant organophosphates have been eliminated, aphids are now the key pests and may require in-season OP or pyrethroid pesticide intervention.

Some mites are also controlled by dormant oil applications, but other mites must often be controlled by miticides during the season. The primary miticide used, and the third most common insecticide used in 1996, was fenbutatin-oxide.

Weed Management – Weed management is similar to that described for the almond crop (see page 28). Glyphosate, oxyfluorfen, and paraquat are the herbicides most commonly used in prune orchards. Glyphosate is applied during the dormant, pre- or post-bloom season; it is used for a broad range of weed species. It is the best material available for perennial weed control.

Oxyfluorfen is a selective broadleaf herbicide that is effective as a pre- and postemergence material. It is particularly useful when combined with glyphosate. The combination increases efficacy on various broadleaf weed species.

Paraquat is a nonselective postemergence material used for quick burn-down of most weed species. It is most effective when used on early spring or winter growth of annual grass species in combination with preemergence herbicides.

Disease Management – The most serious diseases of prunes are brown rot and prune russet scab, which both affect the fruit. Armillaria root rot, Phytophthora root and crown rot, and bacterial canker may kill limbs and trees. Rust attacks leaves and can reduce fruit yield.

Sulfur and iprodione are the main fungicides used in prunes, followed by captan and copper hydroxide. Sulfur is the material most often used for prune rust. Iprodione (often used with oil) is effective against brown rot and rust. Sulfur and iprodione uses generally increased from 1991 through 1996. Rainfall in 1993–1996 was greater than 1991–1992, and growers adopted preventive fungicide spray programs as a hedge against disease occurrence. Copper products are used against bacterial canker, and captan against russet scab.

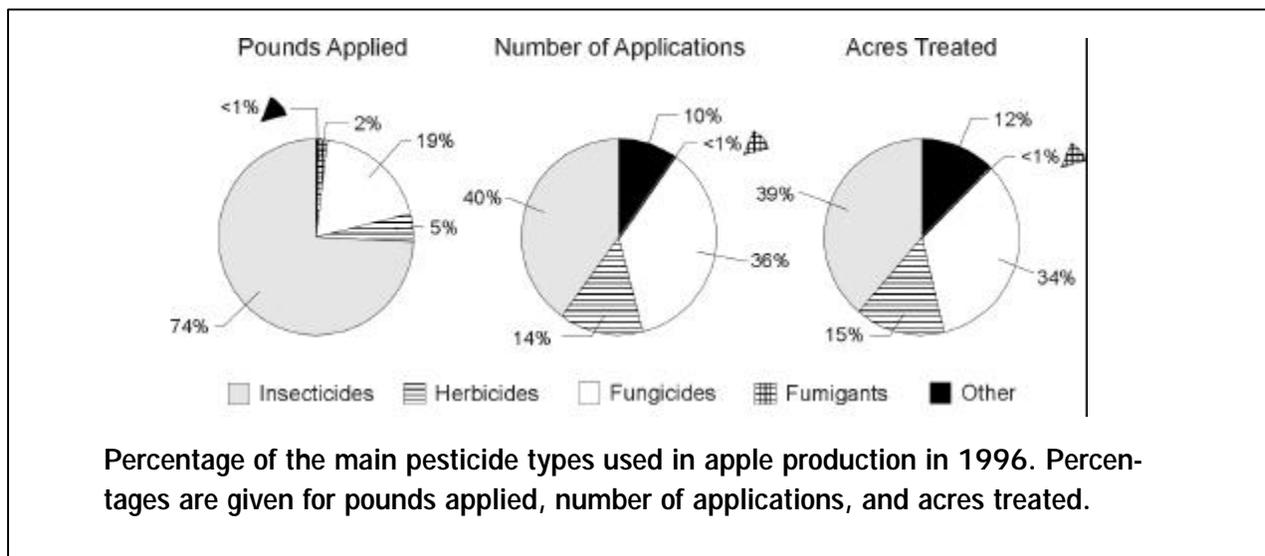
Soil Management – Methyl bromide is used as a soil fumigant to control pests before new trees are planted. Target pests include bacterial canker, Armillaria root rot, and nematodes. Methyl bromide use did not increase from 1991 through 1996 despite the fact that new plantings of prune trees increased almost every year. Non-bearing prune acreage was more than three times greater in 1996 than in 1991.

Apple Production

California ranks third in apple production nationally, with more than 36,000 acres harvested in 1996, or 0.4% of the total acreage for all crops harvested in California. The top apple-growing counties in 1996 were Kern, San Joaquin, Fresno, Sonoma, Santa Cruz, and Madera. Since the 1980s, the main apple-growing area has shifted from the Central and North coasts to the San Joaquin Valley. Presently, 60% of the apples harvested in California are sold as fresh market fruit and 40% for apple sauce, juice, and other processed products.

Pesticide use for apple in 1996.

Measures of pesticide use	Total for apple	Percentage for all crops
Pounds applied	1,464,941	0.84%
Number of applications	18,612	1.14%
Acres treated (cumulative)	490,835	0.93%



Insect and Mite Management – Codling moth is the key pest of apple, but leafrollers, scale insects, and mites also cause major damage. Secondary pests such as leafhoppers and rosy apple aphid can also injure trees and reduce yield.

Codling moth—The larvae of codling moth bore directly into fruit, potentially damaging 60% of the crop. Azinphos methyl is the material of choice for codling moth because it is less disruptive to natural enemies than most other organophosphate (OP) insecticides. Phosmet, another widely used OP insecticide, controls codling moth and other lepidopteran pests. Chlorpyrifos targets codling moth and leafrollers, but also controls scale insects and rosy apple aphid. From 1991 through 1996, use of azinphos methyl gradually diminished as use of chlorpyrifos increased, due to widespread resistance of codling moth to azinphos methyl. Codling moths resistant to azinphos methyl are twice as susceptible to chlorpyrifos, a phenomenon known as negative

cross-resistance. Methyl parathion is another organophosphate to which azinphos methyl-resistant codling moths show high susceptibility. Because of this, use of methyl parathion increased between 1991 and 1996.

Two reduced-risk strategies for managing codling moth have steadily gained favor. Narrow-range oil used in early summer kills eggs of codling moth, giving partial control. Also, more and more growers incorporate mating disruption with pheromones into their pest management program.

San Jose scale—San Jose scale, the most damaging scale on apple, sucks plant juices from nearly all parts of the tree and injects a toxin. Severe infestations can lead to reduction of fruit yield, and weaken or even kill trees. Most growers manage San Jose scale during the dormant or delayed dormant period (just as the leaf buds begin to open slightly) by applying oil either alone or combined with diazinon or chlorpyrifos.

Mites—Mites damage apple by feeding on the epidermis of leaves, potentially causing defoliation, and possible yield reduction. Apple growers primarily use dormant oils to manage mites, although sulfur or fenbutatin-oxide are other miticides used. During the blossoming and leafing-out period, narrow-range oil controls immatures of mites. During summer, oils can cause russetting and are therefore difficult to use in hot-weather areas. When used before or after harvest, oils control mites; however, oils can cause fruit spotting when used within one week of harvest.

The use of oils rose from 1991 through 1996, probably because they fit in well with IPM programs. Oils are not persistent, so natural enemies are only minimally affected. Also, researchers have observed no resistance of insects or mites to oils, and with increasing resistance of mites to many miticides, oils are a preferred reduced-risk material.

Weed Management – Herbicides are used to clean up orchard floors and prevent frost damage. Elimination of weeds is especially important in apple orchards with newly planted trees, since weeds compete for nutrients and water. This competition can contribute to poor growth and susceptibility of young trees to pests and disease.

Apple growers select herbicides based on cost and the weed species growing in their orchard. Weeds commonly found in orchards include annual grasses and broadleaves, and several troublesome perennials. Glyphosate controls most spring and summer weeds, with the exception of the broadleaves clover, filaree, and cheeseweed, and the perennials dandelion, field bindweed, and nutsedge. Glyphosate is applied at low rates several times during the growing season, but continued use can shift the weed population toward glyphosate-tolerant species. Use of glyphosate increased from 1991 through 1996, possibly because it is inexpensive, and when mixed with other herbicides such as oxyfluorfen, growers control almost all weed species in their orchard. By using glyphosate, growers avoid the acute toxicity issues connected with paraquat, which is a restricted-use material.

Disease Management – Major diseases that attack apple include fireblight, apple scab, and powdery mildew. Fireblight, a bacterial disease, attacks blossom clusters in the spring, causing

them to wilt. In the Sacramento Valley and Delta where winters are often mild, dormant oil applications encourage the trees to produce compact rather than straggly blooms, which lowers the risk of fireblight infection. From 1991 through 1996, use of the fireblight antibiotic streptomycin sulfate increased as use of the related streptomycin, a nitrate complex, lost favor due to resistance.

Apple scab, a fungal disease, spots and scabs the fruit. Another serious fungal disease of apple, powdery mildew, coats the leaves and shoots with a white powdery growth and can stunt and distort young growth. Myclobutanil, a systemic fungicide used on apple for scab and powdery mildew, was used most during the wet years of 1995 and 1996. Use of myclobutanil more than doubled from 1991 through 1996. Increased use of mancozeb was correlated with the threat of scab during the rainy years of 1995 and 1996. Use of lime-sulfur and sulfur to control apple scab declined because, unlike mancozeb, they cause phytotoxicity and russetting of fruit.

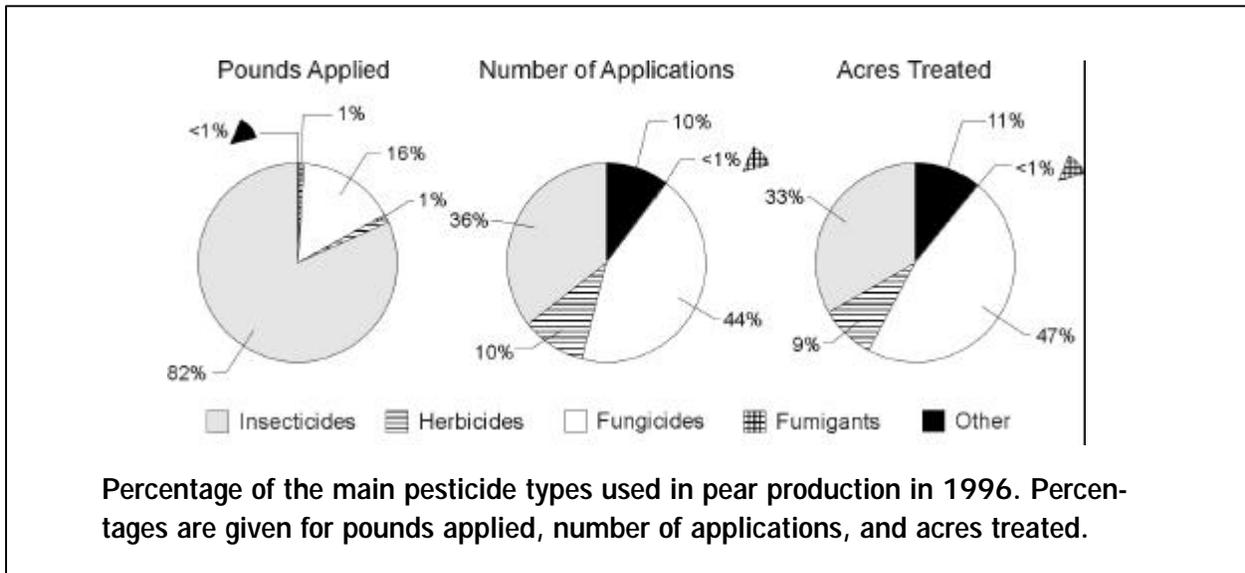
Pear Production

In 1996, California ranked second in pear production nationally, producing nearly 39% of the nation's crop. Almost 25,000 acres of pear are grown in the Central Valley, North Coast and Sierra Foothills, primarily in the counties of Sacramento, Mendocino, Lake, and Tulare. Pear orchards make up less than 0.3% of all bearing acreage in California.

The Bartlett pear is the main variety grown, although since the 1980s other varieties have steadily become more popular. Approximately 25% of the fruit is sold to the fresh market and 75% for processing. Sixty percent of all Bartlett pears grown nationwide are from California.

Pesticide use for pear in 1996.

Measures of pesticide use	Total for pear	Percentage for all crops
Pounds applied	2,397,730	1.38%
Number of applications	11,860	0.73%
Acres treated (cumulative)	415,186	0.79%



Insect and Mite Management – As with apple and walnut, codling moth is the key insect pest, causing major damage to fruit. Pear psylla and mites also cause substantial damage.

Codling moth—Larvae of the codling moth sting the fruit when they bore into the flesh for a short distance before dying, or they tunnel into the fruit and feed in the seed cavity. The feeding damage renders the fruit unmarketable. Azinphos methyl, primarily used for codling moth, also controls secondary pests such as true bugs and leafroller larvae. Use of azinphos methyl sharply declined in 1996 due to the development of codling moth resistance.

Other organophosphate insecticides used to control codling moth include methyl parathion, diazinon, and phosmet. From 1991 through 1996, use of methyl parathion rose dramatically because growers recognized that this material killed moths resistant to azinphos methyl. (Codling moths resistant to azinphos methyl are actually twice as susceptible to methyl parathion.) Use of phosmet declined from 1991 through 1996 because moths resistant to azinphos methyl also showed resistance to phosmet.

As with apple, conventional pear growers are gradually introducing reduced-risk strategies to manage codling moth. Narrow-range oil used during late spring and early summer kills eggs of codling moth, giving only partial control. Mating disruption with pheromones is also becoming more widely accepted.

Pear psylla—The pear psylla injects a toxin into the tree, burning the foliage. Pear psylla also secretes honeydew, a sticky substance that gets overgrown with mold, which in turn interferes with photosynthesis. The worst damage results when pear psylla spreads a microorganism that causes pear decline. Amitraz, the major insecticide used to control pear psylla kills mite predators, resulting in outbreaks of mites. When used during late spring and early summer, narrow-range oil limits infestations of pear psylla.

Mites—Mites damage pear by feeding on leaf tissue, causing mottling or stippling of the leaves, and possible defoliation and yield reduction. Sulfur, used as a miticide, is also effective against pear scab (see *Disease Management*). In 1996, approximately 55% of all oil applications were made as dormant sprays to control mites, pear psylla, mealybugs, scale, and fruittree leafroller. Pear growers used the remaining 45% as in-season and postharvest sprays for pear psylla and mites. More pear acreage was treated with oils from 1991 through 1996 than with any other insecticide or miticide. Use of oils decreased from 1994 through 1996.

Weed Management – The weed complex in pear orchards is similar to that of apple. As with apple, glyphosate was the major herbicide used from 1991 through 1996, and use increased during that time. Glyphosate is popular because it is economical, effective, and broad spectrum. When combined with other herbicides, growers can control most orchard weeds.

Disease Management – Pear scab, the most serious fungal disease of pear, causes lesions to fruit during rainy springs. Mancozeb is used to control pear scab; use of this fungicide increased because of it is effective against scab and not phytotoxic (poisonous to plants). Sulfur is also used to control pear scab, but its use decreased from 1991 through 1996, probably because it tends to cause russetting of fruit and phytotoxicity during warm weather.

Fireblight is a bacterial disease that can kill susceptible pear trees. It tends to be most severe during warm, rainy springs. Use of the fireblight antibiotics, oxytetracycline (calcium complex) and streptomycin sulfate increased during 1995 and 1996, possibly because weather conditions were ideal for fireblight infection. The bacterial strain *Pseudomonas fluorescens* A506 is a new reduced-risk material that controls fireblight; in 1996, it was used on more acreage than sulfur used for pear scab.

USE PATTERNS AND TRENDS OF THE MAJOR PESTICIDES

Sulfur

Sulfur use in production agriculture in 1996.

Measures of pesticide use	Total for sulfur	Percentage for all AIs
Pounds used	62,969,595	36.18
Number of applications	142,082	8.72
Acres treated (cumulative)	5,804,067	11.04

The percentage of sulfur use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
GRAPES	32.1	41.8	41.5
GRAPES, WINE	33.7	37.6	39.6
TOMATOES	16.2	3.8	7.0
SUGAR BEET	6.5	1.3	2.4
PEACH	1.8	3.0	1.6
STRAWBERRY	0.4	1.9	1.2
NURSERY CROPS	0.1	2.0	0.3
PRUNE	0.8	0.6	0.7
PISTACHIO	0.9	0.3	0.9
ALMOND	0.5	0.8	0.7
OTHERS	6.9	7.0	4.1

Sulfur is a naturally occurring element widely used as a fungicide and miticide in both conventional and organic farming. Sulfur was the most common pesticide by all measures of use in 1996, but particularly by pounds applied where it accounted for over 36% of all pesticides applied in production agriculture. Use increased from 1991 to 1996, except for a decrease from 1995 to 1996. Sulfur is widely used because it is relatively inexpensive, has low mammalian toxicity, and controls both mites and fungal diseases. It is usually applied as a dust, which can create respiratory problems for people who work in fields that were recently dusted with sulfur.

Over half of the sulfur used in California was applied to grapes for control of powdery mildew. Sulfur use on grapes increased from 1991 to 1995 probably because of increasing powdery mildew problems. In some areas, sulfur replaced the fungicides triadimefon, fenarimol, and myclobutanil, because the powdery mildew fungus developed resistance to them. Sulfur use increased on tomatoes because of elevated russet mite and powdery mildew problems. On sugar beets sulfur is used for mites and powdery mildew. Its use decreased because sugar beet acreage decreased. On peaches sulfur is used for rust and brown rot, and its use increased because of elevated rust problems (which were especially high in 1995). On strawberry sulfur is used for powdery mildew but use decreased after the introduction of myclobutanil for powdery mildew control in 1991. Myclobutanil is a preferred material because sulfur can damage strawberry plants at high temperatures.

Oils

Oil use in production agriculture in 1996.

Measures of pesticide use	Total for oils	Percentage for all AIs
Pounds used	24,965,968	14.3
Number of applications	31,679	1.9
Acres treated (cumulative)	852,237	1.6

The percentage of oil use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
ALMOND	27.9	17.2	35.6
ORANGE	19.7	14.0	13.0
PEACH	7.4	13.3	7.8
LEMON	13.2	7.1	5.6
PEAR	7.5	5.2	6.5
NECTARINE	4.7	9.3	4.5
PRUNE	5.3	4.5	7.9
PLUM	4.3	7.5	3.6
APPLE	3.4	4.3	4.2
NURSERY CROPS	0.3	7.4	0.7
OTHERS	6.4	10.1	10.7

Oils are represented by a broad group of petroleum based compounds; they are listed under a number of active ingredients in the PUR. For the purposes of this report, mineral oils, petroleum distillates, refined petroleum distillates, petroleum hydrocarbons, paraffin based petroleum oil, and unclassified petroleum oils have been grouped into one category. These oils are used primarily to control aphids, scales, and mites, but they are sometimes used for some fungal diseases. They are often used in combination with other pesticides. When used alone, growers often choose oils because of their low toxicity to humans. Oils play an important role in reduced-risk IPM systems because they are less harmful to natural enemies than most other pesticides. Oils were the second most used pesticide by pounds applied and use generally increased from 1991 to 1996.

In almonds and other stone and pome fruits, oils are commonly used as a dormant season spray. Dormant season oil sprays constitute over 95% of the oils used on almond and stone fruits, and about 60% of the oil sprayed on pome fruits. Growers apply oils during the dormant season (December through January) because beneficial insects are usually not present, and oils have less potential to damage trees during this period. Oils have historically been applied in combination with organophosphate pesticides, but because of concern about possible surface water contamination by organophosphates, there is a trend to use oils alone during the dormant period (see section on almonds). Consequently, the use of oils in the dormant period has remained fairly constant from year to year. In oranges, oil use increased about 500% from 1991 to 1996.

This increase can probably be explained by the increasing reliance on biological control. However, in citrus and other crops, use of oils increased because many pests developed resistance to other pesticides, and oils remain effective by comparison.

Glyphosate

Glyphosate use in production agriculture in 1996.

Measures of pesticide use	Total for glyphosate	Percentage for all AIs
Pounds used	2,723,403	1.6
Number of applications	107,120	6.6
Acres treated (cumulative)	3,434,753	6.5

The percentage of glyphosate use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
ALMOND	20.0	13.6	20.0
COTTON	14.6	5.4	13.2
ORANGE	8.6	12.3	10.5
GRAPES, WINE	9.9	9.5	8.8
GRAPES	5.7	6.4	7.3
TOMATOES	5.3	2.6	5.6
WALNUT	4.0	4.7	4.4
NURSERY CROPS	1.8	6.9	0.8
UNCULTIVATED AG. AREAS	3.3	2.7	3.5
LEMON	3.0	3.7	2.1
OTHERS	23.9	32.3	23.8

Glyphosate is a broad-spectrum, foliar-applied herbicide that provides cost-effective weed control. Glyphosate is the second most widely used pesticide as measured by number of applications and acres treated. Use steadily increased from 1991 to 1996—an 80% increase in pounds applied.

In almonds, glyphosate use increased 55% in pounds between 1991 and 1996 because many growers switched from mechanical mowing of weeds to herbicide use, which was cheaper and faster. Glyphosate is used in cotton to control weeds and stop late-season regrowth; its use increased about 200% between 1991 and 1996, both because its price decreased and because wetter weather resulted in more weeds and late cotton regrowth. Glyphosate's use in grapes and citrus is increasing because trends favor contact herbicides over preemergence herbicides. Use of contact herbicides is increasing because they are more compatible with the cover crops. Use increased in tomatoes because weed problems were brought on by wet weather in 1995 and 1996. Glyphosate's use in tomatoes also increased because of the development of light-weight all terrain vehicles equipped with sprayers which make it possible to spray crops in wet conditions.

Metam-sodium

Metam-sodium use in production agriculture in 1996.

Measures of pesticide use	Total for metam-sodium	Percentage for all AIs
Pounds used	15,072,151	8.7
Number of applications	4,667	0.3
Acres treated (cumulative)	215,761	0.4

The percentage of metam-sodium use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
TOMATOES	25.2	24.1	45.3
CARROTS	30.5	10.5	11.6
COTTON	11.4	9.3	20.9
POTATO	9.5	3.5	4.4
BROCCOLI	2.7	3.7	1.3
LETTUCE, HEAD	3.6	1.8	1.5
LETTUCE, LEAF	1.5	4.0	0.7
SOIL APPLICATION, PREPLANT	1.6	2.6	2.1
PEPPERS (FRUITING VEGETABLE)	1.6	1.9	1.2
CANTALOUPE	1.5	1.4	1.8
OTHERS	10.8	37.2	9.1

Metam-sodium is a fumigant that can be used to control diseases, weeds, insects, and nematodes; it is applied to soil before crops are planted. Over half of the metam-sodium use in 1996, in terms of pounds and acres treated, was on tomatoes and carrots. Metam-sodium's use increased dramatically from 1991 to 1996; it experienced a 211% increase in pounds applied, and a 239% increase in acres treated. However, in terms of the number of applications, metam-sodium use increased less dramatically (48%). Two factors explain how pounds applied and acres treated could increase dramatically with only a small increase in the number of applications: 1) the acres treated per application for carrots and cotton have increased, which could occur, for example, by increasing farm size (Table 1); and 2) there was a proportionally larger increase in the number of applications in tomatoes, which have higher acres treated per application than most other crops, thus resulting on average in more acres treated per application (Table 2). Application rates for metam-sodium have remained fairly constant from year to year for many crops, but have generally increased in carrots, head and leaf lettuce, broccoli, and peppers (Table 3). Application rates are generally less when used to control weeds than to control disease and nematodes.

Table 1. Acres treated per application of metam-sodium (total acres treated/number of applications) from 1991 to 1996 on crops with the highest metam-sodium use.

Crop	1991	1992	1993	1994	1995	1996
ALL CROPS	20	33	35	40	43	46
TOMATOES	62	86	88	85	86	87
CARROTS	46	45	41	49	62	51
COTTON	68	76	96	84	98	104
POTATO	59	53	48	51	62	58
BROCCOLI	16	14	12	10	13	17
LETTUCE, HEAD	26	15	15	15	20	37
LETTUCE, LEAF	2	3	4	4	5	8
SOIL APPLICATION	32	26	9	50	95	38
PEPPERS	40	40	31	35	27	29

Table 2. Number of applications of metam-sodium from 1991 to 1996 on crops with the highest metam-sodium use.

Crop	1991	1992	1993	1994	1995	1996
ALL CROPS	3,151	4,094	3,915	4,587	4,644	4,667
TOMATOES	392	717	648	1,075	904	1,123
CARROTS	223	426	301	309	474	491
COTTON	85	363	343	462	361	433
POTATO	68	67	82	79	142	163
BROCCOLI	42	58	120	167	195	172
LETTUCE, HEAD	76	102	51	68	98	86
LETTUCE, LEAF	292	257	287	287	278	188
SOIL APPLICATION	9	21	17	76	158	120
PEPPERS	21	30	43	83	91	90

Table 3. Rate of use of metam-sodium (total pounds/total acres treated) from 1991 to 1996 on crops with the highest metam-sodium use.

Crop	1991	1992	1993	1994	1995	1996
ALL CROPS	76	63	63	60	75	70
TOMATOES	35	36	39	39	40	39
CARROTS	137	144	142	143	177	183
COTTON	40	41	39	44	34	38
POTATO	167	119	125	130	163	152
BROCCOLI	98	74	97	133	138	141
LETTUCE, HEAD	131	118	120	132	107	175
LETTUCE, LEAF	81	107	114	122	125	154
SOIL APPLICATION	126	93	111	71	43	52
PEPPERS	58	73	91	121	127	93

In tomatoes, metam-sodium is primarily used as an herbicide to control nightshade (processing tomatoes) or as a fungicide to control corky root (fresh market tomatoes). Metam-sodium use increased in tomato crops because of increasing nightshade problems and it was the only cost-effective means of nightshade control. Application rates on tomatoes are low compared to rates on other crops (35 to 40 pounds/acre).

In carrots, metam-sodium is used primarily to control nematodes but is also used for weeds and diseases. Metam-sodium use increased in the early 1990s because 1,3-dichloropropene, which also controls nematodes, was suspended (although limited use was subsequently reinstated in December 1994). Metam-sodium use also increased because more growers learned how to properly apply it. Application rates for metam-sodium are higher in carrots than on most crops and have been increasing (137 pounds/acre in 1991 to 183 pounds/acre in 1996).

In cotton, metam-sodium is used primarily to control weeds (particularly nightshade) but also controls nematodes and seedling diseases. Before 1990, nightshade was controlled by hand hoeing. When metam-sodium was proven to control nightshade effectively and more economically, its use replaced hand hoeing. Metam-sodium use increased from 1991 to 1992 as a result of this shift in nightshade control practices, but since 1991, pounds used and acres treated increased only slightly, and the number of applications remained about the same. Application rates are low in cotton (from 34 to 44 pounds/acre for different years, Table 15).

In potatoes, metam-sodium is used primarily to control soil-borne diseases (stem and stolon canker and powdery scab) but also weeds and nematodes. Metam-sodium use increased nearly three-fold from 1992 to 1996, probably for the following reasons: 1) metam-sodium replaced the use of formaldehyde for soil-borne diseases after formaldehyde use was canceled in 1990; and 2) metam-sodium was used for nematode control after the suspension of 1,3-dichloropropene.

In head lettuce, metam-sodium is used primarily for weed control, but also for nematode and soil-borne disease control. Metam-sodium pounds applied and acres treated decreased from 1991 to 1993 in head lettuce, but increased after 1993. Application rates are moderately high on head lettuce, and vary considerably from year to year (from 107 to 175 pounds/acre).

In leaf lettuce, metam-sodium is used primarily for weed control. Metam-sodium pounds applied and acres treated increased dramatically from 1991 to 1996 (375 percent increase in pounds used); however, the number of applications decreased. This pattern indicates that larger areas are being treated with each metam-sodium application. Application rates on leaf lettuce are also moderately high, but have increased from 81 pounds/acre in 1991, to 154 pounds/acre in 1996.

Methyl bromide

Methyl bromide use in production agriculture in 1996.

Measures of pesticide use	Total for methyl bromide	Percentage for all AIs
Pounds used	14,809,564	8.5
Number of applications	6,905	0.4
Acres treated (cumulative)	96,374	0.2

The percentage of methyl bromide use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
STRAWBERRY	29.5	18.2	22.1
NURSERY CROPS	14.6	25.5	17.4
ALMOND	4.1	12.8	16.7
SOIL APPLICATION, PREPLANT	9.5	9.8	5.7
GRAPES, WINE	10.0	3.6	4.2
WALNUT	3.3	4.9	5.6
SWEET POTATO	4.1	3.3	4.7
PEACH	1.7	3.0	2.6
PRUNE	0.9	2.4	3.3
TOMATOES	2.3	1.2	2.6
OTHERS	19.9	15.4	15.2

The fumigant methyl bromide is used to control soil-borne pathogens, nematodes, and weeds; it is usually applied to the soil before crops are planted. Although the number of methyl bromide pounds applied was relatively high, the number of applications and acres treated remained relatively low. Methyl bromide use has remained nearly the same from year to year. Methyl bromide is typically used at high application rates, in part because it is used to treat a volume of space rather than a surface area (such as the leaves and stems of plants).

Methyl bromide is routinely applied to the soil before strawberries are planted. This pre-plant treatment is made to control what is known as the replant problem, which is a disorder not clearly understood but is thought to be a complex of fungal disease and nematodes. Methyl bromide is also applied to kill weed seeds. Methyl bromide is used in many nursery crops to sterilize the soil of soil pathogens, nematodes, weed seeds, and soil-dwelling arthropods. In addition, to insure that stock is pest free, regulations in California and many foreign countries require that field-grown nursery stock must be grown in soil treated either with methyl bromide or 1,3-D. Methyl bromide is also applied to the soil before nut trees and wine grapes vines are planted. Methyl bromide is used before planting almond and walnut trees to control nematodes and *Armillaria* root rot. The main reason methyl bromide is used for wine grapes is to control the replant problem. Because of problems with phylloxera, which is controlled mainly by using resistant rootstock, many vineyards are being replanted and methyl bromide is nearly always applied before the fields are replanted. The pre-plant soil application category in the PUR includes applications to bare ground where the crop to be planted is not specified.

Chlorpyrifos

Chlorpyrifos use in production agriculture in 1996.

Measures of pesticide use	Total for chlorpyrifos	Percentage for all AIs
Pounds used	2,136,110	1.2
Number of applications	47,661	2.9
Acres treated (cumulative)	1,869,158	3.6

The percentage of chlorpyrifos use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
COTTON	27.6	14.1	36.5
ALFALFA	12.2	15.4	24.5
ORANGE	20.7	8.8	5.8
ALMOND	10.1	5.1	6.7
WALNUT	7.2	6.2	4.8
BROCCOLI	3.8	10.0	3.6
NURSERY CROPS	0.5	11.1	0.9
SUGAR BEET	3.3	2.9	5.2
CAULIFLOWER	1.3	5.2	1.5
APPLE	2.4	3.0	1.9
OTHERS	10.9	18.3	8.6

Chlorpyrifos is an organophosphate insecticide used to control a wide range of insect pests. It is the most highly used insecticide (measured by acres treated), and its use increased dramatically from 1991 to 1995, but fell off somewhat in 1996.

Most of the increase in chlorpyrifos occurred on cotton, where pounds applied increased 2,187% from 1991 to 1995. On cotton, chlorpyrifos is used primarily to control the cotton aphid. This aphid, which was historically only a minor pest, became one of the most serious pests of cotton in the 1990s, exhibiting a peak in 1995.

On oranges chlorpyrifos is used mostly to control red scale, but is sometimes used for citricola scale, ants, caterpillars, and katydids. Chlorpyrifos use increased because it is believed to be more selective than carbaryl, it works quickly, and is less likely to disrupt IPM programs. It is currently considered the best chemical control for citricola scale, although narrow range oil is effective for light to moderate infestations.

On almonds, chlorpyrifos is used during the growing season to control navel orangeworm, peach twig borer, San Jose scale, and ants. Chlorpyrifos is the only pesticide registered for almond that provides effective ant control. It is applied during the dormant season; however, because of concern about possible surface water contamination by organophosphate pesticides, dormant season use has decreased. In 1991–1992, 55,000 pounds of chlorpyrifos was applied between December 1991 through February 1992; this represents chlorpyrifos' peak use year. In 1995–

1996, the use of chlorpyrifos in dormant sprays decreased to 17, 000 pounds. In-season use of chlorpyrifos remained fairly constant over the 1991-1996 period.

On alfalfa, chlorpyrifos is used primarily to control Egyptian alfalfa weevil, aphids, and beet armyworm. It is less harmful to most beneficial organisms than other pesticides. Use may have increased because of resistance developing to methomyl, one of the main alternatives to chlorpyrifos. Use increased because of resistance to other pesticides. On walnuts, it is used to control codling moth, scales, and walnut husk fly. On sugar beets, chlorpyrifos is used mostly to control armyworms and use declined primarily due to the decrease in sugar beet acres.

Copper hydroxide

Copper hydroxide use in production agriculture in 1996.

Measures of pesticide use	Total for copper hydroxide	Percentage for all AIs
Pounds used	3,751,723	2.2
Number of applications	43,297	2.7
Acres treated (cumulative)	1,312,559	2.5

The percentage of copper hydroxide use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
WALNUT	32.1	14.1	16.6
ALMOND	17.9	9.6	15.2
GRAPES	6.7	11.9	16.7
GRAPES, WINE	4.7	8.2	12.4
TOMATOES	5.6	4.0	9.9
ORANGE	6.4	6.4	5.4
PEACH	5.8	6.7	2.9
NECTARINE	4.7	5.0	2.1
NURSERY CROPS	1.2	8.7	1.6
CELERY	0.6	5.7	2.0
OTHERS	14.4	19.6	15.2

Copper compounds are used as fungicides, bactericides, and insecticides; the different copper compounds are often used interchangeably. Copper hydroxide is the most popular of these compounds; other than sulfur, it is the most widely used fungicide. Its use generally increased from 1991 to 1996, although use decreased from 1995 to 1996.

Copper hydroxide is used to control walnut blight, the major disease affecting walnuts. On almonds it is used to control shot hole and brown rot blossom blight. On grapes, it is primarily used for bunch rot and phomopsis. Its use in grapes increased because of increased problems with phomopsis, especially on 'Red Globe' and 'Thompson Seedless' grapes. Its use may have also increased because it was aggressively marketed and is less toxic than most alternatives. On fresh market tomatoes, it is used for bacterial speck, bacterial spot, and powdery mildew. On processing tomatoes it is used mostly for bacterial speck. Use fluctuated on tomatoes due to variation in disease pressure. On oranges, copper hydroxide is commonly applied to prevent growth of brown rot, gummosis, anthracnose, bacterial blast, and Septoria spot. Use probably increased because growers believed the higher rainfall had a greater potential to create more disease problems. For peaches, copper hydroxide is often used with ziram and lime-sulfur during the dormant season to control peach leaf curl and shot hole diseases.

Permethrin

Permethrin use in production agriculture in 1996.

Measures of pesticide use	Total for permethrin	Percentage for all AIs
Pounds used	159,713	0.1
Number of applications	65,854	4.0
Acres treated (cumulative)	1,021,004	1.9

The percentage of permethrin use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
LETTUCE, HEAD	23.7	22.4	25.6
LETTUCE, LEAF	13.9	25.4	14.8
ALFALFA	9.1	2.7	12.7
ALMOND	10.6	2.4	9.3
CELERY	6.3	8.2	6.3
SPINACH	3.3	7.0	3.3
MUSHROOMS	0.5	11.9	0.2
PISTACHIO	6.5	0.7	3.8
PEACH	4.9	2.2	3.3
WALNUT	5.0	1.4	3.7
OTHERS	16.3	15.6	17.1

Permethrin is a synthetic pyrethroid insecticide used on many crops to control a wide range of insect pests. It is an effective pesticide that was relied upon for many years. In 1996, it was the highest use insecticide as measured by number of applications. Use increased from 1991 to 1996, especially in number of applications. Nearly half of the permethrin use in 1996 was on lettuce. On leaf lettuce, permethrin is used for beet armyworm and other lepidopteran larvae. On alfalfa, it is used to control Egyptian alfalfa weevil. On almonds, it was increasingly being used as dormant spray to control San Jose scale and peach twig borer. It started replacing some organophosphate use because of its relative low cost as well as increasing resistance developing to organophosphates.

Paraquat dichloride

Paraquat dichloride use in production agriculture in 1996.

Measures of pesticide use	Total for paraquat	Percentage for all AIs
Pounds used	885,677	0.5
Number of applications	31,191	1.9
Acres treated (cumulative)	1,710,991	3.3

The percentage of paraquat dichloride use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
COTTON	40.9	27.4	52.7
ALMOND	13.4	13.8	10.7
GRAPES	8.6	13.1	8.1
ALFALFA	8.7	7.0	7.2
GRAPES, WINE	4.9	5.8	4.0
PEACH	1.4	5.2	1.2
WALNUT	1.7	3.6	1.5
NECTARINE	1.1	3.9	0.9
TOMATOES	2.8	1.2	1.5
PLUM	1.1	2.9	0.9
OTHERS	15.5	16.2	11.2

Paraquat is a contact herbicide and desiccant. It was the second most commonly used herbicide in 1996 by acres treated and its use generally increased from 1991 to 1996. Over half of the acres treated with paraquat was on cotton in 1996. It is used on cotton to dry leaves out and stop cotton regrowth late in the season (which can be promoted by cool or wet weather). Use of paraquat on cotton nearly doubled from 1991 to 1996. In almonds, paraquat's use increased because chemical "mowing" of weeds began replacing mechanical mowing. In grapes, paraquat is preferred to simazine, because simazine is a known ground water contaminant in some areas of the state and consequently more use restrictions surround simazine's use. Also, growers are tending to use more contact herbicides rather than preemergence herbicides. Paraquat is used on alfalfa to control broadleaf weeds and small grasses in older stands. Paraquat is the only product registered for aerial application in alfalfa; it is used when fields are too wet to apply other herbicides by ground. Paraquat use increased in other crops because abundant rainfall promoted weed growth in several areas of the state in 1995 and 1996.

Oxyfluorfen

Oxyfluorfen use in production agriculture in 1996.

Measures of pesticide use	Total for oxyfluorfen	Percentage for all AIs
Pounds used	403,713	0.2
Number of applications	36,182	2.2
Acres treated (cumulative)	1,313,023	2.5

The percentage of oxyfluorfen use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
ALMOND	22.2	19.6	26.0
COTTON	14.1	9.4	21.2
GRAPES, WINE	18.2	13.3	9.5
GRAPES	8.5	6.7	7.6
WALNUT	3.6	6.3	4.9
PISTACHIO	7.7	2.7	3.4
ONION (DRY)	2.3	2.8	4.7
PEACH	2.1	4.8	1.6
BROCCOLI	0.8	5.8	1.8
PLUM	2.2	3.8	1.4
OTHERS	18.3	24.8	17.9

Oxyfluorfen is a pre- and postemergence herbicide used to control grasses and annual broadleaf weeds. It kills many of the weeds that glyphosate and trifluralin do not. In terms of number of applications it is the second most popular herbicide, and the number of oxyfluorfen applications increased by 91% from 1991 to 1996. Oxyfluorfen is popular because it exhibits a long residual effect, meaning it retains its ability to kill weeds over a long period of time. Oxyfluorfen is used in combination with glyphosate in almonds and walnuts because it controls different weeds than glyphosate. On cotton, oxyfluorfen is used before and after cotton is planted, and late in the season to control weeds tolerant of trifluralin, such as nightshade and annual broadleaf weeds. In grapes it controls the weeds glyphosate misses: cheeseweed, nettle, and filaree. Growers who use drip irrigation favor oxyfluorfen because it does not break down and does not impact non-target plants.

Methomyl

Methomyl use in production agriculture in 1996.

Measures of pesticide use	Total for methomyl	Percentage for all AIs
Pounds used	679,181	0.4
Number of applications	36,291	2.2
Acres treated (cumulative)	1,143,654	2.2

The percentage of methomyl use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
ALFALFA	18.4	10.7	22.1
LETTUCE, HEAD	16.8	17.5	14.9
TOMATOES	12.1	6.0	11.0
LETTUCE, LEAF	4.5	11.8	4.3
CORN	4.4	6.4	6.0
COTTON	7.2	1.4	7.1
SUGAR BEET	5.0	2.4	5.4
CELERY	2.7	6.2	2.4
BROCCOLI	3.1	3.0	2.5
GRAPES	3.6	2.0	2.9
OTHERS	22.3	32.8	21.4

Methomyl is a carbamate insecticide that controls a broad range of insects. Its statewide use did not change much from 1991 to 1996, but its use on some crops did change dramatically. On alfalfa, for example, use increased by 200% from 1991 to 1995. Methomyl in alfalfa is primarily used to control Egyptian alfalfa weevil and aphids during the spring, and beet armyworm in the summer. Some of these pests have developed significant resistance to methomyl. On head lettuce methomyl is used to control the key pests silverleaf whitefly and beet armyworm. On tomatoes, methomyl is used primarily for control of lepidopteran pests, and to a lesser extent, stink bug. The yearly fluctuations in use are caused by variations in pest pressure. On leaf lettuce, methomyl is used for beet armyworm and other lepidopteran larvae. On cotton, it was used primarily to control cotton aphids. Pounds used on cotton increased 12,000% from 1993 to 1995 due to increasing problems with the aphid.

Maneb

Maneb use in production agriculture in 1996.

Measures of pesticide use	Total for maneb	Percentage for all AIs
Pounds used	1,325,508	0.8
Number of applications	40,594	2.5
Acres treated (cumulative)	731,043	1.4

The percentage of maneb use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
LETTUCE, HEAD	28.8	44.0	39.0
ALMOND	37.9	7.1	21.3
LETTUCE, LEAF	9.1	25.3	12.0
WALNUT	15.7	8.0	17.4
NURSERY CROPS	1.3	5.0	0.9
ONION (DRY)	2.0	0.9	2.0
TOMATOES	1.3	1.0	2.3
POTATO	1.2	0.7	1.7
BROCCOLI	0.6	0.8	0.8
ONIONS (GREEN)	0.4	1.0	0.4
OTHERS	1.8	6.3	2.2

Maneb is a fungicide that controls many plant diseases. Statewide maneb use increased every year from 1991 to 1996; pounds used increased 279%. This increase occurred on all the major maneb-using crops. Most of this increase was probably due to increasing plant disease problems thought to be brought on by the higher rainfall, especially in 1995 and 1996. Over half of the maneb use in 1996 was on head lettuce and almond. On lettuce maneb is used to control downy mildew. Its use increased because of increased diseases and because of the development of resistance to metalaxyl. On almonds, it is used to control brown rot and shot hole. Maneb use on almond increased over 400% from 1991 to 1996. On walnuts, it is used to control walnut blight and its use increased because of resistance to copper fungicides. On nursery crops, it is used as a preventive for Botrytis, downy mildew, rust, leaf/bleach spot and other fungal pathogens.

Imidacloprid

Imidacloprid use in production agriculture in 1996.

Measures of pesticide use	Total for imidacloprid	Percentage for all AIs
Pounds used	63,813	0.0
Number of applications	38,622	2.4
Acres treated (cumulative)	1,040,989	2.0

The percentage of imidacloprid use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
COTTON	33.8	11.4	44.9
LETTUCE, HEAD	14.1	17.3	10.7
LETTUCE, LEAF	8.6	22.6	7.4
GRAPES	7.0	8.6	12.0
GRAPES, WINE	5.0	5.7	8.9
BROCCOLI	6.9	7.2	4.6
CANTALOUPE	7.4	0.8	2.0
CAULIFLOWER	3.7	4.3	2.1
CABBAGE	1.4	3.7	1.1
NURSERY CROPS	0.4	4.8	0.2
OTHERS	11.7	13.5	6.1

Imidacloprid is a new, selective, systemic insecticide that causes less disruption to beneficial insects than other pesticides. Imidacloprid is used to control sucking insects and is important in resistance management; however, it is fairly expensive. Imidacloprid was first registered for use in California in 1994. From 1994 to 1996 its use increased dramatically — over 5,000% in number of applications. In cotton, imidacloprid is used mostly for aphids and some for lygus and whiteflies. Its use declined from 1995, the first year of use, to 1996 because aphids were less of a problem in 1996. In head and leaf lettuce, it is used mostly to control silverleaf whitefly and its use increased because of increasing problems with the whitefly. In grapes, it is used to control leafhoppers and its use increased because leafhoppers have become resistant to many other insecticides.

Sodium chlorate

Sodium chlorate use in production agriculture in 1996.

Measures of pesticide use	Total for sodium chlorate	Percentage for all AIs
Pounds used	3,281,435	1.9
Number of applications	9,414	0.6
Acres treated (cumulative)	834,722	1.6

The percentage of sodium chlorate use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
COTTON, GENERAL	96.7	94.9	97.7
PEPPERS (CHILI TYPE)	1.0	2.0	0.4
SUNFLOWER	0.7	0.8	0.5
SAFFLOWER	0.5	0.9	0.4
CORN (FORAGE - FODDER)	0.4	0.4	0.3
SORGHUM/MILO	0.3	0.5	0.3
RICE	0.4	0.3	0.2
OTHERS	0.1	0.2	0.1

Sodium chlorate is used on cotton as a leaf defoliant and desiccant. It is one of the least effective defoliants, but it is widely used because it is inexpensive. Because of its low effectiveness, it is used at higher application rates than other defoliants, and repeated use is not uncommon. Growers use other defoliants in wet, mild weather when cotton can be difficult to defoliate with sodium chlorate. The variation in use from year to year reflects the differences in weather. In most other crops it is used as a soil-sterilant herbicide.

Dimethoate

Dimethoate use in production agriculture in 1996.

Measures of pesticide use	Total for dimethoate	Percentage for all AIs
Pounds used	415,390	0.2
Number of applications	32,097	2.0
Acres treated (cumulative)	955,272	1.8

The percentage of dimethoate use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
ALFALFA	20.5	13.2	27.1
LETTUCE, HEAD	6.7	19.7	12.3
BROCCOLI	6.8	13.7	6.4
TOMATOES	9.9	5.7	9.6
COTTON	9.1	3.4	9.1
ORANGE	11.1	3.6	2.6
BEANS, DRIED-TYPE	6.5	3.9	6.6
LETTUCE, LEAF	1.8	9.6	3.2
SAFFLOWER	5.2	0.5	3.8
WHEAT	2.9	1.8	4.3
OTHERS	19.4	24.9	15.1

Dimethoate is an organophosphate insecticide used to control insects and mites. Use changed little from 1991 to 1996. On alfalfa, it is used to control leafhoppers and aphids. On head lettuce, it used for green peach aphid. On tomatoes, dimethoate is used primarily to control aphids and leafhoppers, which may vector viruses from nearby weed infestations. The yearly fluctuations in use from 1991 to 1996 were mainly due to variations in pest pressure. On cotton it is used to control primarily aphids. On oranges, it is used to control citrus thrips. Thrips began developing resistance to dimethoate, and cyfluthrin is gradually replacing it.

Iprodione

Iprodione use in production agriculture in 1996.

Measures of pesticide use	Total for iprodione	Percentage for all AIs
Pounds used	507,087	0.3
Number of applications	33,774	2.1
Acres treated (cumulative)	803,881	1.5

The percentage of iprodione use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
ALMOND	27.3	16.5	35.8
NURSERY CROPS	2.7	24.3	2.2
PEACH	7.4	10.9	6.8
CARROTS	8.3	3.2	8.9
PRUNE	7.5	3.7	7.2
LETTUCE, HEAD	6.5	7.2	4.7
STRAWBERRY	7.2	4.6	4.9
GRAPES	6.5	2.9	6.3
GRAPES, WINE	5.1	3.7	4.7
NECTARINE	3.6	6.2	3.4
OTHERS	17.7	16.8	15.1

Iprodione is a contact and systemic fungicide; its use generally increased from 1991 to 1996. On almonds, it is used against brown rot, shot hole and leaf spot diseases. Use was highest during the wet years of 1995 and 1996. On nursery crops, iprodione is used to control various diseases affecting roots and leaves. On carrots, iprodione is the most effective compound available to control *Alternaria* leaf blight. On prunes, it is used mostly for brown rot. On head lettuce, it is used for bottom rot and lettuce drop. On strawberries, it is used to control gray mold or *Botrytis* fruit rot, the most common and most serious fungal disease of strawberry. Iprodione is used as a last resort because of its label restrictions and because of gray mold resistance.

Avermectin (abamectin)

Avermectin use in production agriculture in 1996.

Measures of pesticide use	Total for avermectin	Percentage for all AIs
Pounds applied	7,706	0.0
Number of applications	32,171	2.0
Acres treated (cumulative)	946,011	1.8

The percentage of avermectin use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
COTTON	64.0	25.8	72.5
NURSERY CROPS	4.3	37.3	3.1
LETTUCE, HEAD	7.9	14.8	9.0
STRAWBERRY	9.9	6.5	4.7
CELERY	3.4	6.4	2.6
LEMON	2.2	3.1	1.8
PEAR	2.6	1.3	1.6
ORANGE	1.7	1.5	1.3
SPINACH	0.5	1.3	0.4
TOMATOES	0.9	0.3	0.5
OTHERS	2.7	1.8	2.5

Avermectin is used to control insects and mites. Its use increased steadily each year from 1991 to 1996, a 320% increase in acres treated. Most avermectin use is on cotton to control spider mites. The number of applications to cotton increased 560% from 1991 to 1996 because spider mite problems increased and because avermectin is probably the most effective material for controlling mites. Mites on cotton have developed resistance to most other miticides. On nursery crops, avermectin is used to control leafminer, tomato pinworm, and mites; its use generally increased because of its effectiveness. On head lettuce, it is used for pea leafminer. Its use increased dramatically, nearly 14,000% in number of applications, from 1991 to 1996, probably because of increasing problems with leafminers. On strawberries, it is the preferred pesticide for two-spotted mites because it is effective and because it is softer on beneficials than other pesticides.

Trifluralin

Trifluralin use in production agriculture in 1996.

Measures of pesticide use	Total for trifluralin	Percentage for all AIs
Pounds applied	1,132,798	0.7
Number of applications	16,180	1.0
Acres treated (cumulative)	1,086,446	2.1

The percentage of trifluralin use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
ALFALFA	49.1	28.2	27.0
COTTON	21.7	25.0	30.0
TOMATOES	9.7	17.4	18.4
SAFFLOWER	4.3	4.6	5.1
CARROTS	2.8	4.3	4.0
BEANS, DRIED-TYPE	1.0	1.9	1.7
GRAPES	1.2	1.7	1.1
CANTALOUPE	1.0	1.2	1.5
SUGARBEET	0.8	1.0	1.3
ASPARAGUS	1.1	1.3	0.7
OTHERS	7.2	13.4	9.1

Trifluralin is a selective herbicide that can provide season-long control of many annual grasses. Its use remained constant from year to year statewide and fairly constant on most crops. Over half of its use in 1996 was on alfalfa and cotton. On alfalfa it is used as a postemergence herbicide in the spring to control summer annual grasses in established fields. In the late dormant season it is used to manage summer grasses such as yellow foxtail and cub grass. On cotton, trifluralin is used to control most annual grasses. It was the basis for weed control in cotton for many years. It is applied in the fall and winter to most fallow fields that will be planted to cotton. On tomatoes, trifluralin provides cost-effective, season-long control of many annual grass and broadleaf weeds, as well as partial control of seedling field bindweed.

Myclobutanil

Myclobutanil use in production agriculture in 1996.

Measures of pesticide use	Total for myclobutanil	Percentage for all AIs
Pounds applied	86,616	0.0
Number of applications	28,396	1.7
Acres treated (cumulative)	814,227	1.5

The percentage of myclobutanil use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
GRAPES	32.8	22.9	35.4
GRAPES, WINE	23.9	21.8	26.4
ALMOND	9.8	3.6	7.8
PEACH	5.1	10.0	4.1
APPLE	6.2	6.2	5.7
NECTARINE	4.3	8.2	3.4
NURSERY CROPS	1.6	12.4	1.3
TOMATOES	5.7	3.3	6.2
STRAWBERRY	4.5	4.6	4.6
PLUM	2.4	3.7	1.8
OTHERS	3.7	3.3	3.4

Myclobutanil is a systemic protectant and curative fungicide effective against many fungi. It belongs to a class of compounds known as sterol biosynthesis inhibitors (SBIs) or, alternatively, dimethylation inhibitors (DMIs). Its use generally increased from 1991 to 1996. Over half of the statewide myclobutanil use in 1996 was on grapes to control powdery mildew, one of the most important grape diseases. Initially it was very effective, but the powdery mildew fungus is developing resistance to it. However, myclobutanil use on raisin and table grapes generally increased probably because of increasing powdery mildew problems. On almonds, it is used, often in combination with maneb or captan, to control brown rot and anthracnose. On almonds, use was minor or zero until 1996. On apple, it is used to control powdery mildew and scab. It use was high in 1995 and 1996 probably because of increased disease problems caused by high rainfall during those years.

Cryolite

Cryolite use in production agriculture in 1996.

Measures of pesticide use	Total for cryolite	Percentage for all AIs
Pounds applied	2,429,283	1.4
Number of applications	9,869	0.6
Acres treated (cumulative)	430,420	0.8

The percentage of cryolite use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
GRAPES	65.2	75.7	67.2
GRAPES, WINE	27.5	19.0	28.2
ORANGE	3.6	1.9	2.1
PEPPERS (FRUITING VEGETABLE)	1.3	0.9	0.7
TOMATOES	0.5	0.4	0.6
NURSERY CROPS	0.3	0.4	0.3
KIWI FRUIT	0.3	0.5	0.2
PEACH	0.3	0.4	0.2
WATERMELONS	0.3	0.1	0.2
TANGERINE	0.2	0.1	0.1
OTHERS	0.6	0.6	0.4

Cryolite is an inorganic fluorine compound that acts as stomach insecticide. It requires no permits to use because of its low mammalian toxicity (and in fact is allowed for organic production systems). It is selective to leaf chewing insects. Cryolite use generally decreased from 1992 to 1996. By far, most cryolite is applied to grapes, providing long-term protection against lepidopteran pests such as grapeleaf skeletonizer, omnivorous leafroller, and orange tortrix. Its use declined on table and raisin grapes because of declining pressure from the grapeleaf skeletonizer in the Central Valley. On oranges, cryolite is used to control caterpillars, katydids, and Fuller rose beetles.

Copper Sulfate (pentahydrate)

Copper sulfate (pentahydrate) use in production agriculture in 1996.

Measures of pesticide use	Total for copper sulfate	Percentage for all AIs
Pounds applied	2,987,034	1.7
Number of applications	4,912	0.3
Acres treated (cumulative)	241,626	0.5

The percentage of copper sulfate use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
RICE	91.4	66.2	94.1
NURSERY CROPS	0.8	26.5	1.3
CHERRY	1.7	1.6	0.9
RICE, WILD	1.3	0.7	1.2
ORANGE	1.0	1.2	0.7
AQUATIC AREAS	1.8	0.9	0.0
WALNUT	0.8	1.0	0.7
ALMOND	0.4	0.3	0.3
OLIVE	0.4	0.4	0.2
PRUNE	0.2	0.2	0.1
OTHERS	0.2	0.9	0.4

In California copper sulfate is used primarily to control tadpole shrimp and algae in rice, but it is also used to control pathogenic fungi in other crops. On rice, use increased almost 3 times from 1991 to 1996. Methyl parathion may also be used to control tadpole shrimp, but due in part to aquatic toxicity and handling concerns, copper sulfate use is more common. Copper sulfate use also increased because of increasing problems with algae in some rice-growing areas.

Chloropicrin

Chloropicrin use in production agriculture in 1996.

Measures of pesticide use	Total for chloropicrin	Percentage for all AIs
Pounds applied	2,802,061	1.6
Number of applications	3,516	0.2
Acres treated (cumulative)	57,591	0.1

The percentage of chloropicrin use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
STRAWBERRY	70.9	35.0	36.6
NURSERY CROPS	9.8	26.5	24.7
SOIL APPLICATION, PREPLANT	7.1	10.2	7.0
SWEET POTATO	0.1	4.8	5.9
TOMATOES	2.8	2.2	3.8
GRAPES, WINE	0.2	4.0	4.6
LETTUCE, HEAD	2.7	2.1	1.8
CARROTS	0.1	1.9	3.8
UNCULTIVATED AG AREAS	0.7	2.8	1.9
ALMOND	0.0	1.9	2.0
OTHERS	5.5	8.4	7.8

Chloropicrin is a general biocide fumigant and is also commonly used as a warning agent with methyl bromide, which is odorless. It is also often applied with methyl bromide or 1, 3-D to broaden the range of pests killed. Its use was slightly increasing from 1991 to 1996.

Chloropicrin generally has higher toxicity to pathogenic fungi than methyl bromide or 1,3-D, but methyl bromide has greater soil penetration and higher toxicity to weeds and 1,3-D has greater toxicity to nematodes. The formulation used depends on pest pressure and soil type. Heavy soils highly infested with *Verticillium* are commonly treated with a 50/50 mix of methyl bromide and chloropicrin.

On strawberries it is used to control a range of pathogenic fungi including *Phytophthora* spp., *Verticillium dahliae*, and *Rhizoctonia* spp. In nurseries it is used to sterilize container potting soil before potting plants and in the control of *Verticillium*. The pre-plant soil application category includes applications to bare ground, but does not specify what crop is to be planted.

Ziram

Ziram use in production agriculture in 1996.

Measures of pesticide use	Total for ziram	Percentage for all AIs
Pounds applied	1,172,207	0.7
Number of applications	5,546	0.3
Acres treated (cumulative)	219,678	0.4

The percentage of ziram use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
ALMOND	74.8	55.1	76.8
PEACH	13.0	23.1	11.7
NECTARINE	4.1	13.4	3.3
PEAR	4.7	2.6	4.5
APPLE	2.1	1.5	2.2
APRICOT	1.2	3.3	1.1
NURSERY CROPS	0.0	0.6	0.0
GRAPES	0.1	0.2	0.2
CHERRY	0.0	0.1	0.0
GRAPES, WINE	0.0	0.0	0.1
OTHERS	0.0	0.1	0.0

Use of ziram, a fungicide, generally decreased from 1991 to 1996. Most use was on almonds for shot hole and almond scab. Ziram use probably decreased because, although it was effective against shot hole (and scab later in the season), growers found that other fungicides could protect their orchards against a wider range of disease organisms.

Benomyl

Benomyl use in production agriculture in 1996.

Measures of pesticide use	Total for benomyl	Percentage for all AIs
Pounds applied	148,051	0.1
Number of applications	12,178	0.7
Acres treated (cumulative)	310,562	0.6

The percentage of benomyl use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
ALMOND	46.7	22.7	43.9
CELERY	6.2	21.5	13.0
GRAPES	9.3	5.5	9.4
GRAPES, WINE	7.4	5.7	7.0
STRAWBERRY	5.9	6.8	6.3
PISTACHIO	6.8	1.8	4.4
MUSHROOMS	0.5	12.0	0.1
PEACH	3.5	4.5	2.3
NECTARINE	2.5	3.2	1.4
PEAR	2.3	1.9	2.4
OTHERS	8.8	14.6	9.8

Benomyl is a systemic foliar fungicide. Pounds used and acres treated generally increased by a small amount and number of applications generally decreased. On almonds, it is used for brown rot, scab, and anthracnose, often in combination with other fungicides. On almonds, use steadily increased each year probably because of its effectiveness against anthracnose. On grapes benomyl is used to control Botrytis bunch rot. Use on raisin and table grapes generally increased from 1991 to 1995 and decreased from 1995 to 1996. On wine grapes, use generally decreased, possibly because more growers used cultural practices such as leaf removal to avoid the disease. On strawberries, it is used to control anthracnose and Botrytis.

Fenarimol

Fenarimol use in production agriculture in 1996.

Measures of pesticide use	Total for fenarimol	Percentage for all AIs
Pounds applied	12,727	0.0
Number of applications	11,421	0.7
Acres treated (cumulative)	367,686	0.7

The percentage of fenarimol use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
GRAPES, WINE	45.6	44.2	47.9
GRAPES	45.8	38.6	47.8
NURSERY CROPS	3.2	12.8	1.6
APPLE	4.4	4.0	2.2
PEAR	0.9	0.3	0.5
CHERRY	0.1	0.1	0.1
OTHERS	0.0	0.0	0.0

Fenarimol is a foliar fungicide whose use generally decreased from 1991 to 1996. It belongs to a class of compounds known as sterol biosynthesis inhibitors (SBIs) or, alternatively, dimethylation inhibitors (DMIs). Over 80% of fenarimol use in 1996 was on grapes to control powdery mildew, one of the most important grape diseases. Initially it was very effective, but powdery mildew fungi are developing resistance to it and use has generally decreased. On apple, it is used to control powdery mildew. Use has recently declined probably because of resistance problems.

1,3-Dichloropropene

1,3-D use in production agriculture in 1996.

Measures of pesticide use	Total for 1,3-D	Percentage for all AIs
Pounds applied	1,956,731	1.1
Number of applications	550	0.0
Acres treated (cumulative)	17,367	0.0

The percentage of 1,3-D use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
CARROTS	37.3	25.3	41.0
SOIL APPLICATION, PREPLANT	15.2	8.0	5.6
BRUSSELS SPROUTS	3.6	8.2	4.4
POTATO	4.8	3.3	7.0
MELONS	3.3	2.7	5.6
ALMOND	5.5	3.3	2.3
SWEET POTATO	3.7	3.6	3.2
LETTUCE, HEAD	2.4	4.7	3.3
TOMATOES	3.2	2.4	4.2
PEPPERS (FRUITING VEGETABLE)	2.7	2.7	3.2
OTHERS	18.2	35.8	20.3

1,3-dichloropropene (1,3-D) is a general biocide fumigant used especially to control nematodes. In April 1990, high levels of 1,3-D were detected in ambient air in selected sites in Merced County, California. Residues in the air exceeded by several orders of magnitude the level of health concern. DPR immediately suspended all permits for use of 1,3-D but approved limited use of 1,3-D in December 1994.

In carrots, 1,3-D is used to control root-knot nematodes, which are the major soil-borne pests of this crop. After some use of 1,3-D was allowed in 1994, its use increased in carrots because it is the product of choice for nematode control. On almonds, it is used before planting an orchard to control a variety of nematodes and fungal diseases. The pre-plant soil application category in the PUR includes applications to bare ground where the crop to be planted is not specified.

Azadirachtin

Azadirachtin use in production agriculture in 1996.

Measures of pesticide use	Total for azadirachtin	Percentage for all AIs
Pounds applied	811	0.0
Number of applications	13,979	0.9
Acres treated (cumulative)	76,386	0.1

The percentage of azadirachtin use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
LETTUCE, LEAF	20.0	18.3	26.1
NURSERY CROPS	23.1	24.5	7.6
LETTUCE, HEAD	14.8	8.0	21.0
SPINACH	11.1	12.6	15.5
CELERY	12.1	5.9	11.4
MUSHROOMS	0.9	6.8	0.2
ONIONS (GREEN)	1.5	2.0	2.8
BROCCOLI	2.2	0.9	1.5
BOK CHOY	0.6	2.9	0.9
SWISS CHARD	0.3	2.9	0.7
OTHERS	13.5	15.2	12.3

Azadirachtin is an insecticide that disrupts insect molting by antagonizing the insect hormone ecdysone. It is a chemical extracted from the kernels of the neem tree. Its use increased each year from 1992 (the first year of use) to 1996. Over half of azadirachtin use in 1996 was in lettuce and nurseries. On lettuce, it is used for pea leafminer, which has caused increasing problems in the 1990s. On nurseries, it is used for aphids, whiteflies, thrips, leafminers, and caterpillars.

Endosulfan

Endosulfan use in production agriculture in 1996.

Measures of pesticide use	Total for endosulfan	Percentage for all AIs
Pounds applied	223,591	0.1
Number of applications	5,474	0.3
Acres treated (cumulative)	270,662	0.5

The percentage of endosulfan use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
COTTON	22.6	16.7	26.7
CANTALOUPE	18.9	13.8	18.9
LETTUCE, HEAD	11.1	15.3	11.0
TOMATOES	9.9	5.8	8.7
ALFALFA	7.4	4.2	7.4
LETTUCE, LEAF	2.7	7.4	2.6
MELONS	3.6	4.4	3.8
GRAPES	4.2	3.4	2.9
CORN	3.0	2.0	2.4
SUGARBEET	2.5	1.8	2.9
OTHERS	14.1	25.3	12.8

Endosulfan is an organochlorine pesticide used to control insects and mites. Its use generally decreased from 1991 to 1996. On cotton, endosulfan primarily controls cotton aphids and silverleaf whitefly. Use decreased in recent years probably because of the development of resistance in aphids and the availability of better pesticides. ** Also, restrictions on use were made on the permit. ** On head lettuce, it is used to control cabbage looper, corn earworm, and aphids. Endosulfan also controls potato aphids on tomatoes and various aphids on alfalfa.

Triadimefon

Triadimefon use in production agriculture in 1996.

Measures of pesticide use	Total for triadimefon	Percentage for all AIs
Pounds applied	14,112	0.0
Number of applications	4,418	0.3
Acres treated (cumulative)	100,110	0.2

The percentage of triadimefon use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
GRAPES	24.7	9.5	19.6
PEPPERS (FRUITING VEGETABLE)	16.0	12.8	14.6
NURSERY CROPS	3.0	35.8	2.7
WATERMELONS	10.8	5.9	12.0
MELONS	6.9	4.4	8.4
CANTALOUPE	6.0	3.6	9.3
GRAPES, WINE	7.7	3.7	7.3
SUGARBEET	6.7	2.4	6.1
SQUASH	2.8	6.3	3.8
ARTICHOKE	3.7	3.4	5.4
OTHERS	11.7	12.2	10.7

Triadimefon is a systemic fungicide. It belongs to a class of compounds known as sterol biosynthesis inhibitors (SBIs) or, alternatively, dimethylation inhibitors (DMIs). Its use generally decreased from 1991 to 1996. On grapes, it is used to control powdery mildew, one of the most important grape diseases. It was introduced in the mid 1980s but later powdery mildew fungi developed resistance to it which is probably the main reason for its decline in use in grapes.

Parathion (ethyl parathion)

Parathion use in production agriculture in 1996.

Measures of pesticide use	Total for parathion	Percentage for all AIs
Pounds applied	13,989	0.0
Number of applications	104	0.0
Acres treated (cumulative)	5,099	0.0

The percentage of parathion use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
COTTON	4.1	27.9	41.0
STRAWBERRY	17.0	22.1	25.4
GRAPES	41.8	11.5	9.8
ALMOND	20.4	10.6	5.1
RICE	6.0	9.6	12.4
LETTUCE, HEAD	0.4	4.8	2.5
PEACH	4.3	1.9	0.3
GRAPES, WINE	2.0	2.9	1.2
TOMATOES	2.1	1.0	0.4
APPLE	1.7	1.0	0.6
OTHERS	0.3	6.7	1.4

Parathion is an organophosphate insecticide. In September 1991, U.S. EPA announced that most uses of parathion would be canceled. Uses would be allowed, with certain restrictions, for alfalfa, barley, corn, canola, cotton, sorghum, soybeans, sunflower, and wheat. That decision means that sale, distribution, and use of parathion, including existing stocks, is prohibited except for use on these 9 crops. The original cancellation date was December 31, 1991, but this was later extended to July 31, 1992 for non-emulsifiable concentrate formulations. Thus, uses on crops such as grapes, strawberries, almond, and rice, after 1992 was illegal. However, misreporting of other legal uses, such as reporting uses of methyl parathion as ethyl parathion, may account for the parathion values in the PUR. County agricultural commissioners generally follow up on possible illegal uses.

On almonds, it was used with oil in dormant sprays but only through 1992, when all products were canceled.

Mevinphos

Mevinphos use in production agriculture in 1996.

Measures of pesticide use	Total for mevinphos	Percentage for all AIs
Pounds applied	103	0.0
Number of applications	15	0.0
Acres treated (cumulative)	538	0.0

The percentage of mevinphos use in the crops with the highest use.

Crop	Percent Pounds Active Ingredient	Percent Num. Applications	Percent Acres Treated
GRAPES, WINE	15.4	33.3	48.1
GRAPES	46.8	26.7	16.9
LETTUCE, HEAD	28.7	13.3	9.6
ALFALFA	5.2	13.3	20.4
BROCCOLI	3.9	6.7	4.6
PEACH	0.0	6.7	0.4
OTHERS	0.0	0.0	0.0

Mevinphos is an organophosphate contact and systemic insecticide and miticide. U.S. EPA canceled all uses of mevinphos after December 1, 1995. Thus, mevinphos applications in 1996 were illegal. However, misreporting of other legal uses may account for the mevinphos values in the PUR. Even before 1995 mevinphos use was declining.

On alfalfa, it is used to control aphids. Its use has declined because mevinphos is highly toxic to humans and there are other equally effective pesticides.