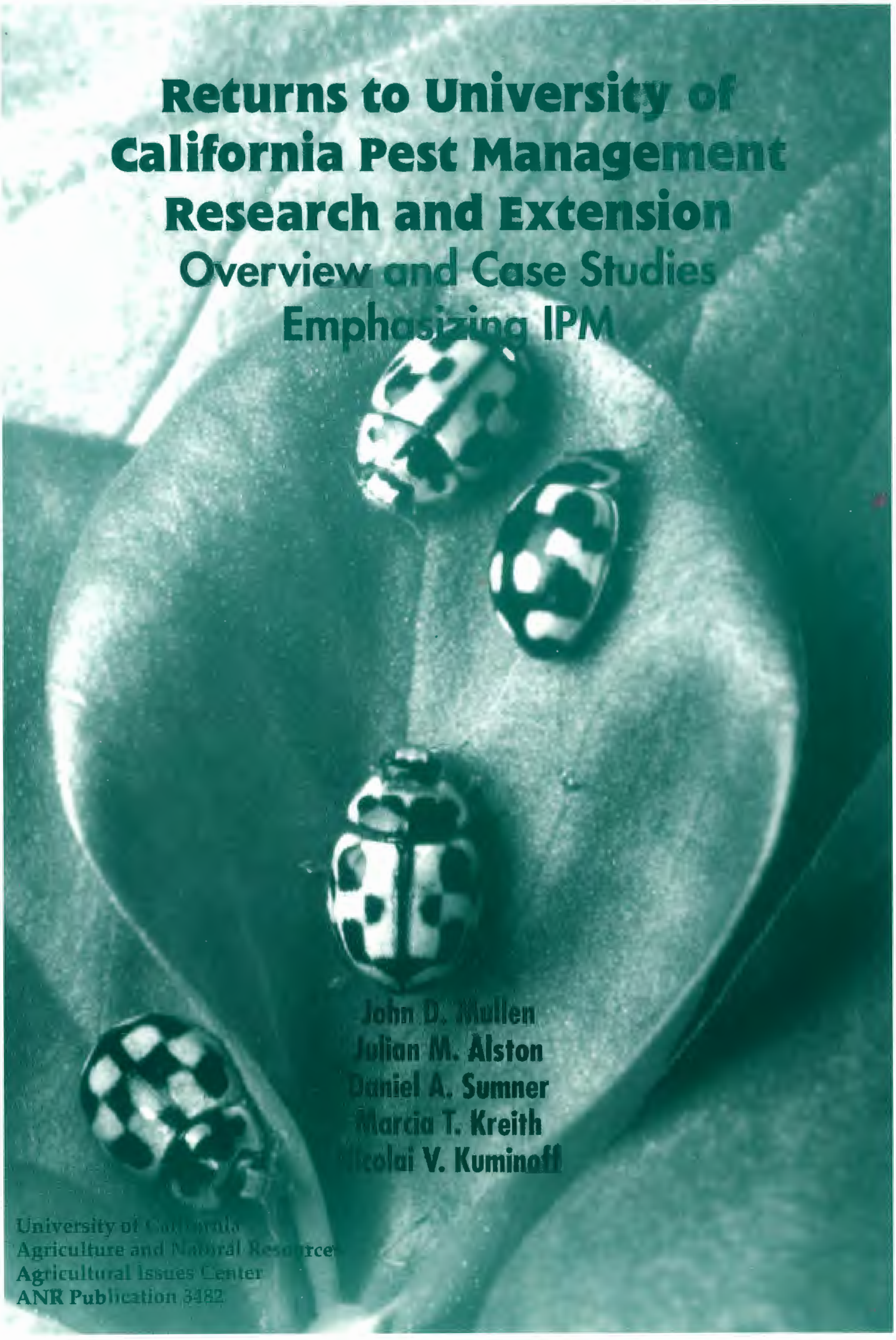

Returns to University of California Pest Management Research and Extension

Overview and Case Studies Emphasizing IPM

John D. Mullen
Julian M. Alston
Daniel A. Sumner
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University of California
Agriculture and Natural Resources
Agricultural Issues Center
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Cover photo: Three-sixteenths-inch-long *Propylea quatuordecimpunctata* (14-spot) lady beetles look for aphids on a fava bean leaf. Photo by Scott Bauer, USDA Agricultural Research Service (ARS).

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EXECUTIVE SUMMARY

In 1997, the University of California system invested almost $87 million in research and extension activities associated with pest management, conducted in many departments across most UC campuses. These activities encompassed a variety of pests that affect California's cropping and livestock industries—including insects and mites, diseases, nematodes, and weeds—and a wide range of control strategies. An important component was the development and extension of integrated pest management (IPM) programs.

Pest management is of interest partly because of its potential contribution to agricultural productivity and net returns to farmers. Pest management is also of interest because of its externalities, or off-site effects, which take the form of either higher costs or yield losses on neighboring farms or increased risks to human health, other species, and the environment through air and water contamination.

The objective of this study was to assess some of the important benefits to industry, consumers and the wider community resulting from the University of California's research and extension programs in pest management. In addressing this objective, we first reviewed key issues in the management of pests in agriculture in California since 1950, including trends in pesticide use, changes in pesticide regulation, and expenditure by the UC system on pest management research and extension. Then we conducted industry case studies of the costs and benefits of pest management technologies, particularly those of an IPM nature that were largely developed and extended by the UC system.

Trends in Pesticide Use

Expenditure on pesticides in California agriculture increased from 1950 to 1999 by a factor of five, to $1 billion (in year-2000 dollars), and accounted for 12 percent of the pesticide expenditures in U.S. agriculture, a little less than California's share of total farm receipts (Chapter 4). By weight, the four most widely used chemicals in California agriculture were sulfur, oils, metam sodium, and methyl bromide. The largest users of pesticides in California were wine grapes (17 percent), table and raisin grapes (16 percent), almonds (8 percent), strawberries (5 percent), and carrots (5 percent). Based on a sample of 62 pesticides, the crops with the highest expenditure on pesticides were cotton (15 percent), almonds (10 percent), table and raisin grapes (9 percent), and wine grapes (7 percent), largely reflecting the relative size of these industries.

The California Department of Pesticide Regulation (DPR) in the California Environmental Protection Agency (Cal-EPA) tracks the use, by weight, of pesticides in a number of categories related to human health risks and air and groundwater quality (Chapter 5). The use of organophosphates and carbamates was slightly lower in 1999 than 1991. Between 1991 and 1999, the use of chemicals known to cause cancer or reproductive problems increased significantly, largely through increased use of metam sodium. The use of toxic air contaminants increased by 23 percent and the use of groundwater contaminants increased by 32 percent between 1991 and 1999.

It is not possible to say whether the state or nation, as a whole, are better or worse off as a result of the changes in pesticide use because 1) trends differ in the use of these classes of pesticides, 2) they pose different risks to human health and the environment, and 3) weight per se may not be a measure of toxicity or carcinogenicity. The limited data collected by the DPR on pesticide-related illnesses and on pesticide residues on food provide no evidence of a change in human health risks associated with agricultural pesticide use. Lack of empirical evidence about human health and environmental outcomes also makes it difficult to assess the public and private benefits and costs associated with regulation. In addition to the costs to agriculture of more expensive pesticides, a cost to the community of pervasive pest management regulation is that food is more expensive, which may lead to higher public health costs because of the resulting reduction in consumption of fruits and vegetables. This cost is sometimes overlooked, and the link between food prices and public health costs has not been empirically analyzed.

The UC Contribution to Pest Management Since 1950

We estimated that UC expenditure on pest management research increased from $32.5 million in 1970 to $60.7 million (year-2000 dollars) in 1997 and generally amounted to about 35 percent of agricultural research in total, and that expenditure on pest management extension increased from $16.2 million in 1970 to $26.2 million in 1997 in year-2000 dollars (Chapter 3).

Agricultural pests are controlled using a variety of techniques and, no doubt, the UC system has operated across the spectrum by developing new techniques and adapting technologies developed by other private and public institutions worldwide to the benefit of both growers and the wider community in California. The contribution of the UC system to the development of integrated pest management (IPM) technologies is widely recognized. These technologies have allowed growers to make more profitable pest management decisions, particularly with respect to the use of pesticides through the use of information about pest populations and knowledge of their interactions with their natural enemies and cultural and chemical control measures. Integrated pest management also has provided better information on which to base the regulation of pesticides.

While UC research and extension resources have been used to develop and extend IPM and other pest management technologies across the broad range of agricultural pests, in our case studies we found that the key UC contributions were often associated with the use of IPM technologies to manage insects and mites (arthropods). One reason for UC leadership in this area of IPM is the public-good nature of technologies based on information and management. The public-good nature of IPM technologies arises not only because they are information- or management-based technologies, but also because they have effects beyond farm boundaries.

The management of insects and mites is made complex by their mobility and ability to adapt to chemical control strategies, perhaps more so than for other pests. This has required a high level of maintenance research to adapt IPM programs to dynamic relationships between pests, their natural enemies, and control strategies.

The Benefits from UC IPM Activities

One way to estimate the benefits from pest management research and extension is to use information on the benefits from agricultural research more generally, a subject of considerable empirical analysis (Chapter 2). In California, agricultural productivity has grown at the rate of about 2.8 percent per annum since 1950. The implied stream of cost savings in California agriculture over 1950-1999 was worth the equivalent of a one-time payment in 2000 of $540 billion (in year-2000 dollars).[1] Our best guess is that, of this total, the UC system may have contributed benefits amounting to $90 billion. The one-time value of the annual investments in research and extension made by the UC system from 1929 to 1997 compounded forward to 2000 was $15 billion. Hence, we estimated a benefit-cost ratio for investments in agricultural research and extension by the UC system of the order of 6:1. Pest management activities have been a significant element of the UC portfolio, and as a first approximation, we would expect that the benefit-cost ratio for investments in pest management would be of a similar magnitude.

We also conducted case studies of pest management in the almond, cotton, orange, processing tomato and lettuce industries in California. We could not individually value the contributions of the host of research and extension programs undertaken since 1950. Our strategy was to identify and value key advances in pest management, usually in the management of arthropods, which could be attributed largely to research and extension by the UC system. Generally, it appears that the key advances are embodied in IPM programs that were adopted by industries since the mid-1970s. The benefit-cost ratios for the almond, cotton, orange and processing tomato industries were 5.5:1, 4.4:1, 0.4:1, and 2.8:1, respectively. The present value in 2000 of the total benefits across these four industries was $1,326.4 million; the cor-

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[1] This present value of benefits was estimated by compounding the annual cost savings over 1950–99 forward to 2000 at a real interest rate of 2 percent per annum.

responding total cost was $460.6 million. Hence the benefit-cost ratio over the four industries was 2.9:1. This is only a partial measure of the benefits, even confining attention to the four industries, and is not comparable to the overall figure of 6:1. We did not attempt to value the benefits to the community from the reduced use of pesticides that was often associated with the new technologies. Also, the measure does not include any benefits from adoption of the same technologies in other states. Nevertheless, the measured benefits from pest management research in just the four industries were sufficient to cover half of the costs of pest management research for all agricultural industries in California.

With the exception of the nematode-resistant tomato varieties, the new technologies in our four case study industries generally depended upon advances in monitoring pest populations and better biological knowledge of the interactions between pests, their natural enemies, and chemical control strategies. Expenditure of $460.6 million on these four commodities amounted to only 16 percent of the total expenditure of $2,803 million on research and extension for pest management. If we had been able to conduct additional case studies of other industries, we would be in a stronger position to generalize about the returns from UC pest management research and extension activities, both with respect to pest management in different types of commodities and with respect to other broad areas of research and extension, such as breeding or plant nutrition programs. The grape industry is likely to account for a significant share of expenditure on pest management research and extension and, hence, would be an obvious candidate for future case study analysis.

CHAPTER 1

Introduction

1.1 Genesis of the Study

The management of pests, including weeds, insects, mites, nematodes and diseases, in California agriculture is an important issue for the producers and consumers of food and fiber because of its impact on the quantity and quality of production and on production costs. Producers obtain higher profits while, at the same time, consumers benefit from lower prices and higher-quality produce as a result of more efficient pest management. The potential to protect yields and reduce costs has been an important incentive for private and public investment in research and development and extension in pest management, and the University of California (UC) has been a prominent participant.

The management of pests is also important to the community in general because some of the effects of pest management practices, good and bad, spill over from the farmers who use them to their neighbors and the rest of the community. The potential "spillovers" come in a variety of forms. Some may affect production costs on neighboring farms because of the mobility of pests, pesticide drift, and the development of pest resistance to control measures. In addition, the use of pesticides on farms involves potential risks to human health, either to farm workers or the larger community through exposure to pesticides through air or water pollution or as residues on food products. Water and air contamination by pesticides also pose threats to other species and to the environment more generally. Concerns about community effects have led to a high degree of regulation of pest management, particularly in California, and to further investments by the UC system to develop and extend pest management technologies that mitigate the spillovers, or externalities, and to educate users about the safe use of pesticides.

The substantial investment of public resources in pest management research and extension in the UC system has not been subject to systematic scrutiny with a view to benefit-cost assessment. The present study was conceived to address that deficiency; more specifically, to describe and document the UC research and extension programs related to pest management and to evaluate their consequences, both qualitatively and, where possible, quantitatively.

1.2 General Strategy, Broad Aims and Specific Objectives of the Study

The focus of this study was on the pest management research and extension efforts of the UC system, paying particular attention to integrated pest management (IPM) and biological control as elements of the pest management program. The general strategy was to provide an overview of this system-wide effort, complemented by aggregate performance measures and case studies in key industries, selected to give a clearer sense of the nature of what had been achieved by the research and extension effort.

The idea was to a) describe the institutional arrangements for financing and carrying out public agricultural pest management research and extension in California, b) document the sources of funds for different types of research and extension over time and the uses to which they have been put, c) document the achievements from this investment over time in terms of significant discoveries, changes in technology facilitated, disasters averted and cost savings allowed in the face of changing pest resistance, new pest problems, changing regulations over pest control methods, and d) attempt to translate the above information on technological potential, sources of new technologies and adoption rates into evidence on productivity enhancement or other benefits as a result of UC pest management research and extension in the context of overall rates of productivity growth and research benefits. In addition, we sought to develop detailed case studies of benefits from the adoption of specific pest management technologies as a result of UC agricultural research and extension which might be compared with the total cost of the research and extension programs as well as with the costs of specific elements.

In conceiving the study, we had in mind to develop approaches for measuring benefits of various types, including benefits from a) enhanced productivity or, in some cases, productivity losses prevented, and profitability of farming, b) improvements in farmworker safety, c) improvements in food safety, and d) reductions in environmental pollution. We also had in mind that these approaches would be applied empirically. To do this would require drawing on, and in some sense integrating, ideas from several strands of applied and technical agricultural economics literature. These strands include literature on modeling and measuring a) productivity change in the presence of distortions arising from environmental externalities, regulation and dynamic responses; b) the benefits and costs and rates of return to public investments in research and extension; and c) the economic impacts of externalities and other environmental factors that affect human health and safety and other environmental concerns.

In practice, not all of the aims outlined above could be fully accomplished. The practical objective of the study was defined more simply: to document the net benefits to industry, consumers and the community since 1950 from

UC research and extension programs in pest management. We focused, in particular, on the benefits from new information-based IPM technologies for the management of arthropods.

Grieshop and Pence (1990) summarized the first decade of IPM program effort and Klonsky and Shouse (2000) summarized the second decade. Both summaries drew on extensive surveys of principal investigators of IPM projects over the decade of interest. For each period, investigators categorized their projects by discipline, crop, and affiliation of participants. They also listed numbers of publications that resulted from their projects as well as their assessment of use of project results in the field, particularly in terms of reduced pesticide application. In both periods, IPM projects included a wide variety of campus-based researchers from all campuses, county-based extension staff and growers, among other participants. Commodity breadth seemed to grow over time. In the earlier decade, more than two-thirds of the projects concentrated on grapes, citrus, cotton, tomatoes, alfalfa and almonds (Grieshop and Pence 1990). In the second decade, investigators listed a higher proportion of cross-commodity projects (Klosnky and Shouse 2000).

Unlike the present effort, the summaries based on surveys of IPM investigators did not place IPM in the context of other pest management research or, most importantly, did not attempt to evaluate the effect of UC research and development on actual outcomes in the field. By relying on surveys of investigators, these summaries focused on objectives of projects and views of the researchers about whether their goals were achieved. They found that most projects were focused on improved pest management procedures and especially on reduced pesticide use and other environmental goals rather than lower farm costs or increased yields or profitability. The present study focuses more on the effect of pest management on agricultural productivity and profitability using measured outcomes that go beyond the views of UC project researchers.

1.3 Focus of the Study

As noted above, and as with any study of this nature, we recognize a number of limitations of the study. Our analysis of aggregate data on UC resources devoted to pest management and the productivity returns associated with those investments are much broader than IPM and much broader than the commodity-focused case studies. All UC investments in pest management R&D are included in the denominator of our cost/benefit calculations and a broad measure of the contribution to productivity growth is in the numerator of that calculation. The same breadth is found in our review of pesticide use and the regulation of agricultural pest management in California. Our economic analysis is limited in that the study is not able to fully account for broad environmental or farm worker health and safety consequences of these broad UC pest management efforts. And, of course, as the title suggests, the focus of the study is explicitly on agriculture as opposed to urban pest management.

When we turn to the crop case studies, we focus on those technologies and topics that were found to be most important for the crops studied. These case studies are not comprehensive. Examining in detail only five crops leaves out a number of kinds of pests or other issues that may have been more important for other commodities. The commodities selected for detailed analysis are each important in their own right and represent the breadth of crop agriculture in California. Almond production is now a billion-dollar industry that has expanded rapidly. Almonds are now grown throughout the Central Valley. California is the dominant almond producer in the world. Cotton has long been the largest field crop in the state by gross value and is well known as a crop with many pest challenges. The orange industry is the major citrus crop in California and a major source of farm income in the southern part of the state. Processing tomatoes have also expanded over the past 50 years and are the most important vegetable for processing grown in California. Lettuce is the most important fresh vegetable crop grown in California. It is a major crop in the Central Coast region. Together these crops represent about $4 billion in gross farm income in California.

We did not consider in the report the counter-factual policy question of what the outcomes would have been if UC pest management investments were allocated differently. Thus we are silent about the payoff to investments that were not made, but might have been. Such policy analysis might be interesting in some contexts, but that was not a part of our objectives. We also did not attempt to evaluate the payoff to specific projects or to rank projects in term of their economic effects. Such analysis is left for future research.

1.4 The UC Contribution

The most significant development in the management of pests has been the availability of synthetic pesticides, starting with 2,4-D, DDT and other phenoxy herbicides and organochlorine insecticides soon after World War II. This development provides a natural way of classifying pest management into three eras:

- Presynthetic pesticide era (i.e., pre-DDT) up to the late 1940s
- Synthetic pesticide era from the 1950s to the late 1970s
- Integrated pest management (IPM) era in the 1980s and 1990s, and continuing.

Since 1950 major advances in the management of pests in agriculture have

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[1] An Agricultural Issues Center report edited by Coppock and Kreith (1999) discusses exotic pests and their implications for California agriculture.

come from such developments as new pesticides, the use of biotechnology to incorporate resistance traits in crops, enhanced training of pest managers and workers, use of knowledge of pest behavior to improve the timing and application of pest control measures, and the development of precision spray equipment. The UC system has contributed across this broad spectrum, and the contribution has taken many forms. In particular the UC system, through applied research and extension in the different production regions of California, has assisted in the widespread and rapid adoption of new technologies based on new pesticides or new varieties developed by others. Perhaps the UC system also contributed some of the basic research that led to new pesticides or chemicals. Another contribution is likely to have been in providing growers with information on how best to manage short-term invasions of pests that are exotic to them.[1] UC pest management research has shifted to some degree toward how best to manage pests to meet community expectations regarding risks to human health and the environment.

The task of fully identifying, let alone valuing, each of these contributions over 50 years was beyond our means. Instead, we identified important UC contributions and quantified benefits from these contributions in a series of case studies. Our expectation was that the benefits flowing from these contributions alone might justify the total investments made by the UC system in pest management.

The UC system has achieved great success in developing and extending the concept of IPM based on the use of information to better manage arthropod pest populations, as proposed by UC scientists, Stern, Smith, van den Bosch and Hagen (1959). They argued that increasing problems in managing arthropod (i.e., insect and mite) pests came from the development of agriculture and the sometimes indiscriminate use of pesticides during the synthetic pesticide era. They called for the integration of biological and chemical control together with monitoring pest populations relative to economic thresholds and outlined a pest management strategy that became the basis of many IPM programs introduced in the decades that followed.

Subsequently the UC system has made investments in research and extension activities that have generated new information about the biology of insects and mites, their population dynamics, and their interactions with their natural enemies, and cultural and chemical control measures. This information has been valuable to growers because it has allowed them to make more profitable decisions about the management of arthropod pests and their natural enemies, particularly with respect to the use of pesticides. The IPM concept has been extended from managing arthropods to the management of weeds and diseases as well. The information has also allowed the government to make better decisions about the regulation of pesticides.

Some of the benefits from this research, particularly those leading to biological controls, have been long lasting because they have the potential to permanently lower pest populations. However, because of the capacity for pests to adapt to some control strategies, particularly those of a chemical nature, continuing streams of research and extension investments are required to maintain the flow of information about the biology of pests and control strategies and, hence, to protect efficiency gains in pest management. Continuing investments to revise pest management strategies are also required because the community's expectations with respect to risks to human health and the environment are changing in response to greater knowledge of the risks and greater wealth.

One reason for the UC system's leadership in this area is that technologies based on information and management have more of the characteristics of public goods that are not supplied adequately by the private sector alone, and investment in these areas fits more naturally with the role of public institutions. Other technologies are often embodied into an input such as a chemical or seed, and hence the role of the private sector in their development has been much larger if not exclusive, particularly with patents on pesticide formulation and the advent of plant variety rights.

The UC system may have been more successful in developing information-based IPM technologies for arthropods than for other pests, but the evidence is incomplete and the question remains unresolved. Some of the pertinent arguments and implications for research management are discussed in Chapter 3. It is important to reiterate that while we have concentrated on valuing UC activities in relation to generating information about the biology of arthropod pests and their natural enemies and cultural practices that lead to profitable pest management decisions, we are aware that many other UC activities related to pest management in areas including toxicology, statistical modeling, engineering innovations, and human health assessments have been of value to industry and the community.

1.5 Outline of the Report

Agriculture in California and the contribution of research to the strong growth in productivity in California agriculture are reviewed in Chapter 2. In that chapter, we start by identifying the significant contribution to the value of agricultural production in California since 1950 that arises from productivity growth from all sources. We then develop a hypothetical view of what might have been the contribution of the UC investments in pest management research and extension to these aggregate productivity gains.

In Chapter 3 significant advances in pest management are discussed, and the UC contribution is identified. Information on the investments in pest management research and extension since 1950 by the UC system is also presented in Chapter 3. In Chapters 4 and 5, the use and regulation of pesticides in California are reviewed. These chapters are based on data from the U.S. Department of Agriculture (USDA) and from the California Department of Pesticide Regulation (DPR), but an important contribution of our study has been to estimate expenditure on pesticides for some important commodities in California.

A review of economic theory and of empirical analyses of pest management issues is presented in Chapter 6. Chapter 7 describes the broad benefit-cost framework used in the case studies of almonds, cotton, oranges, processing tomatoes and lettuce, which also underpins the aggregate analysis in Chapter 2. The choice of these industries for the case studies was based on a number of considerations. All are large industries in California. All use pesticides extensively, and IPM programs have been attempted in each of them. Some, such as almonds, cotton and processing tomatoes had been evaluated to some degree in the past, and historical information was available about the actual or expected impact of new pest management technologies. The case studies then follow in Chapters 8 through 12.

An executive summary draws together this material and concludes by comparing the results from the hypothetical aggregate analysis in Chapter 2 and the case studies to make inferences about the returns from UC research and extension activities in pest management.

CHAPTER 2

Productivity Growth in California Agriculture, 1950–2000

California agriculture is large, diverse, complex and dynamic and has changed significantly over the past 50 years. Perhaps the most noticeable trend is that, while crop acreage has remained relatively stable, agricultural productivity, production and the value of production have increased dramatically. This chapter provides a brief description of California agriculture and of some of the major trends between 1950 and 2000, focusing on productivity growth and its value. A crude benefit-cost analysis places a value on this productivity growth, apportions benefits between the California Agricultural Experiment Station (CAES) and various other sources, and compares these benefits with the CAES investments in research and extension over the period 1929-1997.

2.1 Measures of California Agriculture

California has been the leading state in agricultural cash receipts in every year since 1948.[1] We express prices and expenditures in real year-2000 dollar terms by dividing the nominal values by the U.S. gross domestic product (GDP) deflator, based equal to 1 in year 2000. California's agricultural cash receipts have nearly doubled in real terms since 1950. Table 2.1 shows that in constant year-2000 dollars, cash receipts increased from $13.9 billion in 1950 to $27 billion in 1997 before decreasing somewhat during 1998 and 1999 as a result of such factors as poor weather, the Asian financial crisis and low prices.

About half of California's agricultural production value comes from the San Joaquin Valley. The other major production regions are the Central and South Coast, Desert, and the Sacramento Valley. The share of production across regions in California has changed over time, with steady growth in the San Joaquin Valley. Urbanization has played some role in this process. In 1948 Los Angeles County was the top agricultural county in California and the United States. In 1999 it ranked 25th in California in value of production.

Over the past 50 years there has been a general shift from field crops to fruits, tree nuts and vegetables. The impact of this shift can be seen in increases in cash receipts for such commodities as almonds, wine, processing tomatoes and strawberries, all of which grew between 400 and 800 percent

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[1] A detailed quantitative description of California agriculture can be found in the Agricultural Issues Center report, *The Measure of California Agriculture*, by Kuminoff, Sumner and Goldman (2000).

in real terms between 1950 and 2000. In 1999 fruits, tree nuts and vegetables represented approximately 55 percent of the cash receipts from California agriculture. California is the major or only significant production region in the United States for many of these crops, including almonds, grapes, lettuce and strawberries. Animal products accounted for another 26 percent of cash receipts, field crops for 10 percent and nursery and floriculture for 8 percent. Crops registered as organic represent a small but increasing share of cash receipts—about 0.6 percent of total agricultural production value in 1998.

The top five agricultural commodities in California, ranked by cash receipts, in 1999 were dairy products, grapes, flowers and nursery products, cattle and calves, and lettuce. In 1999 the next five crops were strawberries, processing tomatoes, oranges, almonds and cotton. Table 2.1 shows cash receipts for selected commodities from 1950 to 1999 and their share of total agricultural cash receipts in 1999.

Agricultural cash receipts have grown faster in California than for the nation as a whole. Table 2.2 shows that California increased its share of national agricultural cash receipts from about 8 percent in 1950 to 13 percent in 1999. However, the state's growth in agricultural cash receipts over the past 50 years was slower than its overall economic growth. Table 2.2 also shows that the ratio of agricultural cash receipts to California's gross state product decreased steadily from 5.3 percent in 1963 to 2.0 percent in 1999. When input and processing industries related to agriculture are included, agriculture accounted for about 6.6 percent of California's income and 7.3 percent of its jobs in 1998. Agriculture is particularly important to the San Joaquin Valley, where it accounts for 32 percent of income and 37 percent of jobs when multiplier effects are taken into account (Kuminoff, Sumner and Goldman 2000).

California agriculture is comprised of many small farms. A much smaller number of large farms account for most of the production. For example, the 16 percent of California farms (about 10,000 farms) with sales of more than $250,000 in 1997 also represented over 90 percent of total sales value. Indeed, the 5,000 farms with gross sales over $1 million accounted for 75 percent of sales. Meanwhile, almost 44 percent of California farms sold less than $10,000 worth of agricultural products. Most of these farms were operated by retired or part-time farmers. More than three-quarters of all farms in California are individual or family proprietorships, 15 percent are partnerships, and 6 percent are family farms that are legally organized as corporations. About 1 percent of all California farms are nonfamily held corporations.

Over the past 50 years California's agricultural land base decreased, but its acres of harvested cropland remained constant or increased slightly. Agriculture remains a significant land use. Of California's 99.6 million acres of land, about 43 million were used for agriculture in 2000. Of this amount, about 11 million acres were privately owned cropland, and the remainder was public and private grazing land. According to census statistics, land in California farms decreased by about 27 percent between 1954 and 1997. However, this decrease was mostly due to decreases in rangeland. During the same period harvested cropland increased by 3 percent amid annual fluctuations.

Table 2.1 Cash receipts from California crops, 1950–2000

Year	Alfalfa	Almonds	Carrots	Upland cotton	Grape-fruit	Lemons	Lettuce	Oranges	Processing tomatoes	Raisins	Rice	Straw-berries	Table grapes	Wine	All com-modities
							(year-2000 dollars, millions)								
1950	599	126	120	1,236	20	232	366	563	138	530	230	100	209	231	*13,916*
1951	795	115	170	1,980	18	253	406	459	382	408	303	105	134	150	*15,481*
1952	829	95	146	1,648	23	276	443	460	261	360	412	119	121	113	*14,881*
1953	586	102	168	1,530	24	245	443	492	180	349	368	151	122	120	*14,633*
1954	609	118	171	1,362	26	215	425	511	151	322	308	166	130	138	*13,869*
1955	776	178	151	1,078	29	222	463	579	245	375	264	182	148	116	*14,278*
1956	667	246	127	1,234	26	192	376	534	329	405	279	215	127	128	*14,801*
1957	669	96	147	1,307	33	187	412	546	224	431	220	163	144	143	*13,963*
1958	668	76	117	1,350	25	160	308	606	295	546	209	163	165	146	*14,168*
1959	766	189	133	1,516	23	160	357	562	213	419	271	159	141	136	*15,313*
1960	704	134	116	1,443	19	162	360	515	254	379	294	152	132	134	*15,498*
1961	614	178	120	1,356	21	160	319	434	333	429	317	174	106	175	*15,548*
1962	641	150	111	1,480	32	233	413	557	418	453	384	183	137	196	*16,106*
1963	839	164	89	1,346	55	216	399	601	291	457	330	208	119	159	*16,366*
1964	742	218	102	1,349	41	199	425	503	431	475	372	215	128	201	*16,849*
1965	679	202	119	1,151	54	212	434	497	462	437	352	180	95	163	*16,737*
1966	788	227	134	724	46	220	604	460	495	455	411	178	126	164	*17,671*
1967	769	189	143	706	51	228	494	357	608	440	362	184	114	166	*16,698*
1968	691	181	165	760	44	243	482	426	825	506	482	247	107	188	*17,485*
1969	686	287	139	592	47	231	527	415	438	522	400	235	146	242	*17,359*
1970	724	295	108	519	58	257	538	444	391	506	349	229	134	229	*16,681*
1971	773	305	170	592	61	240	662	431	462	549	316	247	149	373	*17,010*
1972	845	330	185	888	54	264	616	444	517	515	433	227	137	457	*18,535*
1973	1,120	635	166	1,322	39	292	830	499	636	1,004	795	267	263	688	*22,983*
1974	1,268	497	183	1,724	47	261	724	519	1,089	738	862	305	224	481	*25,058*
1975	1,103	316	203	1,365	41	229	669	419	1,214	802	617	300	253	386	*22,632*
1976	1,260	477	147	2,045	48	181	828	405	720	742	385	343	222	455	*22,991*

1977	1,101	636	181	1,781	69	220	721	594	1,012	839	389	400	312	576	*22,423*
1978	925	562	161	1,313	68	248	893	569	747	846	400	320	298	794	*23,683*
1979	1,299	1,143	169	2,427	45	294	754	468	877	1,135	665	347	265	732	*26,368*
1980	1,378	887	176	2,176	69	229	724	547	620	1,194	962	382	329	788	*26,218*
1981	1,023	514	176	1,850	34	145	798	632	544	933	516	383	317	820	*24,102*
1982	1,069	502	187	1,593	39	144	773	511	680	928	385	475	328	756	*23,372*
1983	1,033	360	192	1,069	48	158	796	618	609	587	249	434	274	611	*20,536*
1984	946	668	219	1,398	94	210	757	757	639	533	309	477	216	571	*21,584*
1985	962	523	168	1,340	86	247	666	530	568	508	220	484	194	571	*20,753*
1986	888	655	213	904	80	217	689	616	572	617	125	547	270	618	*21,062*
1987	917	893	222	1,363	78	235	1,030	632	528	667	259	561	324	667	*21,830*
1988	1,084	800	217	1,169	66	267	840	616	514	701	245	520	372	862	*22,152*
1989	895	618	269	1,178	97	308	860	713	753	852	261	478	363	957	*23,347*
1990	899	739	230	1,247	61	299	844	458	763	686	223	516	342	836	*23,747*
1991	688	673	249	971	70	225	717	553	763	638	225	555	324	901	*21,196*
1992	622	805	253	954	52	236	801	550	521	715	220	597	267	1,043	*22,112*
1993	758	1,058	206	1,046	58	235	952	526	601	681	341	521	412	985	*23,394*
1994	829	1,075	254	1,166	58	252	778	527	730	609	320	721	345	953	*24,279*
1995	714	960	299	993	53	229	1,158	534	720	574	339	601	403	1,052	*24,529*
1996	774	1,089	297	938	56	293	781	625	696	658	317	625	411	1,115	*25,152*
1997	925	1,182	362	807	71	227	994	645	583	727	364	720	387	1,843	*27,049*
1998	703	729	347	386	84	222	718	431	591	626	299	784	332	1,545	*25,555*
1999	665	702	461	435	53	277	744	438	881	695	na	894	427	1,588	*25,310*
2000	621	852	347	733	na	na	1,003	na	617	782	na	767	423	1,591	*na*
Share of total								(percentage)							
1999	2.6	2.8	1.8	1.7	0.2	1.1	2.9	1.7	3.5	2.7	na	3.5	1.7	6.3	

Source: Compiled by the authors from the National Agricultural Statistics Service (NASS), Non-Citrus Fruit and Nut Annual Reports, and 2000 Preliminary Summary; NASS, Vegetables Annual Summary Report; NASS, Citrus Fruits, Annual Report; NASS, Agricultural Prices Annual Summary; U.S. Department of Agriculture (USDA) Economic Research Service Data Sets (online data); CASS, Field Crops, Annual Summary; NASS, Agricultural Statistics; Californio Agricultural Statistics Service (CASS), Fruit and Nut Report, Annual Summary; CASS, Vegetable Report, Annual Summary; and NASS, Field Crops, Annual Summary. All NASS publications are online data.

The largest production expenses for California farmers in 1997 were farm labor (29 percent), animals and feed (20 percent), interest, rent and taxes (11 percent), and pesticides and fertilizer (10 percent).

Another important input to agricultural production in California is water. Surface water provides most of the irrigation supply, but groundwater is also an important source in certain areas. A combination of federal, state and local water projects capture, store, transport and import surface supplies. On average, agriculture uses about 43 percent of the state's water budget (Kuminoff, Sumner and Goldman 2000).

California participates in national and international markets for agricultural products. Much of what we eat in California is imported from other states and countries, while most of California's production is shipped out of state. In recent years, between 16 and 19 percent of California's annual agricultural production has been exported to international destinations.

Some of the changes in California agriculture have been driven by changes in demand for food and consumption patterns, reflecting growth in per capita incomes, changing lifestyles, increasing population and other demographic changes. We have seen substantial shifts toward consuming meals away from home, pre-prepared meals and more consumption of fruit and vegetables that have had implications for the demand for California's produce.

From 1952 to 1999 the share of disposable personal income spent on food in the United States decreased from 21 percent to 12 percent. Over the same time period the index of U.S. food prices decreased relative to the Consumer Price Index. In other words, during the past 50 years food has become cheaper relative to other goods, and today we spend a much smaller share of our income on food than we used to.

The fact that food has become cheaper means that supply has been growing faster than demand. That this has happened in spite of considerable growth in the demand for food, a shrinking land base for agriculture, and a much-reduced agricultural labor force reflects remarkable growth in agricultural productivity. California agriculture has participated in these global trends in general, but also has some unique elements related to its particular combination of crops, climate, resources, and technologies.

2.2 Productivity Patterns in California Agriculture

The value of California's agricultural output increased from $13.9 billion in 1950 to $25.3 billion in 1999 (cash receipts in constant, year-2000, dollars). This steady growth in agricultural production happened in spite of decreases in land and labor employed. For many crops, productivity growth is evident from dramatic increases in yields, but yields also reflect changes in inputs, including agricultural chemicals and water. Aggregate measures that take into account changes in all inputs and outputs provide more meaningful information about productivity growth.

Acquaye, Alston and Pardey (2002, 2003) measured growth in aggregate agricultural output, input use and multifactor productivity in each of the 48 contiguous U.S. states for the period 1949-91.[2] For the 48-state aggregate, they reported an average annual, compound productivity growth rate of 1.90 percent per year over the period.[3] They also reported an average annual, compound growth rate of productivity of 1.81 percent per year over the period 1949-91 for California agriculture. Underlying this estimate is an aggregate input growth rate of 1.09 percent per year (such that the index of total inputs grew from 100 in 1949 to 158 in 1991) and a growth rate of aggregate output of 2.89 percent per year (such that the index of total output grew from 100 in 1949 to 337 in 1991). In other words, output grew much faster than inputs.

Productivity is defined as the ratio of total output to total input and was equal to 1.0 in 1949 (given that the indexes of input and output were defined as both equal to 100 in 1949) and, incidentally, was also equal to 1.0 in 1950. By 1991 this ratio of total output to total input had more than doubled, increasing from 1.0 to 2.13. The growth rate of this ratio—the rate of growth of productivity—is equal to the difference between the growth rates of total output and total input, and it measures the rate of growth in production that is not accounted for by growth in inputs. Appendix tables A2.1 and A2.2 provide details on the indices of inputs and outputs and their underlying components.

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[2] Acquaye (2000) provides more detail on methods and additional results.

[3] Acquaye, Alston and Pardey (2002, 2003) compared their estimates with those of Ball et al. (1999) over the shorter period 1960-90 and found that although they reported similar growth rates for the 48-state aggregate (2.00 percent per year versus 1.99 percent per year), they reported quite different growth rates for some states, including California (2.35 percent per year versus 1.93 percent per year for 1960-90). This variance is a consequence of differences in methods between the studies that are not yet fully understood. The comparison is raised here to point out that productivity estimates vary, depending on procedures, and different estimates are useful for different purposes. The Acquaye, Alston and Pardey approach was designed to provide estimates that are useful for measuring consequences of public sector research, with specific effort to remove the effects of improvements in input quality. Such adjustments tend to result in lower measured productivity growth rates. Another interpretation is that the Acquaye, Alston and Pardey estimates, being lower than the Ball et al. estimates, will imply more conservative (at least, lower) estimates of the impacts of research-induced productivity growth.

Table 2.2 California agriculture cash receipts as a share of U.S. agricultural cash receipts and of California gross state product, 1950–1999

Year	California agricultural cash receipts	U.S. agricultural cash receipts	California gross state product	California ag cash receipts/U.S. ag cash receipts	California ag cash receipts/California gross state product
	(current dollars, billions)			(percentage)	
1950	2.3	28.5	na	7.98	na
1951	2.7	32.9	na	8.24	na
1952	2.6	32.5	na	8.13	na
1953	2.6	31.0	na	8.50	na
1954	2.5	29.8	na	8.45	na
1955	2.6	29.5	na	8.95	na
1956	2.8	30.4	na	9.31	na
1957	2.8	29.7	na	9.29	na
1958	2.9	33.5	na	8.57	na
1959	3.1	33.6	na	9.31	na
1960	3.2	34.0	na	9.46	na
1961	3.3	35.2	na	9.28	na
1962	3.4	36.5	na	9.39	na
1963	3.5	37.5	65.9	9.39	5.34
1964	3.7	37.3	70.9	9.85	5.19
1965	3.7	39.4	75.9	9.45	4.90
1966	4.0	43.4	83.0	9.30	4.87
1967	3.9	42.8	88.7	9.20	4.44
1968	4.3	44.2	98.0	9.73	4.39
1969	4.5	48.2	105.8	9.30	4.23
1970	4.5	50.5	111.6	8.98	4.06
1971	4.9	52.7	119.2	9.21	4.07
1972	5.5	61.1	132.2	9.03	4.17
1973	7.2	86.9	146.5	8.31	4.93
1974	8.6	92.4	161.0	9.29	5.33
1975	8.5	88.9	179.9	9.53	4.71
1976	9.1	95.4	201.5	9.54	4.51

(continued)

Table 2.2–Continued

Year	California agricultural cash receipts	U.S. agricultural cash receipts	California gross state product	California ag cash receipts/U.S. ag cash receipts	California ag cash receipts/California gross state product
		(current dollars, billions)			(percentage)
1977	9.4	96.2	229.3	9.81	4.12
1978	10.7	112.4	263.4	9.51	4.05
1979	12.9	131.5	294.9	9.80	4.37
1980	14.0	139.7	327.9	10.01	4.27
1981	14.1	141.6	368.3	9.93	3.82
1982	14.5	142.6	392.9	10.16	3.69
1983	13.2	136.8	425.8	9.67	3.11
1984	14.4	142.8	484.1	10.10	2.98
1985	14.3	144.1	529.0	9.92	2.70
1986	14.8	135.4	567.0	10.96	2.62
1987	15.8	141.8	624.0	11.17	2.54
1988	16.6	151.2	684.5	10.99	2.43
1989	18.2	160.8	742.9	11.31	2.45
1990	19.2	169.5	798.2	11.33	2.41
1991	17.8	167.9	814.2	10.59	2.18
1992	19.0	171.3	831.0	11.09	2.29
1993	20.6	177.9	847.0	11.57	2.43
1994	21.8	181.1	878.1	12.03	2.48
1995	22.5	188.0	924.6	11.97	2.43
1996	23.5	199.1	971.8	11.81	2.42
1997	25.8	207.6	1,043.7	12.42	2.47
1998	24.7	196.6	1,118.9	12.55	2.20
1999	24.8	188.6	1,229.1	13.15	2.02

Sources: Compiled by the authors from the U.S. Department of Agriculture, Economic Research Service, Farm Business Economics Briefing Room, online data, 2001; and California Department of Finance, California Statistical Abstract 2000, online data.

Note: na = not available

2.3 Aggregate Benefits from Research-Induced Productivity Growth

In what follows, we extrapolate the rate of productivity growth from Acquaye, Alston and Pardey (2002, 2003) that was computed using data for 1949-91 and apply it to the period 1950-1999.[4] Compounding this growth rate of 1.81 percent per year over 49 years from 1950, the index of productivity in 1999 would be about 240. That is, if inputs had been held constant at the 1950 quantities, output would still have increased by a factor of 2.4:1. In other words, of the actual output in 1999, only 42 percent (i.e., 100/240 = 0.42) could be accounted for by conventional inputs using 1950 technology, holding productivity constant. The remaining 58 percent (i.e., 140/240 = 0.58) is accounted for by improvements in infrastructure, inputs and other technological changes that gave rise to a 140 percent increase in productivity. Hence, of the total production, worth $25.3 billion in 1999, only 42 percent, or $10.5 billion, could be accounted for by conventional inputs using 1950 technology, and the remaining $14.8 billion is attributable to the factors that gave rise to improved productivity. Among these factors is new technology developed and adopted as a result of UC agricultural research and extension.[5]

If productivity had stayed constant at the 1950 value of 1.0, the pattern of total output would have followed the pattern of total input (i.e., in every year the index of output would be equal to the index of input). Figure 2.1 shows the value of output (expressed in constant year-2000 dollar terms by dividing cash receipts by the GNP deflator based at 1.0 in the year 2000) divided into two parts: 1) the lower part, representing what the value of output would have been, given the actual input quantities, if productivity had not grown since 1950, and 2) the upper part, a residual representing the value of additional output that is attributable to productivity growth.[6]

2.4 Attribution of Benefits and Comparison with Costs

The stream of benefits from productivity growth is attributable to various things, such as public and private investments in agricultural research and extension in California and elsewhere, improvements in infrastructure, investments in education and improvements in human capital (and other

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[4] Data are not available in the right forms to extend the Acquaye, Alston and Pardey (2002, 2003) measures up to the present. If resources were available to do the work, the series could be updated to 1996. There is no reason to believe that the underlying rate of productivity growth was slower in the 1990s than in the previous decades, but past measured rates of productivity growth varied substantially from decade to decade.

[5] Alston, Pardey and Carter (1994) documented the past CAES investments in agricultural research and estimated the rate of return to those investments to be in the range of 20 percent per annum. They also documented case studies pertaining to particular California commodities. Alston and Zilberman (1997) provide a general overview of technological change in California agriculture.

[6] A similar partitioning was made by Alston, Pardey and Carter (1994), who provide a justification for the use of such a measure of benefits from research-induced productivity improvements as an approximation. See, also, Jetter, Alston and Farquharson (2001).

changes in input and output quality that may have not been fully taken into account in the indexing procedures used to measure productivity), and spillovers of knowledge and technology from other (nonagricultural) industries. Compounding the stream forward at a real interest rate of 2 percent per annum, the stream is equivalent to a one-time payment of $540 billion in 2000, an enormous benefit from improved agricultural productivity in California during the post-WWII period.

It is difficult to partition and attribute these benefits appropriately among the various sources. Many past studies have used procedures that would give all the credit to the California Agricultural Experiment Station (CAES).[7] More-careful studies have paid attention to the roles of input quality, private research, different elements of public research and extension, and knowledge and technology spillovers.

Here, we propose a crude partitioning based on various pieces of information. First, in constructing the data used to measure productivity, Acquaye, Alston and Pardey (2002, 2003) made adjustments for measurable changes in input quality, so it may be reasonable to presume that public and private research are responsible for most if not all of the measured productivity growth. Second, since private and public agricultural research expenditures are broadly comparable,[8] perhaps a reasonable approximation is to assign equal shares, such that half the measured growth is attributed to public research investments.[9] Third, Alston (2002) found that federal investments in public agricultural research and spillovers from public agricultural research in other states were each approximately equally as important as public research and extension investments made in California—i.e., the public sector in California is estimated to be responsible for about one-third of California's total productivity growth attributable to all public agricultural research and extension. Hence, combining these three elements, in broad terms, perhaps one-sixth of the measure of California's agricultural productivity growth over the 1950-99 period may be attributable to California's public investments in agricultural research and extension. Even after giving the lion's share—and perhaps too much—of the credit for California's agricultural productivity growth to other sources, a significant benefit can be attributed to California's public investments—this partitioning would suggest $90 billion of the $540 billion in total benefits from productivity growth.

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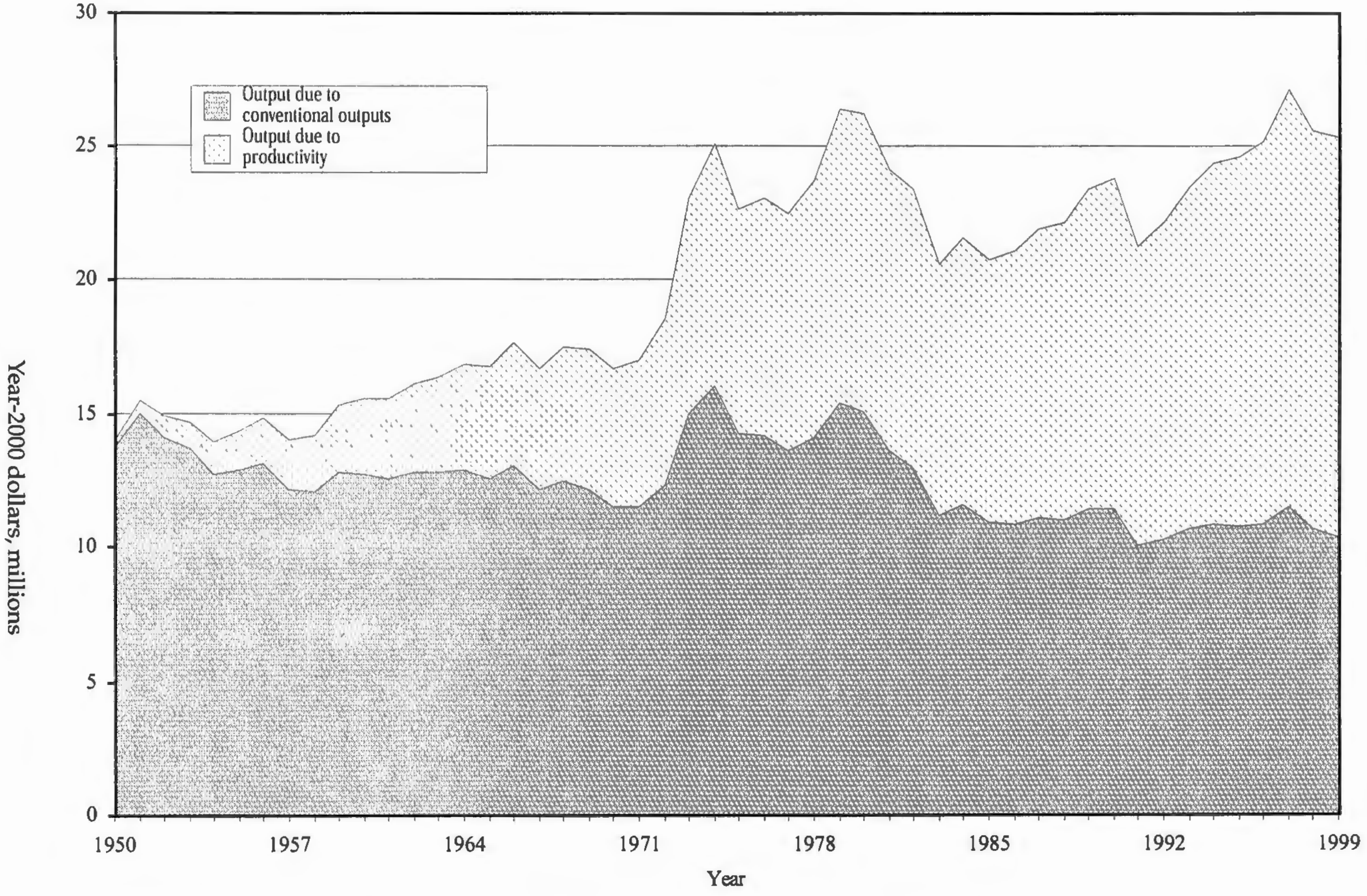
[7] For a comprehensive and critical assessment of this literature, see Alston et al. (2000).

[8] See, for example, Pardey and Beintema (2001) or Alston, Pardey and Smith (1999).

[9] This is perhaps too conservative since private-sector agricultural research spending in the United States has only recently caught up with (and now exceeds) public-sector spending, and would be much less than equal over the entire 20th century, which may be the relevant time period. In addition, some of the consequences of private research have been accounted for already through the input-quality adjustments that were made by Acquaye, Alston and Pardey (2002, 2003), especially in relation to capital inputs in which many private research-induced technological changes are embodied.



Source: Compiled by the authors.

Fig. 2.1 Sources of growth of value of farm output in California, 1950–1999

Allowing for research lags means that these benefits are associated with investments over a longer period. The stream of California's public investments in agricultural research and extension (see Chapter 6, and appendix table A2.3) over the period 1929-1997 were expressed in year-2000 dollars using the GDP deflator and compounded forward to the year 2000 using a 2 percent discount rate. The resulting present value of $15 billion represents the value of a lump-sum payment in the year 2000 that would be equivalent to that stream of past investments. It is reasonable to compare this present value of costs with the present value in the year 2000 of benefits over 1950-1999, which was $90 billion.[10]

Hence, the overall benefit-cost ratio for California's public agricultural research and extension is 6:1 (an average return of $6 for every $1 invested). In the absence of any other information, a reasonable assumption may be that this benefit-cost ratio is applicable across the board to all of the different types of research and extension investments, including pest-management research. Almost surely, however, different types of research and extension have earned different rates of return. Although we cannot provide a specific benefit-cost assessment for any of these components of the aggregate investment, in the chapters that follow we shed some qualitative and quantitative light on the payoff to particular elements of CAES pest management research.

2.5 Appendix

The following tables provide details on indices of inputs and outputs and their underlying components, and the stream of California's public investments in research and extension.

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[10] Some relevant benefits have been excluded (i.e., benefits accruing beyond 1999 as a result of investments made prior to 1997) as have some relevant costs (investments prior to 1929 that yielded benefits accruing after 1950). The omitted benefits are likely to be much greater than the omitted costs.

Table A2.1 California input quantity indexes and cost shares

	Quantity indexes (1949 = 100)					Cost shares (percentage)			
Year	**Land**	**Labor**	**Capital**	**Purchased inputs**	**All inputs**	**Land**	**Labor**	**Capital**	**Purchased inputs**
1949	100	100	100	100	100	24.74	32.99	17.29	24.98
1950	100	101	103	102	102	21.42	33.75	17.79	27.04
1951	100	98	112	112	105	23.16	30.29	18.41	28.14
1952	100	94	119	113	105	25.08	28.91	18.99	27.02
1953	100	92	122	117	106	25.30	29.69	18.94	26.07
1954	100	88	125	116	105	24.34	29.88	19.02	26.76
1955	100	88	129	130	108	23.78	30.11	18.75	27.36
1956	100	88	139	137	111	22.98	29.95	19.55	27.52
1957	99	87	137	142	112	20.94	30.89	20.18	28.00
1958	99	88	137	151	114	20.38	30.57	20.15	28.89
1959	99	89	148	168	120	19.78	29.83	20.91	29.47
1960	99	88	155	178	123	19.80	30.14	20.80	29.27
1961	98	87	158	186	124	19.97	30.03	20.54	29.45
1962	98	83	161	200	126	20.32	28.78	20.09	30.82
1963	98	79	165	203	125	18.53	28.62	20.55	32.31
1964	98	78	175	208	127	17.28	28.84	21.51	32.37
1965	97	77	188	208	128	19.29	28.15	21.76	30.80
1966	96	74	181	204	125	18.41	29.22	21.29	31.08
1967	95	67	165	217	121	19.26	27.91	20.01	32.82
1968	94	69	156	229	123	17.73	30.30	19.47	32.50
1969	93	68	142	233	120	18.47	30.89	18.09	32.55
1970	93	68	134	235	120	17.64	31.78	17.34	33.24
1971	93	66	129	250	120	20.02	30.76	15.88	33.34
1972	94	67	126	247	120	20.59	32.01	15.63	31.77
1973	94	69	125	222	117	19.34	30.88	15.06	34.72
1974	94	77	121	223	121	18.69	31.05	13.54	36.72
1975	96	83	123	229	126	17.45	33.01	13.49	36.05
1976	97	86	127	251	132	16.26	34.09	13.67	35.97
1977	99	82	132	253	132	16.60	34.03	14.00	35.36
1978	101	75	137	294	136	15.32	31.09	14.73	38.86
1979	100	77	145	303	140	15.05	29.42	15.97	39.55
1980	100	76	143	286	136	17.69	27.65	15.38	39.28
1981	99	73	148	272	132	15.49	27.13	16.43	40.95
1982	99	74	154	277	135	16.15	27.61	16.79	39.45
1983	97	69	155	265	129	17.21	27.06	16.96	38.77
1984	95	69	164	275	132	17.36	26.98	16.88	38.78
1985	94	71	170	271	133	19.45	28.34	17.22	34.99
1986	93	66	176	283	133	22.16	26.89	17.34	33.60
1987	93	66	175	296	135	19.06	28.61	17.74	34.59
1988	92	72	181	294	138	18.04	29.44	17.60	34.92
1989	92	76	189	317	145	18.19	29.31	17.07	35.43
1990	92	87	180	343	155	17.34	31.59	15.82	35.25
1991	92	90	176	355	158	17.11	31.83	14.96	36.10
	Annual average growth rates (percentage)								
1949-60	-0.13	-1.14	3.96	5.26	1.86	-2.03	-0.82	1.68	1.44
1960-70	-0.59	-2.54	-1.42	2.74	-0.23	-1.15	0.53	-1.82	1.27
1970-80	0.71	1.08	0.63	1.97	1.25	0.03	-1.39	-1.20	1.67
1980-91	-0.74	1.54	1.88	1.97	1.36	-0.30	1.28	-0.25	-0.77
1949-91	-0.20	-0.25	1.34	3.02	1.09	-0.88	-0.09	-0.35	0.88

Source: Compiled by the authors.

Table A2.2 California output quantity indexes and value shares

	Quantity indexes (1949 = 100)						Value shares (percentage)					
Year	Field crops	Fruit and nuts	Vege-tables	Greenhouse and nursery products	Livestock	All output	Field crops	Fruit and nuts	Vege-tables	Greenhouse and nursery products	All crops	Livestock
1949	100	100	100	100	100	100	22.02	20.84	13.75	2.81	59.42	40.53
1950	93	100	109	106	106	102	22.88	25.35	11.65	2.66	62.53	37.40
1951	125	109	103	112	112	114	26.68	20.63	10.89	2.32	60.51	39.36
1952	132	110	113	118	116	119	25.76	18.71	13.44	2.47	60.38	39.40
1953	129	101	123	124	120	119	24.72	20.87	12.05	2.77	60.42	39.29
1954	130	106	125	131	128	124	24.89	21.43	12.90	3.00	62.21	37.42
1955	120	113	134	141	137	128	21.41	24.17	12.76	3.06	61.40	38.14
1956	135	118	133	151	140	135	22.87	23.77	13.52	3.11	63.27	36.18
1957	139	101	138	153	141	132	23.60	21.87	12.36	3.44	61.27	38.01
1958	143	113	132	161	144	137	23.16	22.30	10.91	3.53	59.90	39.14
1959	161	120	141	174	150	147	23.96	20.62	12.55	3.61	60.73	38.27
1960	158	108	146	196	161	148	22.48	19.95	12.63	4.10	59.16	39.81
1961	148	109	147	203	171	150	22.97	20.27	11.12	4.37	58.72	40.27
1962	168	115	140	220	176	158	23.98	21.26	10.60	4.47	60.30	38.72
1963	154	126	143	222	181	160	22.42	21.78	10.38	4.78	59.35	39.56
1964	169	130	140	248	185	167	23.16	22.04	11.81	5.33	62.34	36.62
1965	161	133	147	245	188	168	21.54	20.29	13.36	5.41	60.61	38.21
1966	153	138	163	249	189	170	19.00	21.17	13.18	5.63	58.98	39.80
1967	144	113	159	246	196	163	19.57	20.68	12.49	5.91	58.65	39.92
1968	192	124	170	244	197	179	21.59	21.79	12.53	5.52	61.43	37.19
1969	163	147	168	260	198	181	17.03	23.19	12.75	5.96	58.94	39.63
1970	168	133	176	278	208	183	17.64	21.80	12.99	6.18	58.61	40.06
1971	166	142	174	276	211	186	17.80	23.19	13.06	6.10	60.16	38.42
1972	195	125	186	300	221	191	19.48	22.62	12.88	6.29	61.27	37.47
1973	199	163	186	354	220	207	22.38	23.82	11.56	5.61	63.37	35.52
1974	235	172	200	390	215	219	28.55	20.92	11.43	5.92	66.82	32.29
1975	262	181	197	409	216	229	27.55	20.87	11.80	6.52	66.73	32.25

(continued)

Table A2.2 Continued

	Quantity indexes (1949 = 100)						Value shares (percentage)					
Year	Field crops	Fruit and nuts	Vegetables	Greenhouse and nursery products	Livestock	All output	Field crops	Fruit and nuts	Vegetables	Greenhouse and nursery products	All crops	Livestock
1976	257	193	200	454	225	236	25.86	21.96	11.76	7.16	66.74	32.29
1977	256	198	220	456	222	239	23.20	24.92	12.40	7.27	67.79	31.21
1978	215	177	212	487	223	223	19.36	27.16	13.00	7.63	67.15	32.17
1979	300	206	222	560	231	257	23.76	27.07	10.15	7.36	68.33	31.03
1980	302	234	221	607	245	272	25.43	24.96	10.31	7.57	68.27	31.23
1981	333	219	232	605	254	279	22.47	24.16	12.37	7.84	66.84	32.61
1982	293	244	241	596	261	284	19.80	26.42	12.39	7.98	66.59	32.21
1983	214	228	232	624	256	261	17.30	22.60	14.70	9.60	64.20	34.94
1984	285	246	256	742	269	293	18.62	23.19	14.23	10.28	66.32	32.85
1985	284	249	250	726	272	294	17.54	25.37	13.25	10.99	67.16	31.77
1986	240	219	275	741	285	284	13.49	26.62	15.02	11.34	66.47	32.76
1987	275	269	276	789	300	315	15.15	28.18	14.30	10.90	68.53	30.66
1988	262	275	285	811	314	322	14.12	28.86	13.92	11.12	68.03	31.04
1989	275	268	306	896	318	330	14.67	28.42	13.38	11.27	67.75	31.11
1990	278	249	305	962	336	333	14.69	26.45	13.11	12.32	66.57	32.07
1991	266	270	280	977	339	337	13.68	28.29	12.39	12.87	67.23	31.30
						Annual average growth rates (percentage)						
1949-60	4.14	0.66	3.42	6.10	4.33	3.57	0.19	-0.40	-0.77	3.44	-0.04	-0.16
1960-70	0.61	2.11	1.92	3.50	2.58	2.09	-2.42	0.89	0.28	4.11	-0.09	0.06
1970-80	5.89	5.67	2.27	7.82	1.60	4.01	3.66	1.35	-2.31	2.03	1.52	-2.49
1980-91	-1.14	1.30	2.12	4.33	2.97	1.93	-5.64	1.14	1.67	4.83	-0.14	0.02
1949-91	2.33	2.37	2.45	5.43	2.91	2.89	-1.13	0.73	-0.25	3.63	0.29	-0.62

Source: Compiled by the authors.

Table A2.3 Research and extension expenditure in California in nominal and real terms

Year	Nominal research expenditure	Nominal extension expenditure	U.S. GDP* deflator	Real research expenditure	Real extension expenditure
	(current dollars, millions)			(year-2000 dollars, millions)	
1929	0.92	0.79	8.48	7.78	6.70
1930	1.04	0.82	8.80	9.14	7.21
1931	1.17	0.84	9.82	11.50	8.28
1932	1.29	0.89	11.13	14.39	9.91
1933	1.20	0.87	11.44	13.73	9.94
1934	0.97	0.72	10.83	10.52	7.83
1935	0.97	0.71	10.62	10.27	7.51
1936	1.03	0.93	10.51	10.86	9.75
1937	1.08	0.94	10.07	10.90	9.43
1938	1.33	0.97	10.38	13.85	10.09
1939	1.45	0.97	10.50	15.19	10.21
1940	1.61	0.98	10.35	16.71	10.15
1941	1.52	1.00	9.69	14.69	9.66
1942	1.53	1.06	8.99	13.79	9.55
1943	1.54	1.06	8.54	13.16	9.07
1944	1.66	1.05	8.34	13.81	8.72
1945	1.91	1.08	8.12	15.52	8.78
1946	2.14	1.23	7.24	15.50	8.90
1947	3.01	1.69	6.54	19.66	11.08
1948	4.00	2.51	6.19	24.73	15.51
1949	4.30	2.81	6.19	26.64	17.39
1950	4.94	3.15	6.13	30.26	19.29
1951	5.29	3.26	5.72	30.23	18.63
1952	5.94	3.53	5.63	33.41	19.87
1953	6.70	3.86	5.56	37.21	21.46
1954	7.90	4.24	5.50	43.47	23.34
1955	8.38	4.66	5.41	45.30	25.20
1956	9.22	5.01	5.23	48.20	26.17
1957	10.62	5.49	5.06	53.75	27.76
1958	12.30	5.89	4.94	60.77	29.11
1959	13.56	6.65	4.89	66.27	32.48
1960	14.64	6.85	4.82	70.55	33.02
1961	16.39	7.75	4.77	78.11	36.95
1962	16.96	8.12	4.70	79.76	38.17
1963	18.00	8.65	4.65	83.68	40.23
1964	20.10	8.97	4.58	92.09	41.07

(continued)

Table A2.3 Continued

Year	Nominal research expenditure	Nominal extension expenditure	U.S. GDP* deflator	Real research expenditure	Real extension expenditure
	(current dollars, millions)			(year-2000 dollars, millions)	
1965	22.45	9.52	4.50	100.97	42.80
1966	24.24	10.25	4.37	106.00	44.83
1967	25.42	10.87	4.24	107.81	46.11
1968	25.85	10.62	4.07	105.08	43.19
1969	27.59	11.61	3.88	106.93	44.98
1970	30.74	13.99	3.68	113.11	51.47
1971	32.72	15.67	3.50	114.63	54.90
1972	32.70	15.69	3.36	109.90	52.72
1973	40.75	17.08	3.18	129.68	54.36
1974	40.43	19.43	2.92	118.04	56.73
1975	48.45	20.64	2.67	129.41	55.11
1976	51.01	23.70	2.53	128.93	59.91
1977	55.83	26.62	2.37	132.58	63.21
1978	62.62	28.98	2.22	138.84	64.25
1979	65.59	30.00	2.05	134.23	61.40
1980	77.61	34.39	1.87	145.48	64.46
1981	89.58	39.37	1.71	153.59	67.50
1982	105.35	44.46	1.61	170.01	71.75
1983	104.18	46.16	1.55	161.74	71.66
1984	106.00	46.92	1.50	158.66	70.23
1985	118.55	50.08	1.45	172.01	72.67
1986	129.62	51.79	1.42	184.02	73.52
1987	139.60	55.29	1.38	192.41	76.20
1988	144.24	58.07	1.33	192.27	77.41
1989	165.45	60.90	1.28	212.45	78.20
1990	171.61	63.73	1.24	212.10	78.77
1991	176.30	65.00	1.19	210.24	77.51
1992	179.95	65.12	1.16	209.49	75.81
1993	177.44	63.78	1.14	201.73	72.52
1994	182.48	62.58	1.11	203.22	69.69
1995	191.00	63.20	1.09	208.18	68.88
1996	189.58	66.31	1.07	202.71	70.90
1997	205.51	69.00	1.05	215.54	72.36

Source: Compiled by the authors.

*GDP = gross domestic product

CHAPTER 3

The UC Contribution to Pest Management in California Agriculture

Agricultural pests are controlled using a variety of techniques, including mechanical and human cultivation, crop rotation, fallowing, field selection, sanitation, encouragement of natural enemies, and planting of disease-free materials or genetically resistant varieties. However, most crops in California are also treated with at least one application of a chemical pesticide. Pesticides account for a significant share of the production costs of farm products, and they are sometimes associated with negative externalities on neighbors and the community; hence the large investments in research to develop more efficient pesticides or nonchemical measures that pose less risk to human health and the environment.

This chapter reviews pest management in California agriculture since 1950 and the contribution of the UC system to its evolution. We start with an overview of the three eras of pest management in California, largely distinguished by how pesticides were used. Then we turn to the focus of this report, which is the widely recognized contribution made by the UC system to the management of insects and mites (and insect-vectored plant diseases) through the provision of new information about the biology of arthropods. The chapter concludes with reviews of where pest management research and extension is conducted in the UC system and of expenditure by the UC system on pest management research and extension activities.

Research by the University of California and others has developed knowledge and information about the biology of arthropod pests and their interaction with their natural enemies, and cultural and chemical control strategies.[1] The use of information of this nature, along with the monitoring of pest populations, is the distinguishing feature of IPM technologies, even though the term IPM is now used to encompass the full range of pest management technologies. While new scientific information has enabled farmers to make more profitable pest management decisions particularly with respect to pesticides, it has also been a valuable input into the public regulation of pest management in California. It is appropriate for a public institution such as the University of California to conduct research and extension activities to generate information of this nature, which has characteristics of public goods and is, to some degree, unique to the agricultural ecosystem of California.

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[1] Because arthropods often serve as disease vectors, control of arthropods often has the secondary benefit of plant disease control.

The contributions of the UC system to agricultural pest management have not been confined to IPM technologies related to arthropod pests. Advances in the management of arthropods and other pests also come from sources other than information-based IPM technologies, such as more effective chemicals and pest-resistant varieties. The UC system has made contributions in these areas, but other public and private institutions have also made large contributions. The private sector is likely to become relatively more important as intellectual property becomes easier to protect. With the exception of nematode-resistant tomato varieties, we have not attempted to evaluate these other technologies.

Undoubtedly, the UC system has developed information-based IPM technologies for the management of weeds, diseases, nematodes and other pests. However, in the case studies, most examples of advances in pest management presented to us for analysis related to arthropods. This suggested the hypothesis that UC research and extension efforts to develop IPM approaches may have reaped greater rewards in arthropod management than in other pest management areas, perhaps because weeds and nematodes did not develop pesticide resistance so obviously or so fast as arthropods, and routine "low information" use of chemicals remained an adequate control. While unable to test the hypothesis, we have begun a discussion as to why it may be true and note that this relativity may not hold in the future as technology advances.

3.1 An Overview of Pest Management in California Agriculture Since 1950

From reviews of the history of pest management in a number of crop commodities, it is apparent that there are common elements across crops in the ways in which pests were managed, although no doubt most crops had pest management problems or strategies that were peculiar to them. The most significant development in the management of pests was the introduction of synthetic pesticides, starting soon after the World War II, with 2,4-D, a phenoxy herbicide, and DDT, an organochlorine insecticide. This development provides a natural way of classifying pest management into three eras:[2]

- Presynthetic pesticide era (i.e. pre-DDT) up to the late 1940s
- Synthetic pesticide era from the 1950s to the late 1970s
- Integrated pest management (IPM) era in the 1980s and 1990s.

The Presynthetic Era up to the late 1940s

In the presynthetic era, pesticides used to control arthropods were toxic fumigants and sprays, including cyanide, arsenate, and lead compounds, as well as less-toxic oils and lime sulfur sprays. Copper and sulfur were widely used to control plant diseases. Mechanical weed cultivation prun-

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[2] This classification was adapted from a review of pest management in citrus by Morse and Luck (2000).

ing, burning, crop rotation, integrated plantings, and planting of pest-resistant varieties to counter arthropods, nematodes, and diseases were also used. Pest control was not wholly effective, and crops were limited by the regional distribution of pests. Morse and Luck (2000) noted that a significant amount of pest research dealt with understanding the biology and ecology of pests and that there had been a number of examples of successful biological control such as the control of cottony cushion scale on citrus by the purposeful introduction of the vedalia beetle and *Cryptocheatum* fly in 1888.

The Synthetic Pesticide Era from the 1950s to the late 1970s

The synthetic pesticide era began with the release of the herbicide 2,4-D and the insecticide DDT in the mid-1940s, followed by other organochlorine insecticides (chlordane in 1945, aldrin and dieldrin in 1948, and others in the 1950s), organophosphates (parathion in 1947, malathion in 1950) and carbamate insecticides, fungicides, and other herbicides (glyphosate in 1971). These pesticides provided a high degree of pest control and allowed crops to be grown in regions previously precluded by pest problems. Generally, these chemicals were broad spectrum in action, controlling a wide range of organisms, some of which caused crop damage and others that either had no economic impact or were beneficial in that they were natural enemies of pests.

This era could be characterized by an almost complete reliance on chemical means of controlling pests. Carlson (1990) observed that pesticides had fallen in price relative to other farm inputs. Morse and Luck (2000) noted that, with the notable exception of biological control insectaries at UC Riverside and UC Berkeley, the focus of pest management research switched from pest biology to aspects of chemical control, including testing for efficacy.

Rachael Carson's *Silent Spring*, published in 1962, raised doubts about the environmental and human safety of DDT and other pesticides, sparking the environmental movement. The problem with the organochlorines was their persistence in the environment. While the organophosphates and carbamates that replaced them were less persistent, they were also more hazardous for humans to apply.

As early as the 1950s and accelerating during the 1960s and 1970s, difficulties with this reliance on pesticides were becoming apparent, particularly in the management of arthropods. The initial response was often to apply higher and more frequent doses of pesticides. A number of factors contributed to the decreased efficacy of pesticides. Of primary concern, target pests developed resistance to some pesticides. Another factor was the release of secondary pests, often because the pesticide eliminated natural enemies of these pests. The response was to apply pesticides to control these formerly insignificant secondary pests. Van den Bosch (1978) referred to this as the "pesticide treadmill." Some have expressed concern that the present trend toward transgenic crops is, in effect, a return to the synthetic pesticide approach and that, unless used as part of an IPM program, these new technologies will also be short lived.[3]

The Integrated Pest Management era in the 1980s and 1990s

The third era is the era of integrated pest management (IPM). A common perception is that IPM was developed in response to environmental and human health concerns. While these concerns have been an important influence, it is more likely that initially IPM developed as a response to a spiraling increase in pesticide use and its impact on farm productivity and profitability (Stern et al. 1959).

Carlson (1990) asserted that in the 1970s researchers in the UC system were at the forefront of the development of IPM and resistance management technologies. Several writers (Moore et al. 1996, Ehler and Bottrell 2001) noted that IPM grew from the concept of "supervised insect control" developed by entomologists in California in the 1940s (perhaps Smith and Smith 1949). Bradley (1996) thought that the term "integrated pest control" was first used by Stern et al. in a 1959 paper, but Michelbacher and Bacon (1952) used this term in a paper on arthropod control in California walnuts in 1952. Nor is it clear who first used the term "integrated pest management." However, as far as we can tell, Stern et al. (1959) were the first to assemble the various concepts that make up what is now referred to as integrated pest management. In addition to integrating chemical and nonchemical control strategies, they mentioned the concept of economic thresholds for pest populations.

IPM programs have to evolve because the balance between pests, their natural enemies, and control strategies is routinely upset by invasions of new pests, the development of resistance to chemical controls by pests, the withdrawal of chemicals for human health and environmental reasons, the introduction of new chemicals, and the discovery of other control mechanisms through biotechnology, for example. In this dynamic environment, as farmers pursue least-cost pest management strategies, information-based (IPM) strategies are sometimes abandoned for broad-spectrum routine chemical programs because there is a lag in adapting the knowledge base to the changed circumstances. As discussed more fully later in this report, particularly in the case studies of the cotton and orange industries, a surge in pesticide use in the late 1980s and early 1990s may have been associated with

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[3] The examples used are the herbicide- and insect-resistant varieties such as Roundup-Ready cotton and Bt (*Bacillus thuringiensis)* cotton. The concern is that the Roundup-Ready strategy will lead to an over-reliance on glyphosate and hasten the evolution of glyphosate-resistant plant species. There is already tolerance of glyphosate in the *Lolium* (rye grass) species, but some scientists argue that *Lolium* is the most likely species to develop tolerance. Widespread resistance to a broad-spectrum herbicide such as glyphosate would impose high costs on agriculture (and the community). Similarly, the widespread use of Bt varieties increases the likelihood of resistance to Bt developing in insect pest populations, a particular concern for organic growers.

pesticide resistance problems and the collateral damage to natural enemies upon the introduction of pyrethroids and insect growth regulators.

Perhaps the clearest signal of the growing concerns about human health and environmental risks was the creation of the U.S. Environmental Protection Agency (EPA) in 1970. The responsibility for registering pesticides was transferred to the EPA from the USDA, and the focus switched from ensuring pesticide efficacy to balancing efficacy against human health and environmental risks. The EPA cancelled most uses of DDT in 1973 and proscribed agricultural uses of many of the other chlorinated hydrocarbons in the late 1970s and 1980s. In general, it would seem that initially these withdrawals imposed few costs on agriculture, as a range of substitutes were available. The issue of regulation is examined in more detail in Chapter 5.

3.2 Integrated Pest Management: A UC Innovation

According to the IPM website at UC Davis, "Integrated pest management (IPM) is an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. Pesticides are used only after monitoring indicates they are needed according to established guidelines, and treatments are made with the goal of removing only the target organism. Pest control materials are selected and applied in a manner that minimizes risks to human health, beneficial and nontarget organisms, and the environment" (UC IPM 2000).

This broad definition encompasses many responses to a broader range of pest problems than the management of arthropods, and it does not clearly recognize that farmers and the community might have different interests with respect to pest management and might integrate practices in different ways. We would expect farmers to choose pest management strategies to enhance the long-term profitability of their investments, whereas the community would be more concerned about minimizing negative spillovers from pesticide use.

The key elements of integrated pest management programs seem to have been first brought together in a classic paper by Stern et al. (1959), all entomologists in the UC system. They discussed the management of arthropod pests and recognized that pests had to be managed in ways profitable to farmers. Their paper began with a discussion of why arthropods had increased in significance as pests of agriculture. They identified the recent development of agriculture and the sometime indiscriminate use of pesticides as the main causes for the increased problems with arthropods. They spoke in terms of "general equilibrium" populations of pests and suggested that, in general, pesticides provided only a temporary lowering of the equilibrium population, whereas biological controls held the potential of a permanent lowering. The objective of pest management was to lower the pest population below an economic threshold, but the problem was complex because the threshold was not fixed, varying with the usual economic, biological and physical parameters.

They called for the integration of biological and chemical control strategies based on greater knowledge of the ecosystem, science-based monitoring and prediction of pest populations, the augmentation of natural enemies, and the use of selective insecticides. All of these have become important components of IPM programs. A component they did not foresee was the use of gene technology, although they did talk about traditional breeding for resistance.

There had been earlier interest in monitoring arthropod populations. For example, Smith and Smith (1949) described groups of cotton growers in the late 1940s employing graduate entomologists over the summer to monitor pests, such as the alfalfa caterpillar, to allow more timely use of insecticide. Metcalf (1980) noted that many of the principles of IPM were enumerated by Forbes (1880) one hundred years previously and were widely practiced before the 1940s when Pickett and Patterson (1953) pioneered their use in Nova Scotia orchards. But according to Bradley (1996), a number of research findings during the late 1960s and early 1970s, including the ability to raise pests in laboratories and understanding diapause and the role of pheromones, were important steps in the development of IPM packages. At this time, efficient field sampling or monitoring techniques also were being developed. It would seem that without these monitoring tools, accurate projection of likely pest populations and their reaction to control strategies would not have been possible, and growers would have been less able to manipulate control strategies to their advantage.

As the more recent definition suggests, interest now is in applying IPM principles across the broad range of pest management problems, and the focus of research in pest management in the UC system may have shifted to some degree toward how best to manage pests to meet community expectations with respect to risks to human health, other species and the environment. There is also now greater interest in the management of pests in urban settings and on public lands, issues not addressed in this report.

In addition to IPM approaches for dealing with arthropod pests, the UC system has contributed significantly to pest management approaches for weeds, nematodes and diseases. In particular, the UC system, through applied research and extension in the different production regions of the state, has assisted in the more widespread and rapid adoption of new technologies based on new pesticides or new varieties developed by others. Another contribution is likely to have been in providing growers with information on how best to manage short-term invasions of exotic pests (Coppock and Kreith 1999). In addition, there have been important advances in pest management over the past 50 years relating, for example, to the development of more efficacious pesticides and breeding resistance into crop species. The UC system also contributed some of the difficult to quantify, but no less important, basic research in biology, ecology, chemistry, physics, hydrology, toxicology, statistics and bio-informatics that underlies much of the applied research that has led to new pesticides or chemicals, improved environmental monitoring and enhanced understanding of pest biology.

The UC system has played prominent roles in various areas of research, development and extension related broadly to the management of agricultural pests, including safety training for pesticide applicators. However, our focus has been on the contributions of the UC system in developing and extending the concept of IPM based on the use of information to better monitor and manage arthropod pest populations, as proposed by Stern et al. (1959).[4] The UC system has made investments in research and extension activities that have generated new information about the biology of arthropods and their interactions with their natural enemies and cultural and chemical control measures that have allowed growers to make more-profitable pest management decisions, particularly with respect to the use of pesticides. An important component of the technology (and a contribution of UC) is the monitoring of populations of pests and their natural enemies. This, along with work by UC toxicologists, epidemiologists, and others, also has provided better information on which to base the regulation of pesticides.

One reason for the UC system's leadership in this area is that technologies based on information and management have more of the characteristics of public goods, and investments in these technologies fit more naturally with the role of public institutions. Other technologies are often embodied into an input such as a chemical or seed, and hence the role of the private sector in their development has been much larger, particularly with patents on pesticide formulations. However, UC has also developed and patented disease- and nematode-resistant seeds and plant materials.

The antithesis of IPM is applying broad-spectrum pesticides on a fixed schedule related to the physiological development of the crop, irrespective of pest populations. IPM involves the close monitoring of pest populations to determine the likelihood that pests will reach a developmental stage or a population where the value of crop damage they cause exceeds the cost of pesticide use. These decisions require information about pest and predator populations and their life cycles, and about the interactions between pests (and their natural enemies) and control strategies such as pesticides. This information is valuable if it allows farmers to make more-profitable pest management decisions. Similarly, it may allow the community to better regulate pest control agents.

The challenge is to identify this new information and determine its value. Clearly, many projects have contributed to this knowledge base since 1950. It is not feasible to evaluate these individually. Some of the new knowledge (e.g., knowledge about the life cycle of pests) may be of lasting value. However other knowledge, such as response to a particular pesticide, might be of value only for a few seasons. This arises because of unanticipated impacts on

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[4] The UC Pest Management Guidelines found on the IPM website in October 2000 provide alternative techniques to control 555 species found on one or more of 40 crops. By species, 27 percent are plant diseases, 44 percent are insects, and 6 percent are mites (Kreith 2001).

other pests and their natural enemies and changing resistance on the part of the target pest. It seems that a high proportion of research associated with the use of pesticides to manage pests is of a maintenance nature.

Recent online UC pest management information reinforces our view that UC IPM technologies have focused on arthropods to a large extent. Virtually all of the quantified action thresholds provided in the Pest Management Guidelines posted at the UC IPM website pertain to control of agricultural insect or mite pests (Kreith 2001). They appear to be most extensively available for citrus, pear, cotton, tomato and lettuce, which, with the exception of pear, are the focus of the case studies in subsequent chapters.

3.3 The Value of IPM Information in Different Crop and Pest Scenarios

Information-based pest management approaches appear to have been more successful in some crops than others, and in the management of arthropods rather than in the management of diseases, nematodes and weeds. We have found little written by biologists to explain these differences and, hence, our attempt to inquire into them is somewhat speculative.

A common component of IPM programs is a reliance on the natural antagonists of pests whenever possible. This requires knowledge of the biology of beneficial species and their interaction with pests and control strategies. Sometimes there are biological limitations to a reliance on natural enemies. Vegetables such as lettuce are in the ground for relatively short periods. These are at the routine, intensive pesticide use, end of the spectrum, partly because it is difficult to gain adequate pest control from natural enemies when the biological cycles are disrupted at short intervals by planting and harvest. In the orange industry case study, we note that the hot summers and cold winters of the San Joaquin Valley pose problems for biological control based on natural enemies. Another limitation to the use of natural enemies occurs when they control only some pests and broad-spectrum pesticides are used to control others, forcing farmers to make a trade-off. Again, oranges in the San Joaquin Valley provide an example of this problem. Finally, there is still much to learn about the interaction of pests and their natural enemies, particularly with respect to disease pathogens and nematodes.

The adoption of information-based pest management strategies is also limited when the economic threshold for the presence of pests is very low. In lettuce, for example, consumers have a very low tolerance for evidence of pests, and this is reflected in prices at the farm gate.

Information about pest populations is more valuable if farmers have time to respond to it. In the case of disease, fungicides are widely used but generally in a preventive mode. Apparently because diseases develop quickly in crops such as lettuce and tomatoes and the accuracy of weather models decreases as the forecast period lengthens, there is little confidence in being able to monitor and spray in a timely fashion. For many crops, an important defense against soil-borne disease is breeding for resistance or production and planting of disease-free materials. Here, too, UC has played a prominent role.

Weeds generally spread slowly, so knowledge of their likely impact is not difficult to obtain, and the appropriate management technology is more obvious. The impacts on secondary pests and on natural antagonists apparently have not been significant considerations in weed management decisions. Even resistance management seems to be less of an issue in weeds than arthropods. For example, information about how populations of weeds grow over time in response to different control strategies, weather patterns, and in a multi-species environment would allow better choices between controlling plants and controlling seed banks (Jones and Medd 2000), but such biological information is not widely available.

Weeds, nematodes and at least some diseases found on any one farm may have small off-site effects on neighboring farms or the community. The mobility of arthropod pests and their natural enemies, on the other hand, means that off-site effects are likely to be far more important. Economists argue that publicly funded research and extension institutions such as the University of California should place a lower priority on pest problems that are private, in the sense that off-site effects are less significant.

An important qualification to this discussion is that technology may change to make pest population information either more valuable for control of diseases, nematodes and weeds or less valuable in the case of arthropods (if, for example, resistance to insects can be developed in plants, as in Bt cotton). Similarly, processing technology that has a higher tolerance of insect and disease damage may make IPM information more valuable to growers.

Our discussion of why information-based technologies have evolved more quickly for some crops than others and for arthropods rather than other pests is somewhat speculative. It does, however, suggest that an important criterion for allocating research and extension resources to IPM projects is the potential to generate timely new information about pests that will be valuable to farmers.

3.4 UC Infrastructure for Research and Extension on Pest Management

UC research on pests and diseases of agriculture and their management is, for the most part, conducted by researchers affiliated with the Division of Agriculture and Natural Resources (DANR): 1) statewide special programs and projects; 2) Agricultural Experiment Station (AES) field research facilities; 3) academic departments within the colleges of agricultural sciences and natural resources located on the three campuses that are constituent to the AES—Davis, Riverside and Berkeley; and 4) county-based Cooperative Extension advisors. In addition to conducting applied research, Cooperative Extension personnel disseminate research results broadly and collaborate with campus-based specialists and AES scientists on field trials. Besides the DANR research and extension personnel who focus on pest and

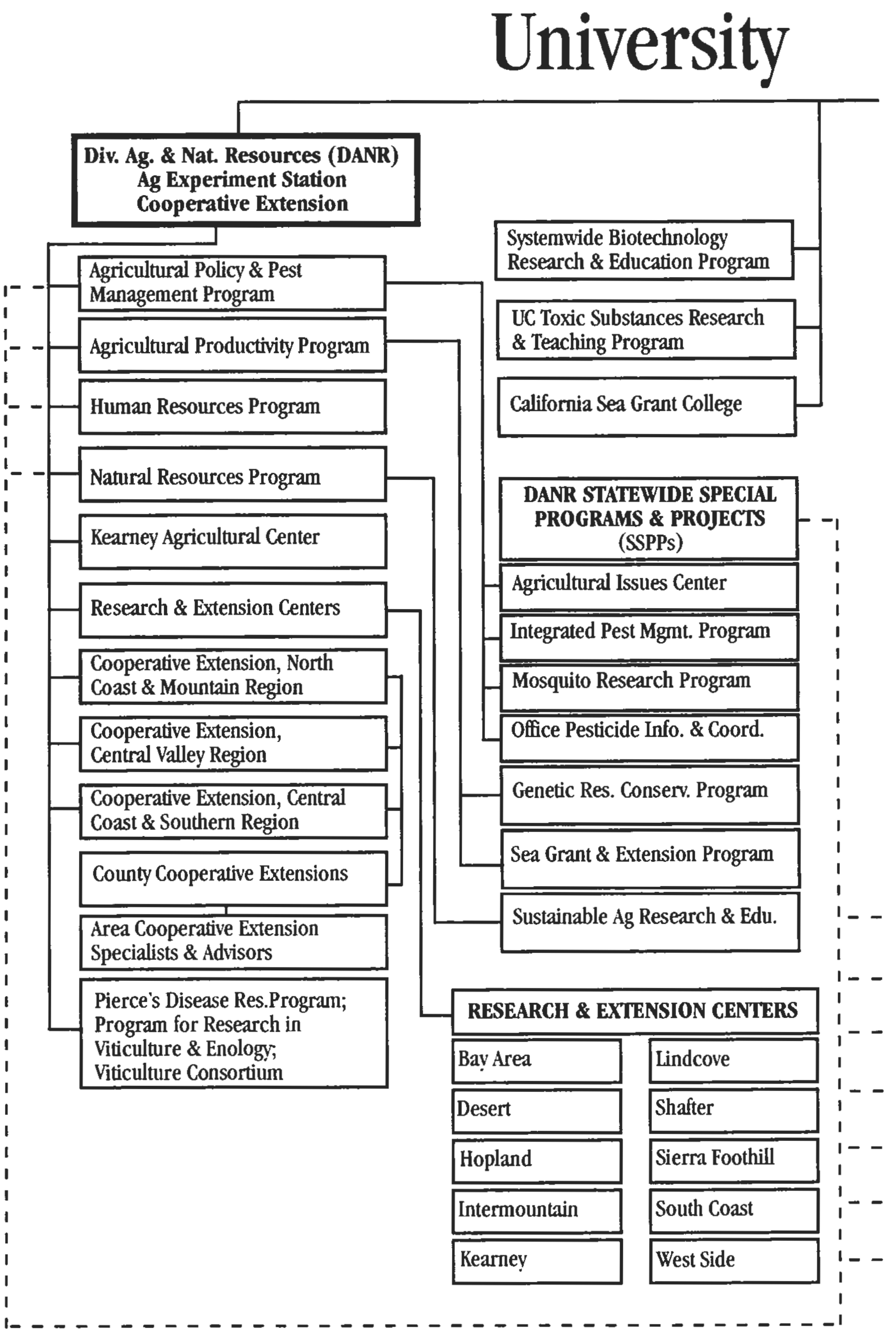
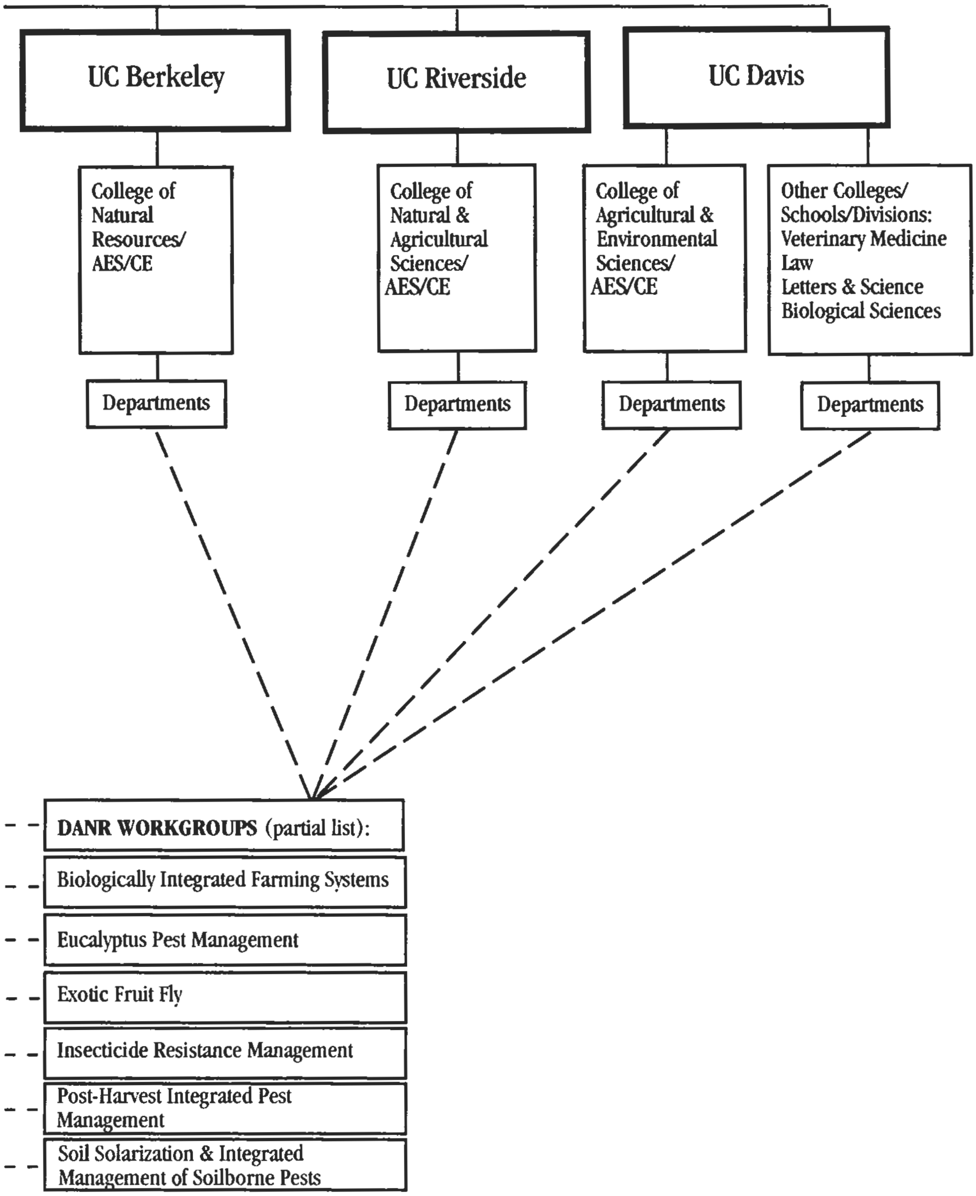
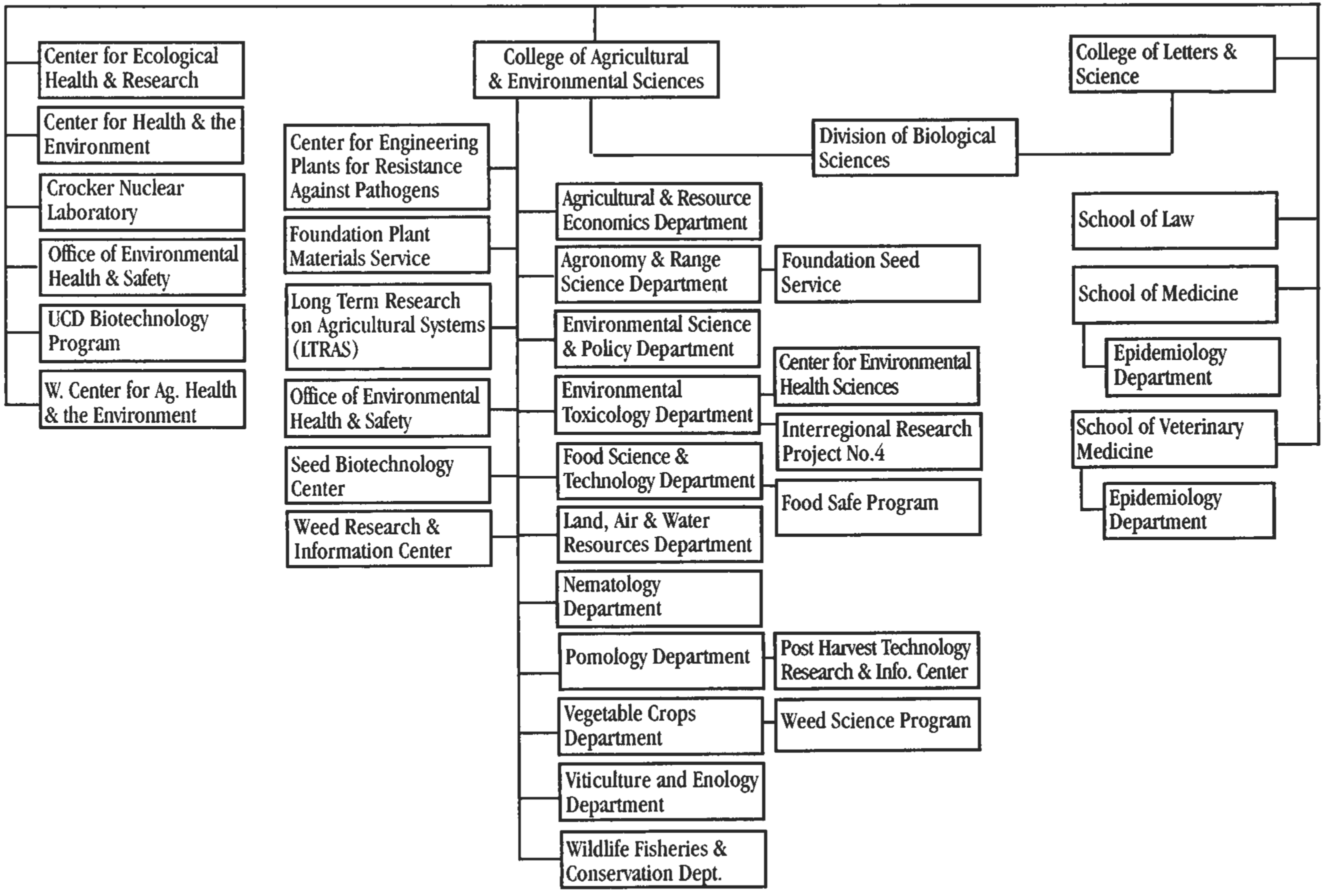


Fig. 3.1 UC principal units with pest and disease management research and extension, May 2002

# of California



UC Davis


Center for Ecological Health & Research
Center for Health & the Environment
Crocker Nuclear Laboratory
Office of Environmental Health & Safety
UCD Biotechnology Program
W. Center for Ag. Health & the Environment
College of Agricultural & Environmental Sciences
Center for Engineering Plants for Resistance Against Pathogens
Foundation Plant Materials Service
Long Term Research on Agricultural Systems (LTRAS)
Office of Environmental Health & Safety
Seed Biotechnology Center
Weed Research & Information Center
Agricultural & Resource Economics Department
Agronomy & Range Science Department
Environmental Science & Policy Department
Environmental Toxicology Department
Food Science & Technology Department
Land, Air & Water Resources Department
Nematology Department
Pomology Department
Vegetable Crops Department
Viticulture and Enology Department
Wildlife Fisheries & Conservation Dept.
Division of Biological Sciences
Foundation Seed Service
Center for Environmental Health Sciences
Interregional Research Project No.4
Food Safe Program
Post Harvest Technology Research & Info. Center
Weed Science Program
College of Letters & Science
School of Law
School of Medicine
Epidemiology Department
School of Veterinary Medicine
Epidemiology Department

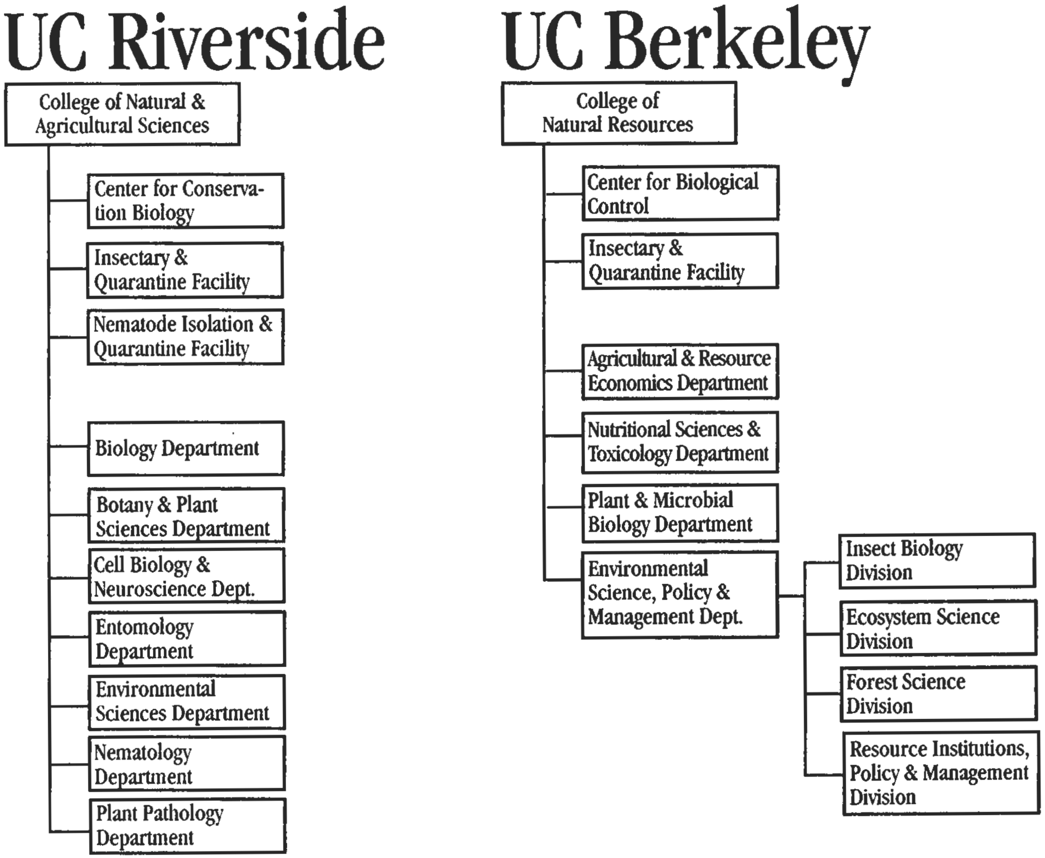


Fig. 3.2 UC campus units with pest and disease management research and extension. (Chart emphasizes units concerned with pests affecting plants but includes a few that focus primarily on animal health.) May 2002.

disease management, a number of other basic and applied researchers are scattered throughout other departments and centers in the 10-campus UC system and at its three national laboratories.

Most of the faculty members in the colleges of agriculture and natural resources on the Davis, Berkeley and Riverside campuses hold split appointments, part within academic departments for research and instruction and part within the AES. Systemwide, the AES is administered by the vice president, DANR, while at the campus level it is administered by the dean of the college, who also serves as associate director of both the AES and Cooperative Extension. The dean reports to the campus chancellor and provost. With the exception of those with split appointments, Cooperative Extension personnel are not employees of the AES, although they may be collaborators in AES research and are housed in academic departments along with AES faculty and other employees.

Emphasizing units within DANR, Figures 3.1 and 3.2 show schematically the administrative relationships of many of UC's entities, with a focus on agricultural pests and diseases and their management. Unfortunately, it is impossible to include within this simplified diagram the many public-sector collaborative research and public service activities in which UC personnel are engaged. Also omitted are most of the departments concerned with pests and diseases of animals and humans, although several concerned with secondary effects are included.

Pest research within the UC Davis College of Agricultural and Environmental Sciences occurs primarily within the departments of Plant Pathology; Entomology; Nematology; Vegetable Crops (weed science); Wildlife and Fisheries Conservation Biology; Biological and Agricultural Engineering; Environmental Toxicology; Food Science and Technology; Agronomy and Range Science; Viticulture and Enology; Pomology; Land, Air and Water Resources; and Agricultural and Resource Economics. The Division of Biological Sciences, School of Medicine, and School of Veterinary Medicine also are concerned with pests and diseases. In addition, at least two School of Law research areas, international trade and endangered species, have direct bearing on pest and disease control regulation.

Departments with a pest management focus in the College of Natural and Agricultural Sciences at UC Riverside include the departments of Plant Pathology, Entomology, Environmental Sciences, Nematology, Botany and Plant Sciences (weed science), Cell Biology and Neuroscience, and Biology.

In the UC Berkeley College of Natural Resources, pest research is conducted in the departments of Agricultural and Resource Economics; Nutritional Sciences and Toxicology; Plant and Microbial Biology; and four divisions within the Department of Environmental Science, Policy and Management—insect biology; forest science; ecosystem science; and resource institutions, policy, and management.

At least seven DANR statewide special programs and projects (SSPPs), including the Integrated Pest Management Program (IPM), have major emphasis on pest management research: the Agricultural Issues Center (AIC), Genetic Resources Conservation Program (GRCP), Mosquito Research Program, Office of Pesticide Information and Coordination (OPIC), Sustainable Agriculture Research and Education Program (SAREP), and Sea Grant Extension Program. The UC Pierce's Disease Research Program, Viticulture Consortium, and the California Competitive Grant Program for Research in Viticulture and Enology, while not administratively considered SSPPs, are equally concerned with pest and disease management. Pest management is also an important research concern at all 10 DANR research and extension centers: Intermountain, Sierra Foothill, Hopland, Bay Area, Kearney, Westside, Lindcove, Shafter, South Coast, and Desert. To ensure that UC suggestions on pesticide use alternatives conform to U.S. and DPR regulations, all UC materials for print or online publication are reviewed by the UC statewide pesticide coordinator in the Office of Pesticide Information.

In addition to the statewide special programs and projects, several UC campuses have their own facilities and centers that focus on pest management. UC Riverside has three such centers: the Center for Invasive Species Research, the Center for Conservation Biology, and the Insectary and Quarantine Facility. Besides its Center for Biological Control, UC Berkeley also has an Insectary and Quarantine Facility. UC Davis has its Postharvest Technology Research and Information Center and the Food Safe Program, which emphasize postharvest technologies to eliminate toxins as well as pathogens and other pests. Affiliated with the UC Davis Veterinary School is the California Animal Health and Food Safety Laboratory System with its five regional diagnostics labs. Other entities at Davis focusing on pest management and intertwined issues include the Western Center for Agricultural Health and Safety, affiliated with the UC Davis Medical School and now a part of the UC John Muir Institute; the Western Region Pest Management Center; Interregional Research Project No. 4 (IR-4); Center for Engineering Plants for Resistance Against Pathogens (CEPRAP); Biotechnology Program; Center for Ecological Health Research; Center for Environmental Health Sciences; Center for Health and the Environment (formerly ITEH); Crocker Nuclear Lab; Long Term Research on Agricultural Systems (LTRAS) Field Research Facility; Foundation Plant Materials Service; Foundation Seed Service; and the Weed Research and Information Center. The campus is constructing a large Insectary and Quarantine Facility.

DANR workgroups promote cross-disciplinary and cross-campus collaborations between academic and extension staff, as well as government representatives and the public. Workgroups receive modest financial support from DANR on a year-to-year competitive basis. More than 20 workgroups are specifically concerned with pests and diseases including: Agricultural Health and Safety, Ant Management; Avocado Arthropod Pests, Biological Control, Biologically Integrated Farming Systems, Citrus IPM, Eucalyptus Pest Management, Exotic Fruit Fly; Insecticide Resistance Management, IPM of Glassy Winged Sharpshooters and the Diseases They Vector, Invasive Species, Lygus Bug Management, Mosquito Research and Extension, Nematology, Pest Management in DANR, Pesticide Use Report Databases, Plant Pathology and Disease Management, Postharvest Integrated Pest Management, Soil Solarization and Integrated Management of Soilborne Pests, Weed, and Food Safety.

The Systemwide Biotechnology Research and Education Program, Toxic Substances Research and Teaching Program, and the California Sea Grant College, which report to the Vice Provost for Research, are other multi-campus research units (MRUs) concerned with pest management.

3.5 California Pest Management Research and Extension Expenditures, 1970-1997

In the remainder of this chapter, we estimate expenditure by the UC system on research and extension activities in pest management for California crop production as a whole and for the individual commodities we have selected for case study analysis. Net returns to investments in research and extension activities can be estimated by relating the benefits flowing from these activities to their costs. Primary sources of data are the USDA Current Research Information Service (CRIS) database for research expenditure, and UC sources for expenditure on Cooperative Extension. The CRIS data used and reported here were provided by Philip Pardey (pers. comm.) who obtained data files from CRIS and provided other data on research and extension in an update of the series published in Alston and Pardey (1996).

Since 1970, CRIS has tracked research funded by USDA agencies, state agricultural experiment stations (SAESs), land-grant colleges and universities, other cooperating state institutions, and USDA grant recipients. For each research project funded or reported by these agencies, the research scientists complete and send detailed forms to CRIS, giving information on the funding and type of research being conducted. For example, for each research project, the scientist estimates the share of the project that is basic research versus applied research and the shares of the research that apply to specific commodities. Most of the research reported in the CRIS database is conducted through the agricultural experiment stations associated with land-grant universities, but other state universities and businesses do a small amount through USDA grants. The CRIS database does not include expenditures on research or other work by UC Cooperative Extension or by researchers in such departments as chemistry and statistics or the medical school, which are not affiliated with the AES.

The CRIS data on public agricultural research funding in California are not the same as agricultural research expenditures by the University of California, nor the California AES. The CRIS data overstate UC research expenditures to the extent that they include research projects funded by govern-

Table 3.1 Agricultural research funding and UC expenditures, 1989–1997

Year	UC Agricultural Experiment Station Research Funding	UC Agricultural Experiment Station Expenditures	UC Cooperative Extension Expenditures	Total Expenditures
		(year-2000 dollars, millions)		
1989	182	178	77	254
1990	175	183	78	262
1991	175	177	77	254
1992	166	169	75	244
1993	166	169	73	242
1994	167	170	70	240
1995	170	175	73	248
1996	175	177	74	251
1997	176	180	73	253

Sources: Compiled by the authors from annual CRIS form AD-419, 1968-1992; USDA, Current Research Information System, Funding Summaries, 1993-2000 (online data); and from data supplied by Philip Pardey, University of Minnesota.

ment agencies and conducted by non-UC schools in California and small businesses. Conversely, the CRIS data understate UC research expenditures to the extent that UC research projects funded by agricultural commodity groups and private companies are not reported to CRIS, or UC departments underreport the research. Our expectation is that both of these effects are relatively small. Table 3.1 includes total California agricultural research funding for 1989-97 taken from the CRIS data (in the first column) and research expenditures by the UC Agricultural Experiment Station (in the second column). In each year, these two estimates of research expenditure differ by only a few percentage points. Hence, we used the CRIS data as a proxy for UC expenditures on pest management because they extend back further in time and provide information on expenditures in a number of important categories.

Expenditure on agricultural research in aggregate by the UC system was about $180 million (in real, year-2000 dollar terms) in 1997 and expenditure on extension activities was $73 million, hence, total expenditure on research and extension in 1997 was $253 million. To identify research expenditures on pest management, we isolated a subset of the CRIS database based on particular "research project areas" and "activities" that we thought would best represent pest management research. Table 3.2 shows the research project areas and activities that represent our definition of pest management research. Data in the following tables and figures are based entirely on this definition.

In constant (year-2000) dollar terms, funding for pest management research in California roughly doubled between 1970 and 1997, while the balance between federal and nonfederal funding remained relatively constant. Total pest management research expenditures increased from $32.5 million in 1970 to $60.7 million in 1997 (Table 3.3). Federal funds, mainly from the USDA, increased steadily throughout the period. Meanwhile, state funds peaked in the 1980s and decreased somewhat thereafter. However, the decrease in state funds during the 1990s was offset by an increase in other nonfederal funds.

Expenditure on extension related to pest management was estimated by making a congruence assumption—that is, by assuming that expenditure on pest management extension as a share of total expenditure on extension was the same as expenditure on pest management research as a share of total research expenditure.[5] On average, pest management accounted for 35 percent of the total annual research expenditure by the UC system. This share increased from 31 percent in 1970 to a high of 43 percent in 1979, and decreased in the 1980s to 29 percent in 1989, after which it fluctuated in the 30 to 36 percent range (Table 3.4). Under this congruence assumption, expenditure on pest management extension grew from $16.2 million in 1970 to $26.2 million (year-2000 dollars) in 1997. Total expenditure on research and extension in pest management was estimated to grow from $48.7 million in 1970 to $86.9 million in 1997.

Table 3.4 also shows that pest management research and extension intensity, a measure of the importance of pest management activities relative to the size of the industry, has trended up, peaking in 1987 and remaining high thereafter relative to the 1970s and early 1980s. This figure was calculated by expressing current pest management research and extension expenditures as a percentage of the five-year moving average of California agricultural cash receipts (where the last year of the moving average is the current year of pest management research).

Figure 3.3 shows that expenditures on basic research increased steadily throughout the period, eclipsing expenditures on applied research in 1991. Expenditures on applied research increased from 1970 to 1982, and trended down afterward.[6]

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[5] Some limited data on the allocation of FTE to pest management were provided by DANR staff. These data suggest that the congruence assumption might overstate the relative contribution of CE advisors and specialists to pest management. According to these data, CE advisors and specialists devoted 17.2 percent of their total FTE to pest management (70.34 out of 409.21 FTE) in 1995, up from 14.9 percent in 1990. In contrast, CAES faculty devoted 26.3 percent of their total FTE to pest management (101.73 out of 386.34 FTE) in 1990, down from 28.9 percent (141.73 out of 490.70 FTE) in 1990. Overall, in 1995, CE accounted for 40.9 percent of DANR's pest management FTE and CAES accounted for 59.1 percent. In 1990, CE accounted for 32.6 percent of DANR's pest management FTE, whereas CAES accounted for 67.4 percent.

[6] Basic research, according to CRIS nomenclature, has a primary goal of gaining fuller knowledge or understanding of a subject, while the primary goal of applied research is the practical application of knowledge to meet a recognized need.

Table 3.2 CRIS research project areas and activities included in pest management research*

204	**Control of insects, mites, slugs, and snails on fruit and vegetable crops**	
	4500	Protection against insects, mites, snails, and slugs and their control agents
205	**Control of diseases and nematodes of fruit and vegetable crops**	
	4600	Protection against diseases, parasites, and nematodes and their control agents
206	**Control of weeds and other hazards of fruit and vegetable crops**	
	4700	Protection against weeds and their control agents
	4850	Protection against birds
	4860	Protection against rodents and other mammals
207	**Control of insects, mites, snails, and slugs affecting field crops and range**	
	4500	Protection against insects, mites, snails, and slugs and their control agents
208	**Control of diseases and nematodes of field crops and range**	
	4600	Protection against diseases, parasites, and nematodes and their control
209	**Control of weeds and other hazards of field crops and range**	
	4700	Protection against weeds and their control agents
	4850	Protection against birds
	4860	Protection against rodents and other mammals
314	**Bees and other pollinating insects**	
	4500	Protection against insects, mites, snails, and slugs and their control agents
	4600	Protection against diseases, parasites, and nematodes and their control agents
	4850	Protection against birds
	4860	Protection against rodents and other mammals
318	**Non-commodity-oriented biological technology and biometry**	
	4500	Protection against insects, mites, snails, and slugs and their control agents
	4600	Protection against diseases, parasites, and nematodes and their control agents
	4700	Protection against weeds and their control agents
404	**Quality maintenance in storing and marketing fruits and vegetables**	
	4500	Protection against insects, mites, snails, and slugs and their control agents
	4600	Protection against diseases, parasites, and nematodes and their control agents
	4860	Protection against rodents and other mammals
	4870	Protection against molds, fungi, and other spoilage organisms
408	**Quality maintenance in storing and marketing field crops**	
	4500	Protection against insects, mites, snails, and slugs and their control agents
	4600	Protection against diseases, parasites, and nematodes and their control agents
	4860	Protection against rodents and other mammals
	4870	Protection against molds, fungi, and other spoilage organisms

(continued)

Table 3.2–Continued

701	**Insure food products free of toxic contaminants, including residues from agricultural and other sources**	
	4500	Protection against insects, mites, snails, and slugs and their control agents
	4600	Protection against diseases, parasites, and nematodes and their control agents
	4700	Protection against weeds and their control agents
	4830	Protection against pollutants
702	**Protect food and feed supplies from harmful microorganisms and naturally occurring toxins**	
	4600	Protection against diseases, parasites, and nematodes and their control agents
	4830	Protection against pollutants
	4870	Protection against molds, fungi, and other spoilage organisms
901	**Alleviation of soil, water, and air pollution and disposal of wastes**	
	4400	Evaluation of alternative uses and methods of use
	4830	Protection against pollutants
906	**Culture and protection of ornamentals and turf**	
	4500	Protection against insects, mites, snails, and slugs and their control agents
	4600	Protection against diseases, parasites, and nematodes and their control agents
	4700	Protection against weeds and their control agents
	4850	Protection against birds
	4860	Protection against rodents and other mammals
	4870	Protection against molds, fungi, and other spoilage organisms

Source: Compiled by the authors from the United States Department of Agriculture, Current Research Information Service, Classification Manual, 1993.

*Research project areas listed in bold; activities in normal text

While funding for pest management research roughly doubled between 1970 and 1997, Figure 3.4 shows that the total number of scientist years for research (excluding extension) remained about the same—157 in 1970 and 156 in 1997. Scientist years increased gradually through the mid-1980s, peaking at about 200 and decreasing gradually thereafter. While scientist years decreased during the late-1980s and 1990s, funding increased. Hence, the funding per scientist increased as well. Most of the decrease in scientist years came from USDA scientists, while the number of nonfederal scientist-years remained relatively stable during the 1980s and 1990s.

3.6 UC Expenditure on Pest Management Research and Extension by Commodity

Table 3.5 details expenditure on pest management research broken down into a number of important commodity categories. Unfortunately, it is not possible to identify expenditure on the individual commodities in which we are interested, apart from cotton. In recent years, much of this research has been basic research that may have had positive spillover effects on pest

Table 3.3 Funding for pest management research by California universities and businesses, by major funding source, 1970–1997

	Federal					Nonfederal		
Year	CSRS[a] administered	USDA appropriations	USDA-CGCA[b] funds	Other federal funds	Total federal	State appropriations	Other nonfederal funds	Total federal & nonfederal
				(year-2000 dollars, millions)				
1970	1.6	10.0	0.5	1.6	13.6	16.5	2.4	*32.5*
1971	1.4	10.9	0.3	1.4	13.9	17.1	2.3	*33.3*
1972	2.0	11.0	0.3	1.5	14.7	17.3	2.6	*34.7*
1973	1.7	8.5	0.2	2.7	13.1	20.5	2.8	*36.4*
1974	1.5	12.3	0.3	3.3	17.3	20.8	2.5	*40.6*
1975	1.5	12.3	0.3	3.8	17.8	24.0	2.7	*44.5*
1976	1.8	12.6	0.1	3.6	18.0	22.9	2.8	*43.8*
1977	2.8	13.8	0.3	3.3	20.1	23.2	3.1	*46.3*
1978	3.5	14.5	0.5	2.7	21.2	23.8	3.3	*48.4*
1979	3.0	15.3	0.5	2.1	20.8	22.8	2.9	*46.5*
1980	2.7	14.5	0.7	1.9	19.8	26.1	3.4	*49.2*
1981	2.9	15.3	0.9	2.0	21.2	29.1	3.6	*53.8*
1982	2.8	14.0	0.9	1.6	19.3	28.0	3.6	*50.9*
1983	2.4	14.3	0.8	1.4	18.9	25.8	3.6	*48.2*
1984	2.3	13.8	1.1	2.4	19.7	26.0	3.6	*49.3*
1985	3.0	13.2	0.6	2.7	19.5	26.6	3.6	*49.7*
1986	3.4	11.7	0.5	2.9	18.5	28.7	2.9	*50.0*
1987	4.3	12.1	0.3	3.1	19.8	29.0	4.1	*52.9*
1988	3.5	11.8	0.3	3.0	18.6	28.8	3.8	*51.2*
1989	2.9	9.1	0.3	3.4	15.8	29.2	3.7	*48.7*
1990	3.2	9.5	0.4	3.5	16.6	27.8	4.9	*49.4*
1991	4.2	9.5	0.6	3.2	17.5	27.2	4.3	*49.1*
1992	6.3	10.9	0.6	3.2	21.0	27.3	4.0	*52.3*
1993	4.8	10.1	0.7	3.2	18.8	24.7	7.4	*50.9*
1994	7.1	10.4	0.8	3.5	21.8	22.6	7.6	*52.0*
1995	6.3	11.3	1.0	4.0	22.6	23.3	7.9	*53.9*
1996	4.1	11.4	1.4	4.7	21.6	24.4	9.3	*55.3*
1997	5.5	13.5	1.6	4.4	25.1	24.7	10.9	*60.7*

Source: Compiled by the authors from United States Department of Agriculture, Current Research Information Service, unpublished data, 2001.

[a] CSRS = Cooperative State Research, Education, and Extension Service

[b] CGCA = Contracts, Grants, and Cooperative Agreements

Table 3.4 California pest management research and extension funding, 1970–1997

Year	Total research funding	Total extension funding	Pest management research funding	Pest management extension funding	Total pest management funding	Pest management share of total	Pest management intensity
	(year-2000 dollars, millions)					(percentage)	
1970	103.3	51.5	32.5	16.2	48.7	31	0.28
1971	104.1	54.9	33.3	17.5	50.8	32	0.30
1972	95.0	52.7	34.7	19.2	53.9	37	0.31
1973	109.4	54.4	36.4	18.1	54.4	33	0.29
1974	119.0	56.7	40.6	19.4	60.0	34	0.30
1975	115.7	55.1	44.5	21.2	65.7	38	0.31
1976	113.1	59.9	43.8	23.2	67.0	39	0.30
1977	114.3	63.2	46.3	25.6	71.9	40	0.31
1978	114.3	64.3	48.4	27.2	75.6	42	0.32
1979	109.5	61.4	46.5	26.1	72.6	43	0.31
1980	121.4	64.5	49.2	26.1	75.3	41	0.31
1981	136.1	67.5	53.8	26.7	80.5	40	0.33
1982	134.8	71.8	50.9	27.1	78.0	38	0.32
1983	134.6	71.7	48.2	25.7	73.9	36	0.31
1984	138.2	70.2	49.3	25.0	74.3	36	0.32
1985	147.2	72.7	49.7	24.6	74.3	34	0.34
1986	155.3	73.5	50.0	23.7	73.7	32	0.34
1987	161.3	76.2	52.9	25.0	77.9	33	0.37
1988	156.4	77.4	51.2	25.3	76.6	33	0.36
1989	169.2	78.2	48.7	22.5	71.2	29	0.33
1990	165.2	78.8	49.4	23.5	72.9	30	0.33
1991	167.3	77.5	49.1	22.7	71.8	29	0.32
1992	158.6	75.8	52.3	25.0	77.3	33	0.34
1993	158.7	72.5	50.9	23.3	74.2	32	0.33
1994	160.0	69.7	52.0	22.6	74.6	32	0.33
1995	164.1	68.9	53.9	22.6	76.5	33	0.33
1996	163.5	70.9	55.3	24.0	79.3	34	0.33
1997	168.0	72.4	60.7	26.2	86.9	36	0.35

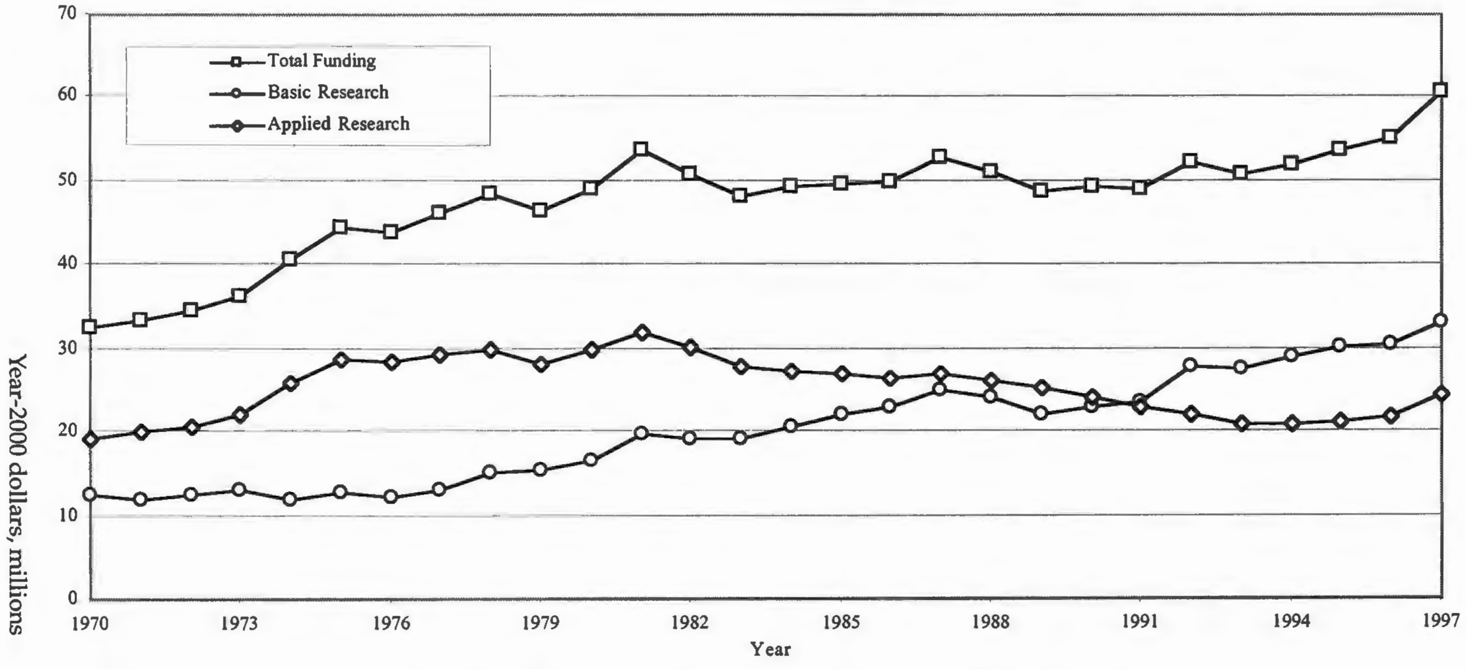
Source: Compiled by the authors from United States Department of Agriculture, Current Research Information Service, unpublished data, 2001.

management for many specific crops. For example, in 1997 basic research accounted for 62 percent of the research on invertebrates and 72 percent of the research on microorganisms and viruses. The share of expenditure on basic research increased steadily as total research expenditure increased.

Figure 3.5 shows that in 1997 about two-thirds of total pest research expenditures in California had a commodity focus. The other one-third of expenditures was primarily focused on pests or on natural resources such as watersheds. Fruits, vegetables and tree nuts accounted for about 50 percent of total expenditures. Table 3.5 shows that since 1970 expenditures on pest management research for fruits and tree nuts and on vegetables tripled, while expenditure on field crops (included in the "other crops" column) increased until the late 1970s and early 1980s and then decreased below its 1970 level in the 1990s. Additional commodity-oriented pest management research is included in the category "plants."

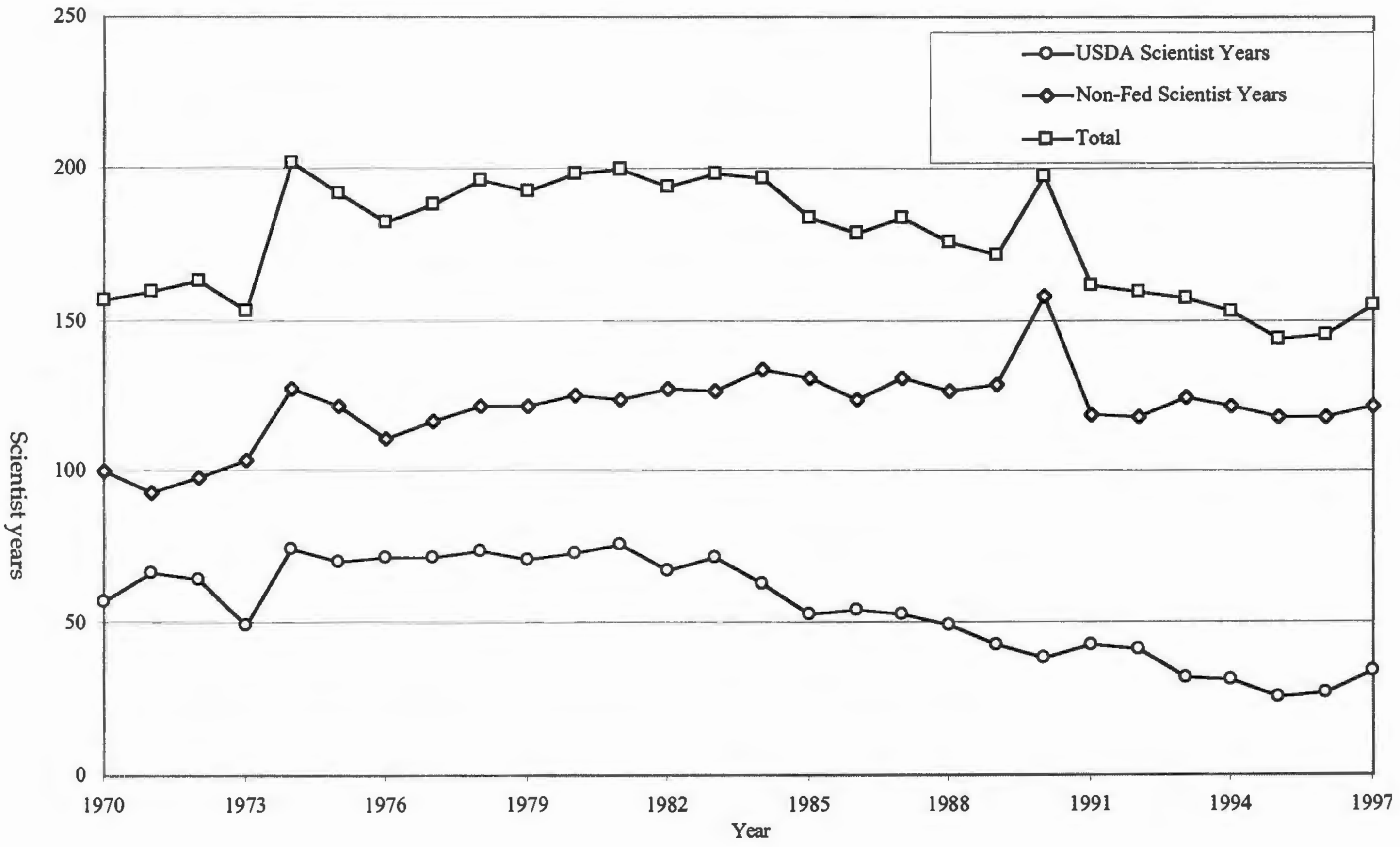
In Table 3.6 we show expenditures on pest management research for cotton, taken from the CRIS data, and our own estimates of expenditures on pest management research for almonds, oranges, head lettuce and processing tomatoes. To estimate pest management research expenditures for the latter four commodities, we applied a type of "congruence" rule. We assumed that research expenditures for each commodity, as a share of total pest management research expenditures in its commodity group, would be equal to the five-year moving average of its share of total annual production value in its commodity group. We then multiplied each commodity's five-year moving average share of annual production value by the total research expenditures for its commodity group. Generally, our estimates for research expenditures on oranges, almonds, head lettuce and processing tomatoes trended upward, while actual cotton research expenditure declined over the 1970–97 period. By this measure, expenditure on pest management research was largest in the orange industry at about $4 million in 1997, followed by almonds at about $2 million, and expenditure for the other three commodities was between $1 million and $1.5 million.

A similar procedure was followed for expenditure on extension by commodity, except that the shares of each of the case study commodities in total farm receipts for California were applied to total estimated expenditure on pest management extension. Following this approach, the commodity ranking is much different from that for research expenditure. The orange industry had the lowest rate of expenditure on extension, and expenditure on extension in cotton and almonds in 1997 was similar (Table 3.7). This difference arises because the CRIS database on pest management research provides information at a more disaggregated level than is available for extension. Given that the state funds a much larger share of extension than research, it is plausible that expenditure on research and extension may diverge in the manner suggested here. Total expenditure on research and extension in pest management by case-study commodity is displayed in Table 3.8. Because of the dominance of research, the ranking by commodity for research and extension is the same as for research only.



Source: Compiled by the authors from United States Department of Agriculture, Current Research Information Service, unpublished database, 2001.

Fig. 3.3 Funding for pest management research by California universities and businesses, 1970–1997



Source: Compiled by the authors from United States Department of Agriculture, Current Research Information Service, unpublished database, 2001.

Fig. 3.4 Scientist years of pest management research by California universities and businesses, 1970–1997

Table 3.5 Funding for California pest management research by category, 1970–1997

Year	Deciduous and small fuits and edible tree-nuts	Vegetables	Other crops	Natural resources	Citrus and tropical/ subtropical fruit	Invertebrates	Plants	Microorganisms viruses, etc.	Livestock and apiary	Other	*Total*
					(year-2000 dollars, millions)						
1970	4.3	3.1	8.7	2.7	5.4	0.0	5.4	0.0	2.0	0.9	*32.5*
1971	4.4	3.3	9.0	4.1	5.3	0.0	5.0	0.0	1.7	0.7	*33.3*
1972	4.0	2.9	10.1	5.9	4.9	0.0	4.8	0.0	1.8	0.4	*34.7*
1973	4.3	3.0	9.0	8.4	5.5	0.0	4.9	0.0	1.2	0.1	*36.4*
1974	6.1	4.5	11.1	7.5	5.5	0.0	3.4	0.0	1.8	0.8	*40.6*
1975	6.6	5.1	11.6	8.8	6.0	0.0	3.7	0.0	1.8	0.8	*44.5*
1976	6.0	5.2	11.4	7.5	6.0	0.0	4.7	0.0	1.8	1.2	*43.8*
1977	7.1	5.5	12.1	7.3	5.9	0.0	4.7	0.0	1.9	1.9	*46.3*
1978	7.3	5.9	11.7	7.3	6.6	0.7	5.0	0.0	1.7	2.1	*48.4*
1979	7.1	5.5	12.3	5.8	6.3	0.9	4.7	0.3	1.5	2.1	*46.5*
1980	7.4	5.5	11.8	6.1	6.8	1.4	5.5	0.1	1.8	2.8	*49.2*
1981	8.3	6.3	13.0	5.7	7.2	1.9	7.0	0.5	1.5	2.5	*53.8*
1982	9.1	6.6	12.3	5.3	7.2	1.5	5.7	0.4	1.0	1.8	*50.9*
1983	7.9	6.1	11.9	5.0	6.3	1.6	5.5	0.6	1.2	2.0	*48.2*
1984	7.2	6.6	11.8	4.8	6.1	1.7	6.3	0.7	2.0	2.2	*49.3*
1985	8.0	6.7	10.7	4.1	6.0	2.4	6.3	1.2	2.0	2.5	*49.7*
1986	8.3	6.8	10.4	3.4	6.3	3.3	4.7	2.1	1.8	3.0	*50.0*
1987	8.1	7.5	10.3	4.9	5.7	3.7	4.5	3.0	2.0	3.3	*52.9*
1988	8.0	7.6	9.2	5.4	5.4	4.1	3.6	2.8	1.9	3.3	*51.2*
1989	8.0	7.0	8.2	5.3	5.3	3.5	3.9	2.9	1.8	2.7	*48.7*
1990	8.0	7.7	8.7	5.2	4.7	3.4	4.6	3.4	1.7	1.9	*49.4*
1991	7.7	7.4	8.5	5.2	4.5	4.0	4.4	3.6	1.5	2.2	*49.1*
1992	7.3	7.6	8.0	6.0	5.4	5.5	5.8	3.4	1.4	1.9	*52.3*
1993	7.5	8.2	8.2	5.0	4.9	4.5	5.4	3.4	2.1	1.8	*50.9*
1994	8.6	7.1	8.2	5.3	5.4	5.1	5.0	3.6	2.2	1.5	*52.0*
1995	10.1	8.9	8.4	4.7	5.9	3.5	4.6	4.1	2.6	1.1	*53.9*
1996	10.5	8.4	8.2	5.4	6.3	3.4	4.8	4.6	2.8	0.9	*55.3*
1997	12.4	10.1	8.0	6.7	6.5	4.3	4.1	4.0	3.3	1.3	*60.7*

Source: Compiled by the authors from United States Department of Agriculture, Current Research Information Service, unpublished data, 2001.

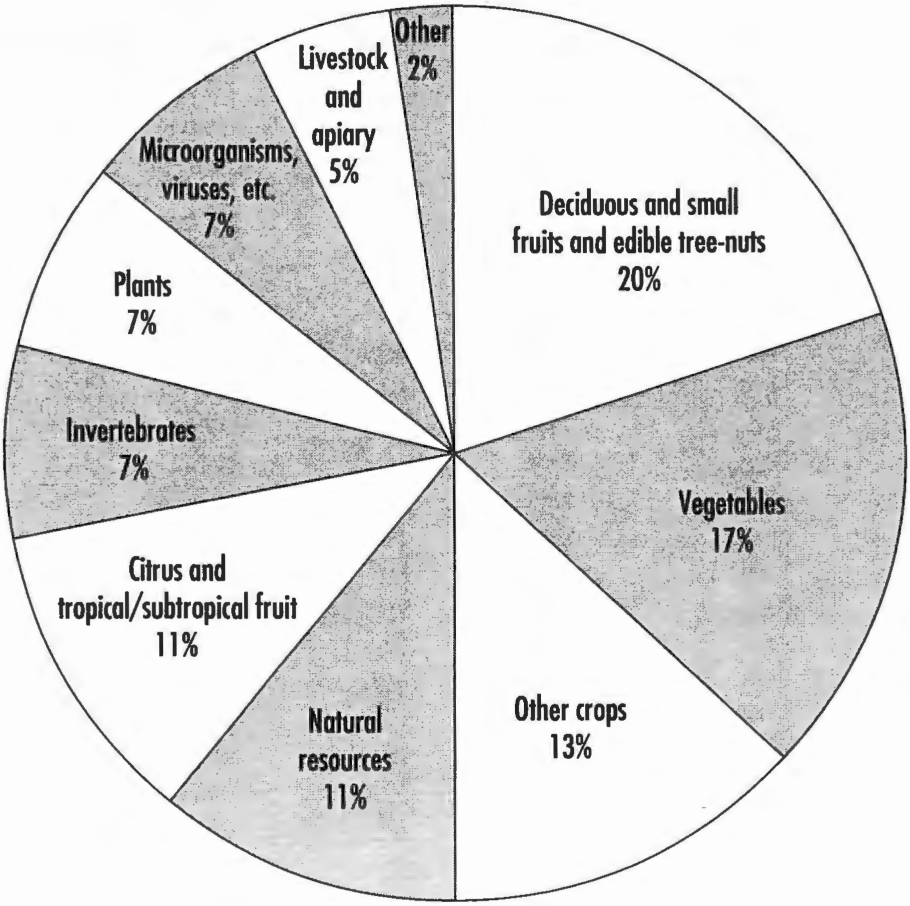


Fig. 3.5. Funding for California pest management research by commodity category, 1997

Source: Compiled by the authors from United States Department of Agriculture, Current Research Information Service, unpublished database, 2001.

Table 3.6 Funding for California pest management research by commodity, 1970–1997

Year	Almonds*	Cotton	Head lettuce*	Oranges*	Processing tomatoes*
		(year-2000 dollars, thousands)			
1970	324	3,561	468	3,214	524
1971	367	3,433	468	3,040	551
1972	373	3,643	400	2,880	476
1973	480	3,575	432	3,105	469
1974	742	3,651	597	3,148	765
1975	764	4,336	654	3,461	988
1976	716	4,000	653	3,530	1,022
1977	888	3,532	675	3,605	1,149
1978	892	3,349	720	4,241	1,239
1979	987	3,114	677	4,009	1,133
1980	1,138	3,299	679	4,325	981
1981	1,241	3,512	737	4,577	1,033
1982	1,302	3,489	792	4,613	970
1983	1,103	3,215	716	4,144	858
1984	939	3,397	771	4,161	851
1985	1,002	2,692	792	4,200	856
1986	1,119	1,898	812	4,408	884
1987	1,226	1,493	937	3,854	985
1988	1,280	1,230	960	3,497	1,003
1989	1,209	1,264	902	3,321	946
1990	1,211	1,287	1,017	2,973	1,098
1991	1,144	1,367	971	2,688	1,083
1992	1,026	1,052	1,031	3,244	1,065
1993	1,097	911	1,162	2,874	1,100
1994	1,386	732	1,008	3,226	901
1995	1,700	1,332	1,358	3,528	1,048
1996	1,846	1,380	1,280	3,972	936
1997	2,231	1,371	1,521	4,117	1,091

Source: Compiled by the authors from the United States Department of Agriculture, Economic Research Service, Farm Business Economics Briefing Room, online data, 2001; and United States Department of Agriculture, Current Research Information Service, unpublished database, 2001.

*Expenditures for almonds, head lettuce, oranges, and processing tomatoes estimated by taking the share of that commodity of total annual production value for its respective commodity group. The resulting share was applied to total expenditures for that commodity group to yield the estimates given in the table.

Table 3.7 Funding for California pest management extension by commodity, 1970–1997

Year	Almonds*	Cotton	Head lettuce*	Oranges*	Processing tomatoes*
(year-2000 dollars, thousands)					
1970	223	622	499	396	519
1971	259	652	557	427	560
1972	309	737	625	478	581
1973	352	743	617	439	475
1974	391	931	656	459	580
1975	412	1,142	707	467	762
1976	464	1,501	760	476	853
1977	566	1,817	833	538	1,030
1978	580	1,920	894	584	1,116
1979	679	1,963	856	545	1,017
1980	784	2,084	847	558	862
1981	803	2,063	849	615	833
1982	779	2,034	867	600	759
1983	707	1,911	828	600	710
1984	626	1,726	839	671	674
1985	572	1,602	845	682	679
1986	598	1,384	813	671	676
1987	729	1,434	929	745	690
1988	833	1,457	938	743	667
1989	719	1,229	840	639	604
1990	780	1,229	895	639	654
1991	756	1,200	870	603	672
1992	809	1,224	902	643	736
1993	795	1,101	852	573	696
1994	854	1,060	807	518	667
1995	890	1,005	859	529	655
1996	999	1,025	898	554	654
1997	1,128	1,048	982	599	703

Source: Compiled by the authors from the United States Department of Agriculture, Economic Research Service, Farm Business Economics Briefing Room, online data, 2001; and United States Department of Agriculture, Current Research Information Service, unpublished database, 2001.

*Expenditures for almonds, head lettuce, oranges, and processing tomatoes estimated by taking the share of that commodity of total annual production value for its respective commodity group. The resulting share was applied to total expenditures for that commodity group to yield the estimates given in the table.

Table 3.8 Funding for California pest management research and extension by commodity, 1970–1997

Year	Almonds*	Cotton	Head lettuce*	Oranges*	Processing tomatoes*
		(year-2000 dollars, thousands)			
1970	546	4,183	967	3,611	1,043
1971	626	4,085	1,025	3,467	1,110
1972	681	4,380	1,025	3,359	1,057
1973	833	4,317	1,049	3,544	944
1974	1,132	4,581	1,253	3,607	1,345
1975	1,175	5,478	1,361	3,928	1,751
1976	1,180	5,500	1,413	4,006	1,876
1977	1,454	5,349	1,508	4,143	2,179
1978	1,472	5,269	1,614	4,825	2,355
1979	1,667	5,077	1,533	4,554	2,150
1980	1,922	5,384	1,526	4,883	1,843
1981	2,044	5,574	1,586	5,192	1,866
1982	2,081	5,522	1,659	5,213	1,729
1983	1,810	5,126	1,544	4,744	1,568
1984	1,565	5,122	1,610	4,832	1,525
1985	1,574	4,294	1,637	4,882	1,535
1986	1,717	3,282	1,625	5,079	1,561
1987	1,955	2,926	1,866	4,599	1,675
1988	2,113	2,687	1,898	4,240	1,670
1989	1,928	2,493	1,742	3,960	1,550
1990	1,991	2,516	1,913	3,612	1,752
1991	1,900	2,567	1,840	3,291	1,755
1992	1,835	2,276	1,932	3,887	1,801
1993	1,892	2,012	2,014	3,447	1,796
1994	2,240	1,792	1,815	3,744	1,568
1995	2,590	2,337	2,218	4,057	1,703
1996	2,845	2,404	2,178	4,527	1,590
1997	3,359	2,419	2,503	4,716	1,794

Source: Compiled by the authors from the United States Department of Agriculture, Economic Research Service, Farm Business Economics Briefing Room, online data, 2001; and United States Department of Agriculture, Current Research Information Service, unpublished database, 2001.

*Expenditures for almonds, head lettuce, oranges, and processing tomatoes estimated by taking the share of that commodity of total annual production value for its respective commodity group. The resulting share was applied to total expenditures for that commodity group to yield the estimates given in the table.

CHAPTER 4

Pesticide Use in California Agriculture

4.1 Introduction

This chapter describes trends in pesticide use by Californian agriculture as a whole and for a selection of particular commodities, focusing on production agriculture. In Chapter 5, the focus shifts to the risks to human health and the environment from pesticide use, and the regulation of pest management.

The magnitude of pesticide use and its changes over time depend, not unexpectedly, on how one defines and measures the quantity of pesticides. There are several reasonable alternatives (depending in part on the use to which the measures may be put), and they show different trends. This chapter lays out these alternatives using the best available (though still imperfect) data.

We used several sources of information on pesticide use in California. One source is the sample survey-based data from the USDA on expenditures on pesticides. This series extends back to 1950 but provides little information on specific crops or pesticides. A second important source of information is the pesticide-use reporting (PUR) system now administered by the California Department of Pesticide Regulation (DPR), extending in some form back to 1970 and reported most recently in Wilhoit et al. (1999). Since 1990 all pesticide use in agriculture in California has been reported. Hence, at least for this decade, data on the use of individual pesticides on individual crops is available on a census (i.e., comprehensive coverage of users) rather than a less-comprehensive sample survey basis. There are, however, limitations to what can be said about trends in pesticide use based on physical information about the weight of pesticides applied.

A contribution of this study has been an attempt to use the DPR data to estimate expenditure on pesticides in California (in total and by crop) by using pesticide price data largely assembled by the USDA. Difficulties arise because about 630 active ingredients are in use as pesticides in California agriculture in any year (Wilhoit et al. 1999, p. 6). Although we have been able to collect prices for only a small sample of these products, the sample accounts for a large share of pesticide use in California.

Two aspects of our assessment of trends in agricultural pesticide use in California should be borne in mind. First, we have followed the lead of the DPR, U.S. EPA, and the USDA in their classification as pesticides those agents that destroy, repel, or mitigate a pest.[1] Pesticides include chemicals used to

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[1] Legal definition of pesticide is found in California Food and Agriculture Code Section 1273 and Title 7 U.S. Code Section 136.

control insects, weeds, agricultural disease pathogens, and nematodes and predatory animals, including rodents, and include sulfur and petroleum oils. Pesticides also include products such as growth regulators and defoliants, but not fertilizers. Pertaining to agricultural use, these agencies further classify the pesticides into one of four broad categories: 1) insecticides to control any invertebrate animal pest, not just insects; 2) herbicides against plant pests or to desiccate plants; 3) fungicides to control pathogens; 4) fumigants to control a broad range of organisms. The range of pesticides available is constantly changing as new products come on line, some products become obsolete, and some are withdrawn through regulation.

Second, while some attempt is made to explain trends in pesticide use in terms of changes in crops and weather conditions, for example, trends in either quantities used or expenditure on pesticides do not provide a sound basis on which to make judgements about whether farmers are using pesticides more or less efficiently. Studies such as those by Fernandez-Cornejo, Jans, and Smith (1998), Lichtenberg, Zilberman, and Archibold (1990), and Antle (1988) reviewed economic theory that explains how farmers make decisions about pest management in situations of uncertainty surrounding weather, price, and pest populations, where pests respond to control strategies, and where pest management is usually associated with spatial and temporal externalities. Profits are maximized when pesticides are used, like other inputs, such that the benefits from the last unit of pesticide (in terms of yield and quality changes and reduced risk of crop loss) are equal to the cost of using this last unit. This cost includes not only application and material costs and health risks to the farm family, but also future costs that may arise from the loss of natural enemies and consequent secondary pest outbreaks and the development of resistance.

In an earlier review of pesticide use in California, Carlson (1990, p. 43) concluded that the use of pesticides in California per acre and per dollar of farm output was low relative to the remainder of the United States for most crops and pesticide types and had been stable or declining. Expenditure on pesticides amounted to about four to five cents per dollar of output. Carlson suggested that this low use was partly explained by the dry climate and partly by the high rate of adoption of reduced-pesticide technologies. He noted a general trend for pesticide use, seemingly measured as numbers of applications, to have increased from 1950 to 1980, which he explained by the availability of new products and a falling price of pesticides. He observed stable or even declining pesticide use in the 1980s as pesticides increased in price relative to other inputs.

4.2 Some Facts About Pesticide Use in U.S. Agriculture

An important source of information about pesticide use in U.S. agriculture is the EPA report by Aspelin and Grube (1999). Unfortunately, the data in this report are not available at a state level. Some key points from this report:

- The United States accounted for about one-third by value and one-fifth by weight of world pesticide use (including chlorine and hypochlorites but excluding wood preservatives) in 1997.
- Agriculture accounts for two-thirds of U.S. pesticide expenditure and three-quarters of the volume.
- Expenditure on pesticides in U.S. agriculture in 1997 amounted to $8.3 billion, or almost $4,400 per farm (on 1.9 million farms), comprising $5.6 billion on herbicides and growth regulators, $1.6 billion on insecticides and miticides, $0.6 billion on fungicides and $0.5 billion on other pesticides (sulfur, oils, nematicides, fumigants and rodenticides).
- Herbicides (atrazine) account for the largest share of both expenditure and quantity of pesticides used by U.S. agriculture.
- Most year-to-year variation in U.S. pesticide use is explained by variation in crop acreages.
- Farmer expenditure on pesticides accounted for about 4.5 percent of U.S. total farm production expenses in 1997, down from 4.6 percent in 1996 and 4.7 percent in 1995.
- Pesticides are used on about one million farms comprising about half of all farms with cropland and two-thirds of all farms with harvested cropland. Most large-scale farms use pesticides.

Additionally the EPA report (Aspelin and Grube 1999) has the following tables:

- Conventional pesticides ranked by quantities used in crop production in 1987, 1993 and 1995
- Conventional pesticide use since 1964 in total and for agriculture, which shows a rising use of pesticides from 1964 to 1978 and then a plateau in use until 1996
- The number of new active ingredients registered by type from 1967 to 1997, which shows that the most active periods for pesticide registrations were in the 1970s and the 1990s—years when pesticide use showed some upward trend (perhaps not significant in the 1990s)
- Pesticide use and expenditure in agriculture by category (referred to as "class") of pesticide since 1979.

4.3 USDA Estimates of Expenditure on Pesticides in California Agriculture

The data on pesticide expenditure in California (and the United States) shown in Table 4.1, Figure 4.1, and Figure 4.2 are estimates compiled by the USDA Economic Research Service (online data, 2001). In census years, the data on expenditure were often taken directly from the *Census of Agriculture*. In noncensus years, when state-level data were not available, regional survey data were adjusted based on expenditures, cash receipts, or other state-level data from the most recent *Census of Agriculture*. In recent years,

Table 4.1 USDA estimates of pesticide use in California, 1950–1999

Year	Pesticide expenditures (year-2000 dollars, millions)	Pesticide expenditures/acre (year-2000 dollars)	California/U.S. pesticide expenditures (%)	California/U.S. farm receipts (%)	Pesticide/total expenditures (%)	Pesticide expenditures/ farm receipts (%)
1950	194.1		17.7	8.1	3.6	1.4
1951	196.7		17.7	8.4	3.1	1.3
1952	188.8		17.7	8.4	3.3	1.3
1953	153.2		17.8	8.5	2.9	1.0
1954	165.3		18.0	8.4	3.1	1.2
1955	196.8		18.2	9.1	3.8	1.4
1956	258.8		18.4	9.3	4.7	1.7
1957	182.5		18.6	9.3	3.4	1.3
1958	209.8		18.8	8.6	3.5	1.5
1959	246.3		17.6	9.3	3.5	1.6
1960	224.4		16.1	9.5	3.1	1.4
1961	235.6		15.0	9.3	3.2	1.5
1962	239.7		13.8	9.4	3.0	1.5
1963	223.7		12.7	9.4	2.8	1.4
1964	212.9		11.6	9.9	2.7	1.3
1965	227.5		10.7	9.5	2.8	1.4
1966	239.3		9.7	9.3	2.9	1.4
1967	366.4		10.9	9.2	4.4	2.2
1968	406.8		12.1	9.7	5.0	2.3
1969	466.2	60.95	13.3	9.3	5.7	2.7
1970	452.8	58.20	12.8	9.0	5.7	2.7
1971	498.8	63.04	12.5	9.2	5.8	2.9
1972	555.8	69.10	12.1	9.0	6.7	3.0
1973	528.6	64.66	11.7	8.3	5.4	2.3
1974	503.3	60.59	11.4	9.3	4.7	2.0
1975	525.3	62.31	11.0	9.5	5.2	2.3
1976	568.9	66.50	10.7	9.5	5.5	2.5
1977	475.1	54.73	10.3	9.8	4.7	2.1
1978	586.9	66.66	10.0	9.5	5.1	2.5
1979	718.0	81.64	10.2	9.8	5.8	2.7
1980	693.4	78.94	10.5	10.0	5.8	2.6
1981	770.6	87.82	10.7	9.9	6.8	3.2
1982	756.3	86.28	10.9	10.2	6.9	3.2
1983	661.9	77.44	11.0	9.7	6.4	3.2
1984	778.2	93.43	11.1	10.1	7.4	3.6
1985	702.0	86.55	11.2	9.9	7.3	3.4

Table 4.1 Continued

Year	Pesticide expenditures (year-2000 dollars, millions)	Pesticide expenditures/acre (year-2000 dollars)	California/U.S. pesticide expenditures (%)	California/U.S. farm receipts (%)	Pesticide/total expenditures (%)	Pesticide expenditures/ farm receipts (%)
1986	689.9	87.39	11.2	11.0	7.6	3.3
1987	703.5	91.65	11.3	11.2	7.6	3.2
1988	611.7	79.52	11.1	11.0	6.3	2.8
1989	696.8	90.38	10.8	11.3	6.5	3.0
1990	701.6	90.80	10.6	11.3	6.4	3.0
1991	779.8	100.70	10.3	10.6	7.0	3.7
1992	843.5	108.68	11.2	11.1	7.9	3.8
1993	863.9	109.12	11.3	11.6	7.2	3.7
1994	880.1	109.00	10.9	12.0	7.2	3.6
1995	980.5	119.13	11.7	12.0	7.3	4.0
1996	1,060.6	126.46	11.6	11.8	8.0	4.2
1997	1,163.3	136.17	12.3	12.4	8.0	4.3
1998	1,106.7	127.21	11.8	12.6	8.3	4.3
1999	1,037.3	117.13	11.8	13.1	7.3	4.1

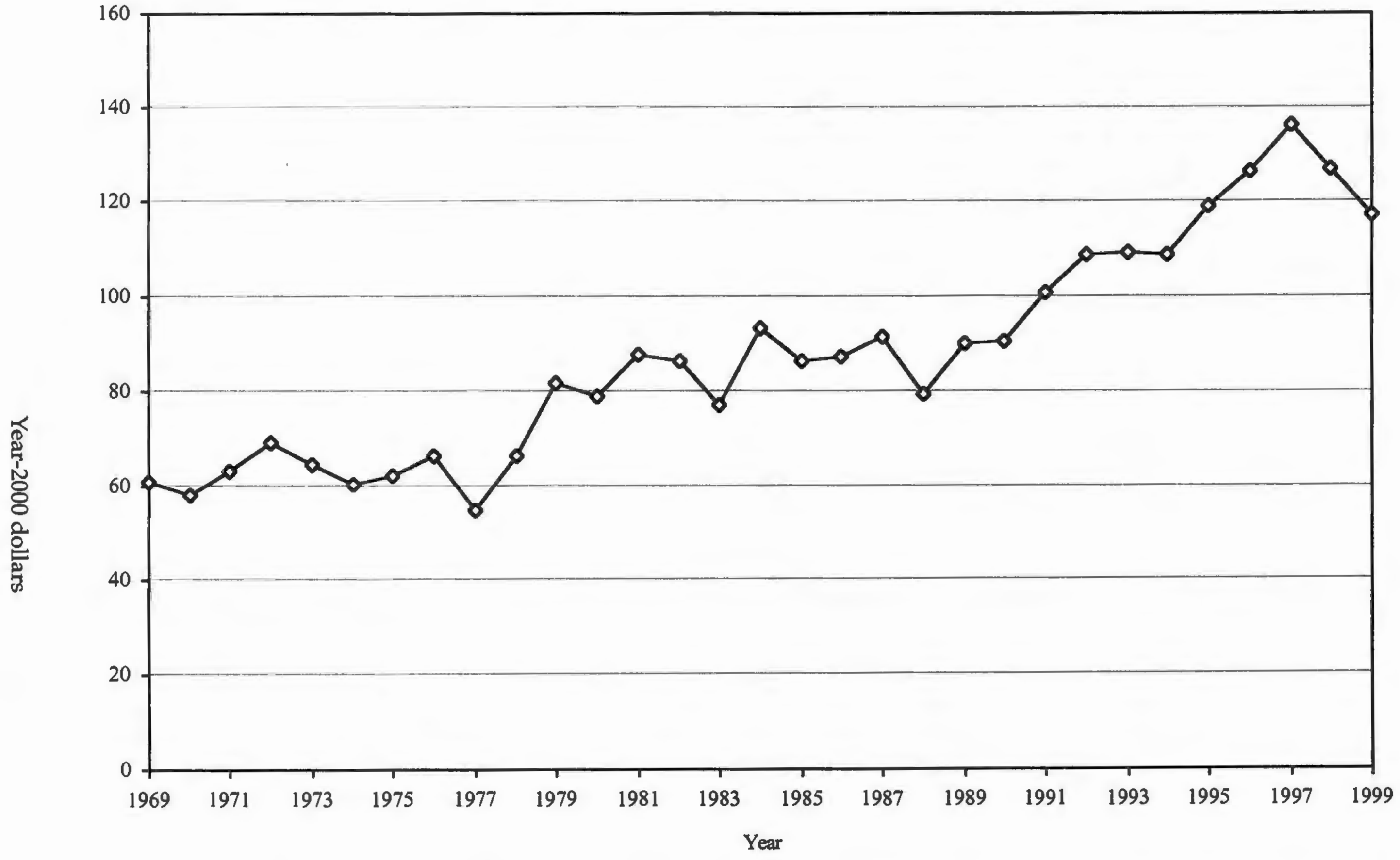
Source: Compiled by the authors from the United States Department of Agriculture, Economic Research Service, Farm Business Economics Briefing Room, online data, 2001.

the regional surveys used were the *Agricultural Resource Management Study* and the *Farm Costs and Returns Survey* (McGath 2001). The Economic Research Service (ERS) pesticide data may understate actual pesticide expenditures to the extent that census data form the basis for ERS estimates. This is because about one-third of all California farms (22,300) reported no pesticide or fertilizer use in the *1997 Census of Agriculture*. This figure seems high given there are only about 1,500 registered organic farmers in California (Kuminoff, Sumner and Goldman 2000). There is also some question as to accuracy of the estimate of the area of cropland harvested in California that is used to derive expenditure on pesticides per harvested acre. This was estimated from census data, and in recent years the ERS acknowledged that the area might be understated. Data on harvested cropland go back only to 1969.

Over the last 50 years, California farmers have increased their expenditure on pesticides from about $200 million (in year-2000 dollars) in 1950 to just over $1 billion in the late 1990s (Figure 4.1). On a per acre basis, expenditure rose from $61 in 1969 to $136 in 1997 before falling to $117 in 1999 (Figure 4.2). Some of the increase in total expenditure resulted from the increase in harvested cropland from 7.6 million acres in 1969 to 8.9 million acres in 1999.

Source: Compiled by the authors from USDA Economic Research Service data.

Fig. 4.1 Real expenditure on pesticides in California, 1950–1999



Source: Compiled by the authors from USDA Economic Research Service data.

Fig. 4.2 Pesticide expenditure per acre on crops in California, 1969–1999

However, there is some evidence in Figures 4.1 and 4.2 that pesticide expenditures increased most rapidly in the 1970s and 1990s, and this is consistent with the argument put forward in Chapter 3 that those periods coincided with the adoption of new classes of pesticides as growers learned how to manage new control strategies and their interaction with evolving insect populations. The period in the 1980s of little growth in pesticide expenditure coincides with the introduction of IPM programs in many crops. Some of the increase in pesticide expenditure since the mid-1960s can be attributed to the introduction and rapid adoption of herbicides.

We found that pesticide expenditures in California accounted for a growing share of total expenditures on production inputs, increasing from a 3 to 4 percent share in the 1950s to a 7 to 8 percent share in the 1990s (Table 4.1), such that the share of production expenses associated with pesticide use is higher in California than for U.S. agriculture in general (Aspelin and Grube 1999). This may be because of the greater importance of fruit, nut, and vegetable crops in California, which have a low tolerance for insect damage, particularly in fresh markets. As a share of farm receipts, pesticide expenditure in California rose from 1.4 percent in 1950 to 4.1 percent in 1999.

4.4 Pesticide Use Reporting in California

There has been some degree of pesticide-use reporting in California since at least 1950, but consistent statewide data first became available in 1970 with the introduction of new reporting requirements. Between 1970 and 1989, the California Department of Food and Agriculture (CDFA) required farmers to report their use of "restricted-use materials"[2] and required commercial pest control applicators to report their use of all pesticides. Each year, these data were summarized and reported in annual *Pesticide Use Reports*. Starting in 1990, farmers were also required to report use of all (not just restricted) agricultural pesticides. This practice continues today. In 1991 the responsibility for pesticide regulation was transferred to the newly created California Environmental Protection Agency, Department of Pesticide Regulation (DPR), which has continued to publish the *Pesticide Use Reports*.

Full-Use Reporting, 1990-Current

Since 1990, California has kept the most detailed records of agricultural pesticide use of any state. It has required that all agricultural use of pesticide products be reported to the county agricultural commissioner in the county of application, who then sends the reports to the DPR for entry in the pesticide-use reporting (PUR) database. Each year, the pesticide-use data are organized into two reports, one organized by commodity and the other organized by chemical active ingredient (ai). Both reports include data on

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[2] Permits are required to possess and apply these materials determined to have potential for injury to other crops, people and the environment. See Chapter 5 or Glossary.

the number of applications, pounds of active ingredient applied, and acreage on which each active ingredient was applied. DPR advises that 1990 data are not comparable because site and commodity categories were different and because of data collection problems.

Publications by DPR (Wilhoit et al. 1998, 1999) and others (Epstein et al. 2000) warn of the care required in interpreting these data. For example, tracking the number of applications gives no information about the amount applied in each application, and aggregate annual acreage treated may exceed total acreage planted to a crop since a single active ingredient may be applied to the same acres more than once during the crop year.

The most commonly used DPR measure of pesticide use seems to be the quantity of active ingredient. However, as DPR publications often note, aggregate poundage indicates neither toxicity nor environmental persistence. An increase in poundage does not necessarily imply there has been an increase in toxic chemicals applied per acre nor any change in the use of IPM practices by growers (Wilhoit et al. 1998, 1999). Changes in pounds of pesticides applied may be related to many factors, including but not limited to the weather, pest infestations, shifts between different chemicals, changes in crops grown, and increases or decreases in planted acres. Further, the role of prices of outputs and inputs is often not adequately recognized as a cause of changing pesticide practices.

In addition to tracking overall trends in pesticide use, DPR tracks the use of several specific chemical groups, namely reproductive toxins, carcinogens, cholinesterase inhibitors, groundwater protection list "a" pesticides plus nurflurazon, toxic air contaminants, reduced-risk pesticides, biopesticides, and oil pesticides.[3] DPR' s classification of chemicals is an ongoing process. As new information becomes available, the lists are updated and refined. The U.S. EPA has an expedited registration process for pesticides perceived as posing "reduced risk" to humans, but this classification does not consider whether the pesticides adversely affect biocontrol organisms. Registration of the first reduced-risk pesticide by the U.S. EPA occurred in 1994, which explains why the DPR reduced-risk list does not include chemicals registered prior to 1994, even though they may meet the reduced-risk criteria.

Partial-Use Reporting, 1970–1989

As already noted, prior to 1990 farmers had to report their use of restricted materials, and commercial pest control applicators had to report their use of all pesticides. However, it is difficult to draw general conclusions about trends in pesticide use from the 1971-90 data because of their inconsistent nature. The major problem with partial data is that it is unclear whether perceived trends are real or simply the result of substitution between re-

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[3] See Glossary for definitions and lists.

ported and nonreported chemicals—nonreported either because they were not required to be reported or because of under-reporting. The fact that the list of restricted materials was changing throughout the period compounds this issue, as growers are likely to substitute away from restricted materials. In addition, the use of petroleum products was not reported from 1984 through 1988. Because petroleum products represent a large share of total pesticide poundage, the series for total pounds applied for 1984-88 is not comparable with other years that include petroleum products. For example, the apparent decrease in pounds of applied pesticides on almonds in 1984 was almost entirely due to oils and other petroleum products being removed from the reports, whereas the apparent increase in 1989 was due to oils and petroleum products being reinstated in the reports.[4]

4.5 Trends in Pesticide Use in California from the DPR Database

Prior to 1990 much of the use of pesticides went unreported. In addition, according to DPR, data for the first full-use reporting year, 1990, is flawed because of changes in recording and data entry problems (site and commodity names changed). Hence, the discussion below focuses on the period starting in 1991 when full-use reporting to DPR was fully implemented.

Aggregate use of pesticide in California agriculture increased from 133 million pounds in 1991 to about 199 million pounds in 1998, and then dropped to 186 million pounds in 1999 (Figure 4.3). We estimate that about 0.1 percent of total pesticides were used in livestock enterprises. On a per acre basis, pesticide use appears to have increased by about one-third, from 14 pounds per acre in 1991 to 20 pounds per acre in 1999.[5]

Tables 4.2 and 4.3 provide data on the use of particular pesticides and classes of pesticides during the 1990s. Some of the data in Table 4.3b are based on a subset of 62 pesticides for which we were able to obtain price data, and these data are discussed in more detail in section 4.6.

In terms of total pounds, fungicides account for the largest share of pesticide active ingredients in California, followed by fumigants, herbicides and insecticides. In contrast, for the United States as a whole, herbicides account for most of the pesticide poundage, followed by insecticides and fungicides. In California, the ratio of pounds of fungicide to pounds of herbicide is roughly 8 to 1, or excluding sulfur (a fungicide acceptable for organically grown crops) about 1.5 to 1. For the United States as a whole this ratio, excluding sulfur, is about 1 to 7 (Anderson and Heimlich 2000). The dramatic difference in fungicide use between the United States as a whole and California is likely due to California's large amount of fruit and vegetable crops for which fungicides are used frequently.

Four pesticides account for about 70 percent of the total pounds of pesticides used by California agriculture. They are sulfur, oils, metam sodium,

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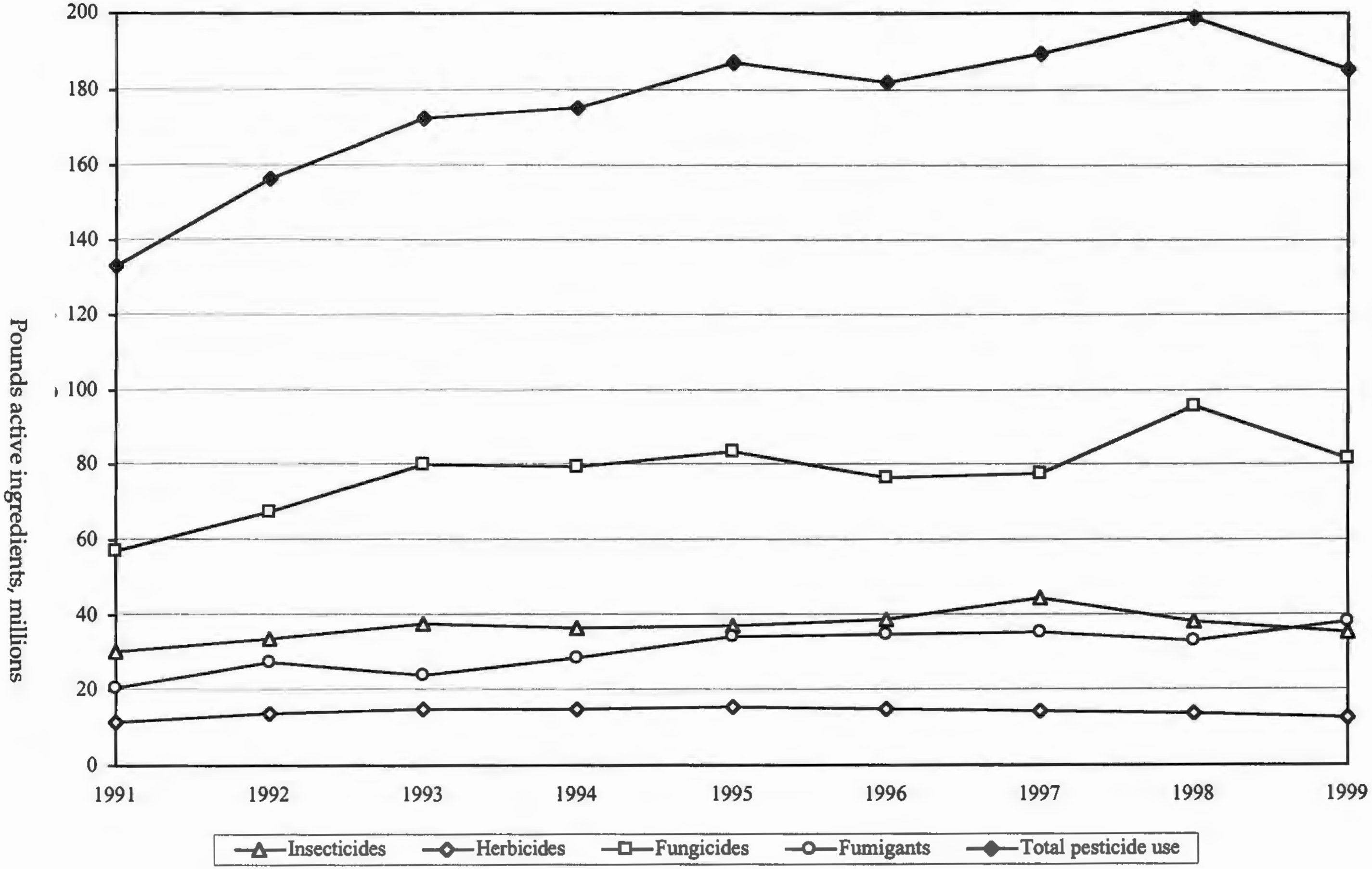
[4] Other problems with the data prior to 1984 are noted in the CDFA 1989 *Pesticide Use Report*.

[5] Estimated as total pesticide use in agriculture in California divided by total harvested acres.



Source: Compiled by the authors from California Department of Pesticide Regulation, PUR database, 2001.

Fig. 4.3 Pesticide use by California agriculture, 1991–1999

Table 4.2a Top 10 pesticides applied to California agriculture, 1991–1999

						Year				
Pesticide	**Class**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
						(million pounds active ingredient)				
Sulfur	Fungicide	48.1	57.6	67.6	67.3	68.8	63.0	64.6	78.0	68.6
Oils	Insecticide	19.3	21.5	25.7	23.9	23.2	26.1	31.3	27.6	25.8
Methyl bromide	Fumigant	13.7	16.4	12.9	15.1	16.0	14.8	14.6	12.6	14.3
Metam-sodium	Fungicide	4.9	8.5	8.6	11.1	14.9	15.1	14.8	13.6	16.7
Copper hydroxide	Fungicide	2.8	2.6	3.6	3.6	3.9	3.8	3.6	5.3	3.5
Sodium chlorate	Herbicide	2.6	4.0	4.3	3.6	3.8	3.3	2.9	2.4	2.2
Chloropicrin	Fumigant	2.2	2.5	2.1	2.5	2.8	2.8	2.8	3.0	3.6
Copper sulfote, all	Fungicide	2.0	2.8	2.9	3.3	3.7	3.7	4.2	3.5	3.0
Glyphosate, all	Herbicide	1.5	2.0	2.3	2.3	2.6	2.7	2.7	3.0	2.8
1,3-Dichloropropene, all	Fumigant	0.0	0.0	0.0	0.0	0.4	2.0	2.4	2.9	3.3
Top ten total		*97.1*	*117.9*	*130.1*	*132.7*	*140.1*	*137.2*	*143.8*	*152.0*	*143.9*
Total production agriculture		132.7	156.7	172.5	175.4	187.6	182.4	189.8	198.6	185.5

Source: Compiled by the authors from the California Department of Pesticide Regulation, *Pesticide Use Reports*, 1997–1999; Wilhoit et al., 1999; and Wilhoit, 2001.

Table 4.2b Top 10 pesticides per harvested acre, 1991–1999

						Year				
Pesticide	**Class**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
						(pounds active ingredient per acre)				
Sulfur	Fungicide	6.2	7.4	8.5	8.3	8.4	7.5	7.6	9.0	7.8
Oils	Insecticide	2.4	2.7	3.2	2.9	2.7	3.0	3.6	3.2	2.9
Methyl bromide	Fumigant	1.8	2.1	1.6	1.9	2.0	1.8	1.8	1.5	1.7
Metam-sodium	Fungicide	0.6	1.1	1.1	1.4	1.8	1.8	1.7	1.6	1.9
Copper hydroxide	Fungicide	0.4	0.3	0.5	0.5	0.5	0.5	0.4	0.6	0.4
Sodium chlorate	Herbicide	0.3	0.5	0.6	0.5	0.5	0.4	0.3	0.3	0.2
Chloropicrin	Fumigant	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4
Copper sulfate, all	Fungicide	0.3	0.4	0.4	0.4	0.5	0.4	0.5	0.4	0.3
Glyphosate, all	Herbicide	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.3
1,3-Dichloropropene, all	Fumigant	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.3	0.4
Top ten total		12.5	15.1	16.3	16.3	16.9	16.2	16.8	17.5	16.4

Source: Compiled by the authors from the California Department of Pesticide Regulation, *Pesticide Use Reports*, 1997–1999; Wilhoit et al., 1999; and Wilhoit, 2001.

Table 4.3a All pesticide use by California agriculture, 1991–1999

					Year				
Pesticide	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
					(thousand pounds active ingredient)				
Reproductive toxins	20,193	26,626	23,992	28,323	33,116	32,039	31,251	27,731	32,330
Oils	19,339	21,470	25,745	23,888	23,157	26,114	31,306	27,640	25,788
Toxic air contaminants	18,353	20,656	17,952	20,636	22,746	22,873	22,525	22,229	22,586
Cholinesterase inhibitors	11,869	12,496	13,305	14,544	15,848	14,352	15,042	11,936	10,916
Carcinogens	8,270	12,775	13,281	16,283	21,590	23,434	22,915	24,031	25,375
Organophosphates	6,868	7,304	7,554	8,398	9,492	7,815	8,518	6,544	6,129
Carbamates	4,193	4,583	4,891	5,299	5,374	5,586	5,643	4,632	4,055
Potential groundwater contaminants	1,267	1,459	1,567	1,543	1,421	1,646	1,603	1,777	1,678
Biopesticides	47	56	59	78	90	100	182	204	250
Reduced risk pesticides				0	8	5	71	285	354
Total pesticide use*	132,740	156,686	172,496	175,409	187,578	182,376	189,796	198,571	185,529
				(lbs)					
Active ingredient per acre	14	17	19	19	20	19	20	21	20

Source: Compiled by authors from Wilhoit, 2001.

*Total pesticide use = all pesticides used in production agriculture

Table 4.3b Use of 62 major pesticides by California agriculture, 1991–1999[a]

Class	1991	1992	1993	1994	Year 1995	1996	1997	1998	1999
					(million pounds active ingredient)				
Fungicides	57.5	67.8	80.2	79.5	83.5	77.1	77.8	95.8	81.8
Insecticides	30.1	33.8	37.9	36.9	37.0	38.7	44.5	38.2	35.4
Fumigants	20.7	27.4	23.8	28.7	34.4	35.2	35.4	33.0	38.6
Herbicides	11.2	13.7	15.0	14.7	15.3	15.0	14.4	13.7	12.5
Plant growth regulators	0.8	0.6	0.9	0.9	1.0	1.0	0.9	0.8	0.8
					(percentage of total California use, by weight)				
Fungicides	47.8	47.3	50.8	49.5	48.8	46.2	45.0	52.8	48.4
Insecticides	25.0	23.6	24.0	23.0	21.6	23.2	25.7	21.1	21.0
Fumigants	17.2	19.1	15.1	17.9	20.1	21.1	20.4	18.2	22.8
Herbicides	9.3	9.6	9.5	9.1	8.9	9.0	8.3	7.6	7.4
Plant growth regulators	0.7	0.5	0.6	0.6	0.6	0.6	0.5	0.4	0.5
					(year-2000 dollars, millions)				
Estimated expenditures[b]	528.5	599.0	652.4	672.5	756.6	745.3	738.2	713.2	674.0
					(year-2000 dollars/acre)				
Estimated expenditures[b]	54	65	74	74	80	76	77	76	73

Source: Compiled by the authors from the California Department of Pesticide Regulation, Pesticide Use Summary, annual reports, 1991–1999; University of California, Davis, Agricultural Issues Center data; and Wilhoit, 2001.

[a] The 62 pesticides are listed in Table 4.5

[b] Estimated expenditures are for the 62 major pesticides

and methyl bromide. Use of the first three increased significantly during the 1990s, while poundage of methyl bromide trended downward slightly amid annual fluctuation. Table 4.4 shows the crops that accounted for the largest shares of each of these four pesticides. The grape industry uses the most sulfur, the almond industry uses the most oils, the carrot industry uses the most metam sodium, and the strawberry industry uses the most methyl bromide.

The price of methyl bromide has risen by 60 percent since 1991. The price of sulfur has fallen more than 60 percent (Table 4.5), while there has been no clear trend in the prices of oils and metam sodium, although the prices of both were higher in 1999 than in 1991.

Sulfur, a natural element that has been used for at least 2,000 years for pest control and is approved for use on certified organic farms, accounted for between 34 percent and 39 percent of the total annual pesticide poundage used by California agriculture during the 1990s. Wilhoit et al. (1999) reported that sulfur is widely used because it is relatively inexpensive, has low mammalian toxicity, and controls both mites and fungal diseases. Nevertheless, because it is used as a powder, it can cause respiratory illness in those working in recently dusted fields. In 1999, grapes, tomatoes and sugar beets accounted for over 90 percent of the sulfur use in agriculture, and grapes alone accounted for about 70 percent.

Oils include all petroleum-based compounds, and as a group represented between 12 percent and 17 percent of total pounds of all pesticides (not just the top 10) applied to California agriculture during the 1990s. Oils are used to control insects including aphids, scale and mites, and are also used to control fungal diseases. Some oil pesticides are carcinogens, but DPR also notes that in many cases they serve as alternatives to highly toxic pesticides. Oils often have been used in conjunction with organophosphates as a dormant season spray but they have increasingly been used alone because of concerns about routine detection of several organophosphates in the Sacramento and San Joaquin River watersheds after storms (Willhoit et al. 1999). In 1996 almonds accounted for the largest share of oil pesticides used on any specific crop (27 percent), followed by oranges (19 percent) and lemons (13 percent).

Metam sodium was the third-ranked pesticide in terms of total pounds applied in 1999, and its use more than quadrupled during the decade, increasing from 4 percent of total pounds applied in 1991 to 9 percent in 1999. Applied as a broad-spectrum, preplant fumigant, metam sodium is used to treat diseases, insects, weeds, and nematodes. DPR lists it as both a carcinogen and a reproductive toxin. Wilhoit et al. (1999) noted that the large increase between 1991 and 1996 resulted from both more pounds applied per application and more acres treated, while the number of applications actually decreased. Metam sodium is mostly used on vegetables and field crops, with carrots (39 percent), processing tomatoes (23 percent), and potatoes (12 percent) representing the largest shares of its use.

Table 4.4 Top commodities as a share of total pounds active ingredient applied, 1999

Pesticide	Commodity	Share
		(percentage)
Sulfur		
	Grapes, wine	38
	Grapes	34
	Tomatoes, processing	10
	Others	9
	Sugarbeets	8
	Peaches	1
	Total	*100*
Oils*		
	Almonds	28
	Others	24
	Oranges	20
	Lemons	13
	Pears	8
	Peaches	7
	Total	*100*
Metam-sodium		
	Carrots	38
	Tomatoes, processing	23
	Others	20
	Potatoes	12
	Cotton	4
	Cantaloupe	3
	Total	*100*
Methyl bromide		
	Others	51
	Strawberries	34
	Grapes, wine	5
	Peppers	4
	Walnuts	3
	Sweet potatoes	3
	Total	*100*

Source: Compiled by the authors from the California Environmental Protection Agency, Department of Pesticide Regulation, Pesticide Use Reports, various years.

*From 1996 DPR data published in Wilhoit *et al.*

Table 4.5 Price of chemical per pound of active ingredient, 1991–1999

Pesticide	1991	1992	1993	1994	1995	1996	1997	1998	1999
					(year-2000 dollars)				
1,3-dichloropropene, all	**1.72**	**1.72**	**1.72**	**1.72**	**1.72**	**1.72**	**1.72**	**1.72**	1.72
2,4-D, all	3.37	3.41	3.64	3.76	3.87	3.96	3.91	3.86	3.80
Acephate	15.58	15.68	16.22	16.63	16.86	17.11	17.90	17.26	17.15
Aldicarb	26.47	**25.77**	25.09	27.47	26.52	25.80	25.87	25.55	25.65
Avermectin	**5,813.33**	**5,813.33**	**5,813.33**	**5,813.33**	**5,813.33**	**5,813.33**	**5,813.33**	**5,813.33**	**5,813.33**
Azadirachtin	**3,152.94**	**3,152.94**	**3,152.94**	**3,152.94**	**3,152.94**	**3,152.94**	**3,152.94**	**3,152.94**	**3,152.94**
Azinphos methyl	15.74	**15.83**	15.92	18.60	18.68	18.52	18.08	18.58	18.78
Bacillus thuringiensis	17.41	15.02	14.89	15.04	14.39	13.37	12.90	12.53	12.35
Benomyl	37.68	37.95	38.65	39.87	39.24	39.13	38.18	37.91	37.96
Captan, all	6.11	6.68	6.78	6.86	7.22	7.06	6.82	6.96	7.00
Carbaryl	5.29	5.76	6.10	6.03	6.25	6.20	6.24	6.42	6.56
Chloropicrin	**2.42**	**2.42**	**2.42**	**2.42**	**2.42**	**2.42**	**2.42**	**2.42**	2.42
Chlorothalonil	8.71	9.36	9.82	9.65	9.54	9.96	9.96	9.63	9.95
Chlorpyrifos	12.70	13.16	13.67	13.48	13.43	13.66	13.29	13.21	13.01
Chlorthal-dimethyl	**22.44**	**22.44**	**22.44**	**22.44**	**22.44**	**22.44**	**22.44**	**22.44**	22.44
Copper hydroxide	3.56	3.33	3.54	3.66	3.55	3.58	3.49	3.40	3.35
Copper sulfate, all	2.70	2.20	2.36	2.71	2.55	2.64	2.55	2.50	2.33
Cryolite	**6.39**	**6.24**	**6.09**	**5.97**	**5.84**	**5.73**	5.62	5.55	**5.47**
Cyanazine	6.74	6.78	6.74	7.29	7.71	7.86	7.87	8.18	8.24
Cypermethrin	104.51	99.91	96.74	93.96	103.05	99.54	96.11	99.44	95.75
Diazinon	9.24	9.87	9.18	9.33	9.54	9.76	9.47	9.04	9.11

Dicofol	25.89	28.61	28.29	29.85	29.09	30.49	30.57	31.37	30.32
Dimethoate	9.25	12.95	12.56	10.80	11.02	12.49	12.92	13.46	13.42
Diuron	6.26	8.15	7.67	7.32	7.00	6.95	6.88	6.81	6.52
EPTC	4.40	4.13	4.15	4.16	4.23	4.53	4.67	4.88	4.83
Esfenvalerate	224.05	224.02	227.38	234.55	239.46	241.39	235.19	232.28	210.30
Ethephon	**46.05**	**46.05**	**46.05**	**46.05**	**46.05**	**46.05**	**46.05**	**46.05**	46.05
Fenarimol	**113.79**	**113.79**	**113.79**	**113.79**	**113.79**	**113.79**	**113.79**	**113.79**	**113.79**
Fosetyl-al	19.23	27.65	28.71	21.44	20.98	21.52	17.44	16.44	16.71
Gibberellins, all	**1,551.97**	**1,420.30**	**1,294.43**	1,177.35	883.63	794.29	756.64	699.20	663.36
Glyphosate, all	16.52	12.81	14.81	14.92	14.74	14.89	14.87	14.58	11.61
Imidacloprid	**333.16**	**336.16**	**338.94**	**342.46**	**345.37**	**348.84**	352.01	357.37	361.66
Iprodione	48.18	50.76	51.84	51.90	50.14	49.83	47.83	48.06	47.15
Lime-sulfur	1.60	**2.10**	2.57	2.41	2.17	2.12	2.15	2.21	2.35
Malathion	4.63	4.49	4.55	4.70	4.93	4.96	5.06	5.18	5.12
Mancozeb	4.22	4.42	4.47	4.31	4.37	4.46	4.49	4.48	4.08
Maneb	3.73	3.25	3.68	3.52	3.68	3.98	4.10	4.03	3.98
MCPA, all	3.88	3.78	4.15	4.09	4.33	4.49	4.41	4.38	4.21
Mepiquat chloride	**473.14**	**473.14**	**473.14**	**473.14**	**473.14**	**473.14**	**473.14**	**473.14**	**473.14**
Metalaxyl	88.84	86.15	86.97	90.21	92.64	91.95	92.82	93.23	95.42
Metam-sodium	**0.86**	0.89	**0.98**	**1.06**	**1.14**	**1.22**	1.29	**1.19**	1.08
Methamyl	25.56	25.15	25.50	26.89	26.56	27.76	27.81	26.73	27.23
Methyl bromide	2.00	2.26	2.65	2.88	3.17	3.23	3.47	3.35	3.22
Molinate	**5.03**	6.13	**6.96**	**7.77**	**8.54**	**9.29**	**10.01**	10.77	12.86
Myclobutanil	173.81	**178.41**	182.76	178.47	188.29	197.54	188.52	181.27	185.74
Oils, All	0.65	0.95	0.79	0.80	0.79	0.76	0.77	0.79	0.75

(continued)

Table 4.5 Continued

Pesticide	1991	1992	1993	1994	1995	1996	1997	1998	1999
Oryzalin	**20.77**	20.86	21.21	23.79	24.81	**22.14**	19.57	21.67	21.90
Oxydementon-Methyl	**23.83**	25.61	26.03	29.46	33.08	34.27	33.09	34.55	36.84
Oxyfluorfen	**54.75**	**54.75**	**54.75**	**54.75**	**54.75**	**54.75**	**54.75**	**54.75**	**54.75**
Paraquat Dichloride	**17.22**	**14.95**	**14.83**	**14.79**	**15.26**	**15.48**	**15.86**	**16.16**	**14.21**
Permethrin	**62.28**	**62.28**	**62.28**	**62.28**	**62.28**	**62.28**	**62.28**	**62.28**	**62.28**
Propargite	24.25	22.12	20.84	21.98	21.40	22.13	22.69	22.13	23.17
Propyzamide	**91.69**	**91.69**	**91.69**	**91.69**	**91.69**	**91.69**	**91.69**	**91.69**	**91.69**
Pyrethrins	67.42	67.16	67.34	65.54	64.56	64.15	64.14	64.54	58.09
S,S,S-Tributyl Phosphorotrithioate	**10.60**	**10.60**	**10.60**	**10.60**	**10.60**	**10.60**	**10.60**	**10.60**	**10.60**
Simazine	4.50	4.60	4.83	5.10	4.96	4.92	4.77	4.79	4.64
Sodium Chlorate	**3.13**	**3.13**	**3.13**	**3.13**	**3.13**	**3.13**	**3.13**	**3.13**	3.13
Sodium Tetrathiocorbonate	**2.74**	**2.74**	**2.74**	**2.74**	**2.74**	**2.74**	**2.74**	**2.74**	**2.74**
Sulfur	0.87	0.80	0.60	0.43	0.40	0.41	0.37	0.33	0.34
Thiobencarb	**0.13**	**0.13**	**0.13**	**0.13**	**0.13**	**0.13**	**0.13**	**0.13**	0.13
Trifluralin	8.94	9.31	9.18	9.05	8.94	8.71	8.23	7.74	7.45
Ziram	3.86	**3.98**	4.10	4.12	3.99	4.01	4.11	3.93	3.92
Index of Pesticide Prices	**.89**	**.92**	**.93**	**.95**	**.96**	**.99**	**1.00**	**1.01**	**1.00**
Index of Pesticide Use	**.75**	**.85**	**.93**	**.96**	**1.09**	**1.07**	**1.06**	**1.04**	**1.00**

Source: Compiled by the authors from the USDA, National Agriculturol Statistics Service, Agricultural Prices, annual reports, 1992-2001; Roy Riegels Chemical Company, Woodland, California, Personal Communication, July 2000; University of California Cooperotive Extension and Department of Agriculture and Resource Economics, Cost and Return Studies, various reports, 1991-1999, and GDP Deflator from the United States Department of Commerce, Bureau of Economic Analysis, National Income and Product Accounts, online data, 2001.

Note: Observotion in bold represent years where price data were not available and the authors interpolated or assumed a constant real price.

Methyl bromide, the fourth-ranked pesticide by pounds applied, decreased during the 1990s in terms of actual pounds applied and as a share of total pounds applied. It ranged from a high of 10 percent of total pounds applied in 1991 to a low of 7 percent in 1998. Methyl bromide is a fumigant generally used to control nematodes, disease pathogens, and weed seeds. This pesticide is classified by DPR as a toxic air contaminant and reproductive toxin and, because it is an ozone depleter, is scheduled to be phased out from use in the United States by 2005 under the Montreal Protocol. In California, methyl bromide is used as a preplant fumigant in the production of many crops. In 1999 strawberries accounted for about 37 percent of the use of methyl bromide, and grapes for 8 percent. The fumigants are used on comparatively limited acreages, though in large tonnages, and their use is heavily regulated. The environmental and public health implications are thus constrained to some extent.

We also examined pesticide use by 13 important commodities in California (alfalfa, almonds, carrots, cotton, grapefruit, head lettuce, oranges, rice, strawberries, processing tomatoes, table and dried grapes, wine grapes, lemons). In 1999 these 13 commodities accounted for 74 percent by weight of pesticides used in agriculture in California. As expected, wine grapes (17 percent), table and dried grapes (16 percent), almonds (8 percent), strawberries (5 percent) and carrots (4 percent), which were large users of the four main pesticides identified above, also had relatively large shares of total pesticide use. Other heavy users included processing tomatoes (7 percent) and cotton (5 percent). Cotton's share in 1999 was lower than usual because of the contraction of the industry.

4.6 Estimates of California Pesticide Expenditures Based on DPR Data

A contribution of this project has been to estimate expenditure on pesticides for California crops in total and for individual crops using the DPR *Pesticide Use Report* data on pesticide quantities and price data we assembled largely from USDA sources. We compiled data for 62 pesticides that accounted for between 90 percent and 92 percent of total pounds applied. In 1996 these 62 pesticides accounted for 46 percent of total pesticide applications, and 44 percent of cumulative acres treated, which implies that we have left out some chemicals applied widely but at low rates. The 62 pesticides, which are listed in Table 4.5, were primarily taken from lists of major active ingredients by pounds applied, applications, and acres treated in Appendix B of Wilhoit et al. (1999). We added a few pesticides that were important to the commodities in our case studies and where price data were available. For each pesticide, we obtained data on pounds of agricultural applications from 1991 through 1999 from the Department of Pesticide Regulation (Wilhoit 2001).

We obtained data on pesticide product prices from three different sources. Our primary source was U.S. average prices reported in the USDA's National Agricultural Statistics Service, *Agricultural Prices*, annual reports. This source contained about two-thirds of all the product prices for our 62 pesticides for 1991-99. For prices not listed in *Agricultural Prices* we turned to UC Cooperative Extension commodity budgets and personal communication with a representative from Roy Reigels Chemical Company in Woodland, CA. Prices from these last two sources are for California, rather than the United States as a whole. We did not have the resources to assemble a consistent set of prices for California. Anecdotal information suggested that for many pesticides there is significant variation in price among states, regions within a state, crops, and among different-sized farms. Nevertheless, we expect that our set of prices is a reasonable representation of the trends in pesticide prices experienced by growers in California since 1990.

In cases where we were not able to find a price for a particular product for one or two years between 1991 and 1999, we estimated price through linear interpolation. In cases where we were not able to find a pesticide price for any year in 1991-99, we used the 2000 price and assumed that the real price of that pesticide remained constant from 1991 to 2000. Finally, we converted pesticide product prices to dollars per pound of active ingredient, using conversion factors given on the pesticide labels. Table 4.5 shows our data on pesticide prices, converted to year-2000 dollars using the GDP deflator. The observations in bold represent years where price data were not available and we interpolated or assumed a constant real price.

Table 4.6 shows total expenditures and expenditures per acre since 1991 on the 62 pesticides for California as a whole and for the five case-study commodities. In general there is close correspondence between the ERS estimates of expenditure on pesticides and our estimate based on 62 pesticides from the DPR database. Our estimate of expenditures by California agriculture on the 62 pesticides ranged from 63 percent to 77 percent of total expenditures reported by ERS. However, as can be seen in Figure 4.4, our estimate of expenditure peaked in 1995 whereas, according to the ERS estimate, expenditure kept rising until 1997. In terms of pounds of active ingredient applied, pesticide use peaked in 1998.

Turning to the 13 commodities we have been tracking, expenditure on the 62 pesticides by this group accounted for 63 percent of total expenditure in California in 1999. In terms of expenditures, the largest users were cotton (15 percent), almonds (10 percent), table and dried grapes (9 percent), and wine grapes (7 percent), largely reflecting the size of these industries (Table 4.7). On a per acre basis the ranking was quite different. The strawberry industry applied pesticides worth $1,300 per acre, a rate more than six times higher than head lettuce ($200), the next highest user on an expenditures per acre basis. The average rate of pesticide expenditure (for the 62 chemicals) in California was approximately $73 per acre in 1999 (Table 4.6). Of the

Table 4.6 Expenditures on 62 pesticides, 1991–1999*

Year	California	Almonds	Cotton	Oranges	Processing tomatoes	Head lettuce
			(year-2000 dollars, millions)			
1991	528.5	52.8	96.5	14.9	na	23.9
1992	599.0	58.8	102.5	23.5	na	28.3
1993	652.4	60.6	128.4	24.6	na	28.9
1994	672.5	56.4	143.6	25.9	na	27.8
1995	756.6	58.8	199.2	26.5	19.5	35.0
1996	745.3	67.3	174.9	27.0	23.4	34.1
1997	738.2	70.9	162.5	29.9	16.5	28.6
1998	713.2	79.8	129.6	24.2	20.1	29.7
1999	674.0	66.6	98.1	18.6	19.5	28.0
			(year-2000 dollars per acre)			
1991	54.3	139.1	92.4	82.1	na	157.1
1992	65.0	146.6	92.4	127.6	na	192.4
1993	73.7	150.8	112.5	133.0	na	204.8
1994	74.2	137.9	121.6	135.7	na	191.9
1995	79.9	147.1	155.0	135.4	58.8	242.9
1996	76.1	166.2	150.1	135.1	73.7	226.8
1997	77.0	172.9	152.6	149.2	61.2	203.1
1998	76.1	173.5	152.5	120.0	71.4	220.1
1999	72.7	138.7	115.5	93.1	57.7	200.0

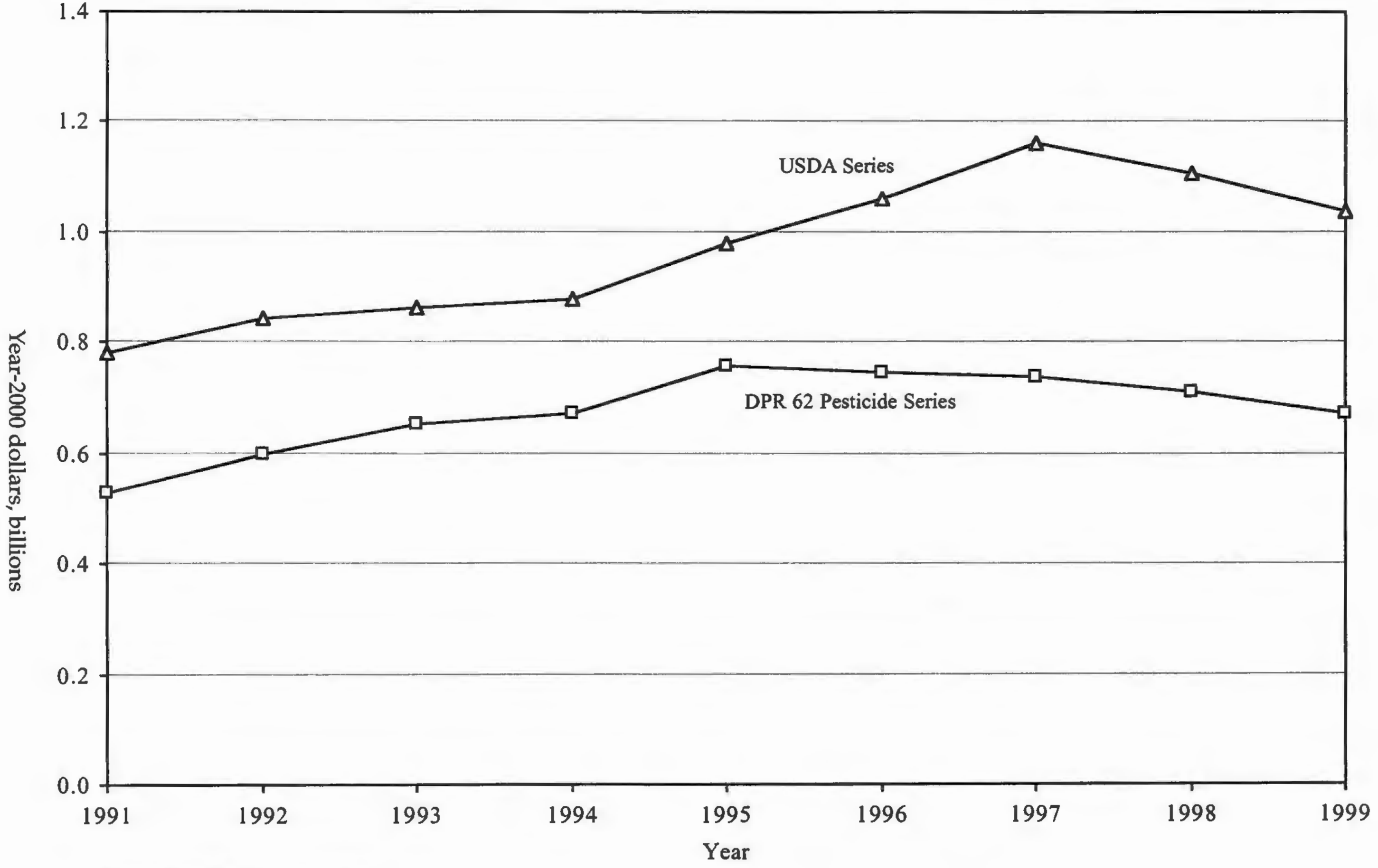
Source: Compiled by the authors from the University of California, Davis, Agricultural Issues Center data.

*The 62 pesticides are listed in table 4.5

Note: na = not available

13 commodities we tracked, processing tomatoes, alfalfa, rice and grapefruit were below this average. The data are consistent with the view that there is little tolerance for insect and disease damage in the fresh fruit and vegetable industries.

For many of the 13 commodities, real expenditures per acre generally increased from 1991 to the mid-1990s and then fell to 1999. Expenditure per acre on the 62 pesticides in the almond, alfalfa, and carrot industries, both grape industries, and the grapefruit industry was the same or lower in 1999 compared with 1991. In the table and dried grape industry, expenditure per acre had fallen by more than 10 percent. In the head lettuce and strawberry industries, however, expenditure per acre increased between 1991 and 1999 by more than 25 percent.



Source: Compiled by the authors.

Fig. 4.4 DPR and USDA estimates of California pesticide expenditure, 1991–1999

4.7 The Index Number Approach to Pesticide Use

The measures of pesticide use that have been reviewed to this point have a number of deficiencies that make it difficult to make unequivocal statements about whether pesticide use has increased. One problem area is in how the quantities of pesticides are aggregated. The usual approach is to simply add up pounds of active ingredient. This is the approach used by DPR, for example. With this approach, pesticide use can appear to change, even though there has only been a shift between pesticides of different efficacy. Furthermore, even if climatic factors influencing pest populations are constant, changes in total pesticide use may come from either a change in the total area treated or in the rate of treatment per acre. In addition, the quality of pesticides has changed with the advent of new products and restrictions on the use of old products. Hence, a significant area of research, largely conducted within USDA and EPA, has involved the development of indices of pesticide prices and quantities that might more accurately reflect real movements in the prices and quantities of pesticides used.

The standard approach in much empirical work has been to form indices by weighting the members of the index, in this case individual pesticides, by their share in total expenditure on pesticides. Index number theory and practice is reviewed in Diewert (1992). Provided that adequate information on prices and quantities of all class members is available, price and quantity indices for the class can be estimated that are consistent with the choices of a profit-maximizing farmer. We followed this approach in deriving price and quantity indices for our sample of 62 pesticides over the 1991-99 period.

To gain some appreciation of the overall trend in prices and use of these 62 pesticides, indexes of prices and quantities were derived (Table 4.5).[6] The price index rose by about 10 percent from 1991 to 1996. Prices have since remained stable. The quantity index rose by more than one-third from 1991 to 1995. It has since fallen but was still one-third higher in 1999 than 1991. These movements in prices and quantities are mirrored in our estimate of expenditure on the 62 pesticides, which rose from $529 million (year-2000 dollars) in 1991 to $757 million in 1995 before falling to $674 million in 1999, as shown in Table 4.6 and Table 4.7. Expenditure per acre rose from $54 per acre in 1991 to $80 per acre in 1995 and then fell to $73 per acre in 1999. This estimate of expenditure per acre is about two-thirds of the estimate for California derived from the USDA data and largely reflects the incomplete coverage provided by our sample of 62 pesticides.

A pervasive source of bias is the inadequate accounting for the range of quality differences, especially those related to effectiveness, within a category. If these differences are ignored and a number of different categories are treated as one, the estimated changes in the indices of price and quan-

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[6] Fisher indexes were estimated by procedures described in Alston, Norton and Pardey (1995).

Table 4.7 California pesticide use by commodity, 1991–1999

Year	California Total	Almonds	Cotton	Head lettuce	Oranges	Processing tomatoes	Alfalfa	Carrots	Grapefruit	Table grapes and raisins	Wine grapes	Lemons	Strawberries	Rice
						(million pounds applied active ingredient)								
1991	132.7	12.4	9.6	1.7	3.6	na	3.5	3.4	0.4	20.1	15.4	3.1	6.9	2.4
1992	156.7	12.8	11.5	1.8	6.0	na	2.4	4.0	0.8	24.0	21.0	3.9	7.2	3.7
1993	172.5	13.4	13.0	1.8	7.6	na	2.3	3.6	0.6	28.6	27.2	3.9	5.8	3.7
1994	175.4	12.6	14.0	1.8	7.5	na	2.9	4.1	0.5	28.3	26.3	3.2	6.9	4.5
1995	187.6	11.6	17.1	2.7	9.0	11.6	3.3	6.6	0.5	31.0	26.3	3.9	7.0	5.1
1996	182.4	14.0	14.4	2.3	9.6	14.7	3.3	6.3	0.3	24.9	25.6	4.2	7.3	5.2
1997	189.8	14.4	13.3	1.7	11.5	11.1	3.6	7.5	0.4	26.7	27.0	5.0	6.8	5.5
1998	198.6	16.0	9.5	1.9	10.2	11.6	3.8	7.3	0.3	34.7	34.4	4.0	7.3	5.0
1999	185.5	14.8	8.4	1.6	8.7	12.7	3.7	7.9	0.3	29.3	30.6	3.3	8.8	4.9
Share of Total *Use in 1999*		*0.08*	*0.05*	*0.01*	*0.05*	*0.07*	*0.02*	*0.05*	*0.00*	*0.16*	*0.17*	*0.02*	*0.05*	*0.03*
						Expenditures on 62 pesticides ($m) year-2000 dollars*								
1991	528.5	52.8	96.5	23.9	14.9	na	20.1	7.1	0.8	71.0	31.6	4.3	19.5	8.7
1992	599.0	58.8	102.5	28.3	23.5	na	15.3	7.5	1.5	82.7	41.0	6.4	22.6	12.9
1993	652.4	60.6	128.4	28.9	24.6	na	14.5	8.5	1.3	75.5	54.4	6.1	21.0	14.8
1994	672.5	56.4	143.6	27.8	25.9	na	19.0	10.2	1.0	81.0	37.0	6.1	26.1	18.6

1995	756.6	58.8	199.2	35.0	26.5	19.5	22.5	13.4	0.9	68.7	37.4	7.0	28.0	19.9
1996	745.3	67.3	174.9	34.1	27.0	23.4	21.5	13.5	0.8	58.2	41.4	7.6	29.6	20.9
1997	738.2	70.9	162.5	28.6	29.9	16.5	23.3	14.8	0.8	66.2	43.6	9.0	27.7	20.4
1998	713.2	79.8	129.6	29.7	24.2	20.1	23.1	11.3	0.6	69.2	50.2	7.5	28.9	17.1
1999	674.0	66.6	98.1	28.0	18.6	19.5	19.8	11.2	0.5	62.8	46.7	5.8	32.4	17.0
Share of Total *CA in 1999*		0.10	0.15	0.04	0.03	0.03	0.03	0.02	0.00	0.09	0.07	0.01	0.05	0.03

Expenditures on 62 pesticides per acre ($)

1991	54	139	92	157	82	na	19	126	42	208	108	93	925	25
1992	65	147	92	192	128	na	16	125	82	240	138	139	940	33
1993	74	151	113	205	133	na	16	146	70	220	174	133	835	34
1994	74	138	122	192	136	na	20	164	57	233	121	133	1,120	38
1995	80	147	155	243	135	59	24	222	50	199	124	151	1,188	43
1996	76	166	150	227	135	74	23	193	41	169	136	160	1,173	42
1997	77	173	153	203	149	61	24	201	48	191	117	186	1,228	40
1998	76	174	152	220	120	71	22	125	37	193	130	154	1,196	37
1999	73	139	115	200	93	58	19	123	32	172	110	119	1,318	34

Source: Compiled by the authors from the University of California, Davis, Agricultural Issues Center data; California Department of Pesticide Regulation, *Pesticide Use Summary, annual reports*, 1991–1999; and Wilhoit, 2001.

*The 62 pesticides are listed in Table 4.5

Note: na = not available

tity are likely to be biased because substitution between categories by the farmer is not accounted for. A standard approach to ameliorate this problem is to estimate the indices over a wider range of finer categories.

Some (Beach and Carlson 1993; Fernandez-Cornejo and Jans 1995) have argued, however, that in the case of pesticides these standard index number procedures are still inadequate and likely to result in biased estimates of the changes in pesticide use and price. One reason for this is that the range of pesticides available to farmers is constantly changing both positively as a result of new technology and negatively because of more stringent regulatory standards. A second reason, as demonstrated by Beach and Carlson (1993), is that the price farmers are willing to pay for a pesticide is influenced not just by its contribution to farm profitability but also by the health risk it imposes on farm workers and its persistence in the soil or as a residue on product. Hence farmers' decisions about which pesticides they use are influenced not just by their contribution to pest abatement and profits, but also by perceptions of health risk to themselves and others. Chemical manufacturers are likely to price products with these factors in mind. The implication of this is that the observed behavior of farmers concerning pesticide use is unlikely to be consistent with simply defined profit-maximizing behavior of a firm (because it is influenced by these other factors), and hence the standard approach to estimating an index of pesticide use is likely to be biased for some purposes.

In response to these problems, a number of studies, reviewed in Fernandez-Cornejo and Jans (1995) and Morrison et al. (2002), have applied hedonic analysis, as described in Berndt (1990), to estimate "quality-adjusted" indices of pesticide price and quantity. We have not pursued these approaches to developing quality-adjusted measures of pesticide use and price in California. At present the California DPR database only extends back to 1990 and does not contain information on pesticide prices.

CHAPTER 5

The Regulation of Pest Management in California Agriculture

5.1 Introduction

The potential for pesticide use in agriculture to impose externalities on neighbors and the community at large will be discussed more fully in Chapter 6. Externalities associated with the use of pesticides cause a divergence between the interests of farmers and the community at large. The direct regulation of pesticide use is a standard response to these problems.

This chapter reviews the regulation of pest management in California agriculture and the limited evidence of the impact on the community from the use of pesticides in agriculture by:

- Describing some of the regulatory infrastructure and history governing the registration and use of pesticides
- Discussing, at least in qualitative terms, some of the benefits and costs of pesticide regulation
- Examining some of the limited evidence (based on data from the DPR) on the use of important categories of pesticides that may pose risks to human health or the environment, on pesticide-related illnesses, and on pesticide residues on foods.

5.2 The Regulation of Pest Management in California

Pest management regulation in California takes a number of forms. One concerns the requirements for registering and using pesticides, discussed more fully below. Another is quarantine regulations.[1] Pest management in California is also regulated in a variety of less well-known ways. Some industries such as cotton and grapefruit have statutory arrangements for the eradication of pests, such as bollworm and scale, that require growers to undertake specific cultural and control strategies and are at least partly funded by levies collected from growers. In other industries, such as grapes and citrus, growers in some regions are required to finance commissions that coordinate pest control strategies. In some cases, a commission has the power to require growers to follow prescribed pest control strategies. In other cases, a commission merely provides a forum in which growers may voluntarily agree to coordinate their pest control activities. In the processing tomato industry, quality standards with respect to pest damage have statutory backing. We have not attempted to enumerate all forms of pest

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[1] Ventura County enacted the first plant quarantine in the state in 1886, prohibiting the transportation of anything with scale or insects injurious to fruit trees and vines.

management regulation in California.

The first regulation of pesticides in California occurred in 1901 and was solely a consumer protection law focused on the quality of one arsenic-based pesticide, "Paris Green." The UC Agricultural Experiment Station director implemented the law and oversaw chemical analyses. Sellers of deficient products were subject to fines.

Registration of pesticides commenced with California's 1911 legislation requiring that insecticides and fungicides be registered with the University of California before they could be sold. With the passage of the Economic Poison Act of 1921, regulation of pesticides was expanded to include herbicides and rodenticides and covered use as well as manufacture and sale of pesticides. This act authorized cancellation or denial of registration for products found detrimental to agriculture or public health, or which were ineffective. It also transferred regulatory authority to the newly created California Department of Food (renamed Department of Food and Agriculture in 1972). In 1991 this responsibility was transferred from the CDFA to the Department of Pesticide Regulation (DPR) in the newly created California Environmental Protection Agency.

There were about the same number of registered pesticide products for use in California in 1956 as in 2001, however these "new, improved" products often have new active ingredients. In November 2001, 894 active ingredients, including 198 spray adjuvants,[2] were registered for agricultural or nonagricultural pesticidal use in California and incorporated into 11,693 registered pesticide products.[3] In 1925 about 1,700 products were registered in California; in 1935, 3,500 were registered (DPR 2001).

In California, regulation of pesticide residues began with the California Spray Residue Act (1927), which made it illegal to pack, ship, or sell fruit or vegetables exceeding allowable arsenic residues. The CDFA began requiring safety training and protective clothing and equipment for pesticide handlers soon after 1972, when California mandated worker safety regulations. In that same year, a major rewrite of the 1947 Federal Insecticide, Fungicide, Rodenticide Act (FIFRA) shifted emphasis toward protection of health and the environment. It required applicator training and launched the lengthy process of pesticide reregistrations.

The first federal statues regulating environmental effects of pesticides occurred in 1972 with passage of the Federal Environmental Pesticide Control Act. The Federal Clean Water Act, U.S. Endangered Species Act, and Safe Drinking Water Act passed within the next two years were all to influence pesticide regulation. Similarly, in California in the 1980s, a number of

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[2] Adjuvants are chemicals added to a pesticide product to improve its effectiveness and include wetting agents, emulsifiers, spreaders, and penetrants (DPR, 2001).

[3] http://www.cdpr.ca.gov/docs/label/actai.htm, Nov. 27, 2001.

environmental and health-focused laws were enacted. These laws continue to exert major influence over registration and use. These statutes include the Toxic Air Contaminant Act (1983), Birth Defect Prevention Act (1984),[4] Pesticide Contamination Prevention Act (1985), and the Safe Drinking Water and Toxic Enforcement Act (Prop. 65, 1986). Concerned not only with pesticide use, but also with worker, consumer and environmental protection, California's pesticide regulations today are far more comprehensive than the U.S. EPA's minimum pesticide requirements.

Pesticide Registration

The broad issues prompting pesticide registration processes include efficacy; food safety and pesticide residues; health risks to those who handle or are exposed to pesticides, particularly farm workers and neighboring farm communities; and potential threats to the environment and nontarget species through direct contact and air and water contamination. Registered pesticides must be applied in ways compliant with regulations designed to reduce these risks, and labeling must address protecting against adverse impacts.

Manufacturers of pesticides must seek registration both from the U.S. EPA and, for use in California, from the DPR to allow specific pesticides to be used on specific crops to control specific pests. Although pesticide labeling is regulated only at the federal level, California has its own registration requirements and can refuse to allow the possession, sale or use of particular pesticide products. The DPR determines whether to register a pesticide product—or suspend or cancel its registration—after evaluating data submitted by the potential registrant on toxicology, effectiveness against targeted pests, hazard to nontarget organisms, effects on fish and wildlife, degree of worker exposure, and its chemistry. Registrations are not static. The registrant requests renewal, and the DPR is required to reevaluate registrations based on pesticide illness investigations, residue analyses and environmental monitoring.

Specific regulations for each crop use define the maximum application rates and minimum periods after which farm workers may reenter sprayed fields and after which produce may be harvested. As members of the DPR's Pesticide Advisory Committee, UC scientists regularly review the science issues underlying proposed registrations, pesticide risk evaluations, and other public policies. In the course of strengthening this process (reregistrations were accelerated pursuant to a 1988 FIFRA amendment), some pesticides have been withdrawn from use or registration, and others may be withdrawn as the 1996 federal Food Quality Protection Act (FQPA) is gradually implemented.

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[4] Of the 200 priority active ingredients identified for further study under the Birth Defect Prevention Act, 55 are no longer registered or had been suspended by June 1999 (http://www.cdpr.ca.gov/docs/dprdocs/sb950q&a/sb950rep98.htm).

A good description of the current federal pesticide registration standards and their historical development can be found in Schierow (2000).[5] In 1996 the FQPA was passed partly to coordinate the pesticide registration process, which was governed by FIFRA and the Federal Food, Drug and Cosmetic Act (FFDCA). FIFRA directs EPA to restrict the use of pesticides to prevent unreasonable adverse effects on people and the environment, taking into account the economic, social and environmental costs and benefits of various pesticide uses (Schierow 2000, p. 18). The states have primary responsibility for enforcing FIFRA pesticide provisions.

The FFDCA was designed to limit pesticide residues on foods in interstate commerce to "safe" tolerance levels. FQPA, however, establishes the health-based standard of "a reasonable certainty of no harm," and for the first time cumulative effects of aggregated exposures and sources must be considered. In addition, tolerance standards must emphasize safety for infants and children. As a result of FQPA, old pesticides must be evaluated for compliance with the new EPA standards by 2006. Organophosphates are currently being reviewed, and the EPA is almost certain to find that the total risk of exposing children to organophosphates is greater than allowed under the FQPA and is likely to regulate to reduce risk (Schierow 2000). FQPA also promotes use of IPM and, especially important to California growers, it facilitates minor crop pesticide registrations.

Regulation of Pesticide Use

In California the Secretary of Food and Agriculture has exercised authority over the use of pesticides in the field since the late 1920s. Pesticide-use regulations are also enforced at the county level.[6] All pesticide use in agriculture must be reported to the county agricultural commissioner. For restricted-use pesticides, further conditions on use may be applied at the county level, and a permit must be sought even for their possession. An important outcome is that since 1990 all agricultural pesticide use in California has been reported to the DPR.

The 1972 amendments to FIFRA empowered the U.S. EPA to register pesticides as general use or restricted use. Such a distinction has existed in California since 1949, when growers of grapes and cotton sought regulatory protection from an externality in the form of off-site crop damage due to herbicide drift, which led to restriction. Restricted materials are pesticides that are believed to have a high potential to cause harm to other crops, public health, farm workers, domestic animals, honeybees, the environment and wildlife. According to the DPR, the current California list of restricted

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[5] The same issue of *Choices* magazine features several articles on the FQPA and a web-based bibliography related to the act.

[6] Imperial County initiated the first pesticide permit system in the state in 1938 (Baker 1988).

materials includes roughly 100 active ingredients, some of which may no longer be registered.[7] Listed by chemical are 44 California-restricted ingredients, another 50 unique to the groundwater protection list "a" (a list of chemicals that have been detected in groundwater or soil),[8] dusts in containers greater than 25 pounds, and by reference, all FIFRA Section 18 emergency products and all federally restricted-use pesticide (RUP) products. In November 2001 there were 19 Section 18 products.[9] (We were unable to ascertain the number of federally restricted use pesticides, but many already are restricted by California.)

Between 1950 and 1974, about 65 pesticides (20 of these before 1960) were cumulatively listed by California as restricted use. Only 30 of these active ingredients are still registered for use in California. Another 25 were put on the restricted list during the years 1975-88, before the groundwater list commenced, and of those 25 only 16 remain registered. All told, two-thirds[10] of the California-restricted chemicals that were listed over the 1950-2001 period, including those on the groundwater list, were still registered for use in California in November 2001.

With some exceptions,[11] in order to possess or apply a restricted-use material, an individual pesticide applicator must first obtain a permit from the county agricultural commissioner.[12] The permit may specify limitations on use based on the application site, timing and environmental conditions and may require supervision.

Finally, in California anyone who recommends specific pest control strategies to growers must be a licensed agricultural pest control advisor (APCA). Those who use or supervise the use of state or federal restricted-use pesticides must have a Qualified Applicator Certificate (QAC) or Qualified Applicator License (QAL) from the state. To obtain a license or a certificate requires passing an examination. Biennial renewal requires continuing education course credit (40 hours for APCA, 20 hours for QAC and QAL.) Starting with the first licensing requirement in 1950, the University of California

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[7] www.cdpr.ca.gov/docs/license/pr-pnl-013a.pdf, Nov. 2, 2001.

[8] Sixty-six are listed for groundwater protection, but 16 are also California-restricted.

[9] Under Section 18 of FIFRA, absent the regular lengthy EPA registration process, for emergency situations states are allowed to issue emergency exemptions for pesticide use under specific circumstances and for limited periods. County agricultural commissioner offices, pest control advisors, university experts, and growers provide the supporting documentation and justification.

[10] A close reckoning is 97 out of 147.

[11] The county agricultural commissioner has discretion for federal RUPs listed on California restricted list by reference only (http://www.cdpr.ca.gov/docs/enfcmpli/penfltrs/penf2001/2001019.pdf, April 2001).

[12] http://www.cdpr.ca.gov/docs/license/pr-pml-013a.pdf, Nov. 27, 2001.

has worked closely with CDFA, DPR, USDA and U.S. EPA and has had a major role in developing study materials, pest management short courses, exam pool questions and, at times, certifying the exams. In addition, to implement the law requiring that pesticide handlers and agricultural field workers be trained about the safe use of pesticides, the UC IPM Project routinely has held workshops to train trainers of handlers and field workers.

5.3 The Benefits and Costs of Pest Management Regulation

The benefits from regulation are expected to come in the form of ameliorating the externalities on growers and the community from pesticide use. In this section, our primary focus is on the benefits to the community in the form of reduced risks to human health and to the environment. Human health risks arise as an occupational hazard for farm workers—field workers as well as those involved directly in mixing, loading and applying pesticides—and from residues on food and contamination of air and water for society as a whole.

Some environmental benefits from pesticide regulation are aesthetic and some relate to the preservation of biodiversity. Environmental and human health objectives may sometimes be at odds. For example, Meiners and Morriss (2001), among many other observers, noted that while the withdrawal of DDT may have provided significant environmental benefits, these may have come at a high public health cost, particularly in less-developed countries plagued with insect-borne diseases—though many less-developed countries still use DDT.

As the DDT example shows, the regulation of pesticide use also imposes costs on growers and the community. Some of these costs are passed on to consumers in the form of higher prices. The costs imposed on growers take a variety of forms. The most obvious is an increase in the cost of pest control as growers are forced to switch to treatments that are more expensive per unit of effective pest control or lead to yield or quality losses. Some are less direct. For example, a requirement that rice growers must hold water in fields for 30 days after the application of herbicides may impose high costs on them in years of poor crop establishment because it prevents them from re-sowing. A decision to lengthen either the period for safe reentry into pesticide treated fields or the minimum time before harvest after pesticide application may encourage growers to use calendar-based rather than IPM-based spraying strategies, with potential costs to the community as well as to growers.

An extensive literature on the impact of the withdrawal of pesticides and of restrictions on their use has focused on the costs to agriculture. These types of analyses are reviewed in a 1988 UC Agricultural Issues Center report and by Parker, Zilberman and Lichtenberg (1990); Harper and Zilberman (1990); Lichtenberg, Zilberman and Archibald (1990); and Morrison et al. (2002). The general conclusion of these analyses was that the withdrawal of single pesticides had little impact on the price of an agricultural product, but there were important distributional effects among producers unless other chemicals or control strategies were available to all growers. However, in some cases of phasing out a single material, such as methyl bromide, the costs to growers, particularly strawberry growers, may be quite high. For example, Carter et al. (2001) reviewed a range of studies reporting anticipated costs of a methyl bromide ban to producers and consumers of strawberries in California (and sometimes other crops) typically in the range of $100 million to $200 million per year. The authors also presented their own estimates of the impacts on California strawberry industry acreage, yield, production and revenue. Their most likely scenario has a revenue decline of 17 to 28 percent (a $130.4 million to $214.8 million per year reduction in strawberry production revenue, based on year-2000 values).

Goodell and Zalom (1992) referred to a 1990 study in which UC experts identified 38 specific crop/pest combinations for which there were no alternatives to the pesticide strategy at that time. The expectation (of these analyses) was that the withdrawal of a broad class of pesticides was likely to have greater consequences. Shierow (2000) noted that the use of the whole class of organophosphates is currently under scrutiny and this has raised concerns, particularly among growers.

The pesticide registration process has been long and costly. Ollinger and Fernandez-Cornejo (1998) estimated that it took an average of 11 years and between $50 million and $70 million to develop and register a new pesticide, which presents difficulties both to small chemical firms and to small agricultural industries. The relevant literature is reviewed in Fernandez-Cornejo, Jans and Smith (1998). Through EPA' s expedited review process for "reduced risk pesticides" and the IR-4 Program to develop data supporting registration of "minor use" pesticide products,[13] the FQPA of 1996 is meant to reduce the regulatory burden of registration. The community shares in the costs of pesticide regulation in ways other than higher food costs. The rate of productivity growth in agriculture, an important source of economic growth for many economies, is slowed by stringent regulation. Perhaps overlooked are the public health benefits of less expensive food and fiber, particularly fruits and vegetables. These costs may be particularly high for the poor in undeveloped economies. Mill taxes on pesticide sales are used to partially finance pesticide regulation in the DPR and the CDFA, but the administration of pesticide regulations also imposes costs on the public revenue, money that could be used to address other sources of risks to human health and the environment.

Decisions about the regulation of pesticides can be couched in a benefit-cost, risk assessment framework. Focusing on human health issues, the com-

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[13] See Glossary. Most of California' s crops, collectively worth $25 billion per year, are "minor" crops.

munity benefits from restricting pesticide use have to be expressed as a measure of expected savings in health costs in either monetary terms or in some other measure such as human lives saved. These expected benefits must be compared with the community benefits from less-restricted use of pesticides—from reduced public health costs or lives saved because of the greater consumption of fruits and vegetables allowed by lower food prices. Similarly, the benefits and costs of changed environmental outcomes must be valued in some way. On either side of the ledger are private costs and benefits in the form of changes in profits to farmers and processors and changes in the well-being of consumers.

The impact of agricultural pesticide use on human health and the environment is highly uncertain. Some means of measuring human exposure to pesticides is required, and then exposure has to be translated into disease incidence. Krieger (1998) and Ross, Dong and Krieger (2000) argued that standard risk assessment techniques based on animal experiments sometimes overstate actual exposure risks by two orders of magnitude and called for research to measure actual human exposure. Similarly, Ames and Gold (1996) noted many reasons why regulations based on animal experiments may vastly overstate potential danger to humans. Further, using carcinogenic potency in rodents as a measure, they showed that humans consume far less carcinogenic pesticide by eating produce than the amount of natural carcinogens consumed by eating foods such as lettuce, coffee, orange juice, beer and hamburgers. The counter view is that certain populations are more vulnerable to health risks—i.e., pregnant women, infants, the aged, and immuno-compromised individuals.

Even though policy decisions might involve substantial risk assessments, they are usually still made in the absence of complete and explicit quantitative analyses. Nevertheless, any decision on pesticide regulation reflects an implicit assessment of these benefits and costs, requiring at least a qualitative identification of the tradeoffs at stake. For example, there was widespread criticism of the Delaney clause (an amendment to the FFDCA), which called for zero tolerance of residues of carcinogenic food additives and pesticide residues in food. Critics argued that zero tolerance implied a very high (infinite) value to the community of costs associated with pesticide use that is not consistent with the value the community appears to place on other risks to human health, such as foods naturally containing carcinogens, which have a higher probability of carcinogenicity. For pesticide residues, the Delaney clause has been replaced with a standard of reasonable certainty of no harm to infants and children in the Food Quality Protection Act of 1996 (FQPA).

Empirical analyses of the impact of pesticides on human health and the environment are scarce. An alternative approach has been to use contingent valuation techniques to measure the willingness of consumers or society to pay to avoid health or environmental risks. Examples include a study of the Virginia peanut IPM program by Mullen, Norton and Reaves (1997) and a survey of consumers and their attitudes about pesticide residues on produce by Eom (1994). Using hedonic techniques, Beach and Carlson (1993) found evidence that the price of pesticides was influenced by the hazards they posed to farmers and farm workers. The emergence of a market for organically grown produce, even though small, is evidence that some consumers will pay more for produce grown using less pesticides.

The material presented below, while pointing out the tradeoffs involved in pesticide regulation, stops well short of the quantitative assessments of benefits and costs referred to above. At the farm end of the problem, we present data from the DPR Pesticide Use Reports (PUR) on trends in the use (measured in pounds) of important groups of chemicals that pose risks to human health and the environment. The DPR tracks the use of the following legally defined chemical categories: reproductive toxins, carcinogens, cholinesterase inhibitors, groundwater protection list "a" pesticides and norflurazon, toxic air contaminants, reduced-risk pesticides, biopesticides and oil pesticides.[14] DPR warns that these categories are not intended to serve as indicators of pesticide risks to the public or the environment. Rather, the data support DPR regulatory functions to enhance public safety and environmental protection (Wilhoit et al. 1999).

As can be seen in Table 5.1, which lists the predominantly used chemicals in each category, some chemicals are listed in more than one category. When different categories—carcinogens and cholinesterase inhibitors, for example—move in opposite directions, there is no way of saying that the community is better or worse off without valuing potential health outcomes. Metcalf (1994) has developed an index for pesticides based on average environmental persistence and toxicities for rats, pheasants, mallards, trout and honeybees, with the LD_{50} for rats being the proxy for humans and domestic animals and the other four organisms being important environmental indicators.[15] The validity of such indices is always subject to criticism—for example, should the toxicity value for trout carry equal weight with that of the pheasant, and is the rat indicative of human toxicity? At the societal end of the problem, we present DPR data on pesticide-related health incidents and on pesticide residues in food.

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[14] See Glossary.

[15] The LD_{50} is the lethal dose for 50 percent of the test organisms. In presenting mammalian toxicity, usually oral toxicity, it is expressed as milligrams of toxicant per kilogram of body weight (Ware 2000). Since it is a measure of the amount of material given at once to cause death of half of the group of organisms tested, it is a measure of acute toxicity or poisoning (Canadian Centre for Occupational Health and Safety, http://www.ccohs.ca/oshanswers/chemicals/ld50.html, 2002).

Table 5.1 Top 10 pesticides by pounds applied to California agriculture, 1999

Rank	Class	(pounds active ingredient applied)
	Reproductive toxins	
1	Metam-sodium	16,660,379
2	Methyl bromide	14,325,739
3	EPTC	447,669
4	Cyanazine	179,714
5	Benomyl	132,928
6	Oxydemeton-methyl	122,579
7	Bromoxynil octanoate	119,500
8	Myclobutanil	90,235
9	Linuron	77,509
10	Vinclozolin	52,415
	Carcinogens	
1	Metam-sodium	16,660,379
2	1,3-Dichloropropene	3,261,667
3	Propargite	1,471,456
4	Maneb	1,042,631
5	Captan	960,076
6	Chlorothalonil	710,479
7	Mancozeb	589,446
8	Iprodione	398,922
9	Propyzamide	100,816
10	Thiodicarb	60,452
	Cholinesterase inhibitors	
1	Chlorpyrifos	1,538,484
2	Molinate	911,376
3	Thiobencarb	732,481
4	Ethephon	732,464
5	Phosmet	638,728
6	Malathion	599,810
7	Diazinon	552,439
8	Methomyl	551,092
9	Dimethoate	463,720
10	EPTC	447,669
	Groundwater contaminants	
1	Simazine	679,918
2	Diuron	609,172
3	Norflurazon	269,397
4	Atrazine	60,606
5	Bromacil	53,834
6	Atrazine, other related	3,233
7	Bentazon, sodium salt	1,833
8	Bromacil, lithium salt	4
9	Prometon	2

Table 5.1 Continued

Rank	Class	(pounds active ingredient applied)
	Toxic air contaminants	
1	Methyl bromide	14,325,739
2	1,3-Dichloropropene	3,261,667
3	Trifluralin	1,249,025
4	Maneb	1,042,631
5	Captan	960,076
6	Moncozeb	589,446
7	Carbaryl	372,165
8	S,S,S-Tributyl phosphoro-trithioate	347,833
9	2,4-D, Dimethylamine salt	301,035
10	PCN8	42,969
	Oil pesticides	
1	Petroleum oil, unclassified	20,025,514
2	Mineral oil	4,706,896
3	Petroleum distillates	557,250
4	Petroleum hydrocarbons	394,813
5	Petroleum distillates, refined	99,935
6	Petroleum distillates, aromatic	3,957
7	Petroleum naphthenic oils	2
8	Petroleum derivative resin	<1
9	Petroleum sulfonates	<1
	Reduced risk	
1	Potassium bicarbonate	92,940
2	Azoxystrobin	87,449
3	Cyprodinil	56,268
4	Mefenoxam	53,930
5	Spinosad	44,491
6	Tebufenozide	8,812
7	Cinnam-aldehyde	6,756
8	Pyriproxyfen	3,060
9	Carbo methoxy ether cellulose, sodium salt	638
10	Iron phosphate	152
	Biopesticides	
1	Clarified hydrophobic extract of neem oil	94,438
2	Encapsulated delta endotoxin of *Bt* var. *Kurstaki* in killed pseudomonas fluorescens	28,385
3	*Bt*, subsp. *Kurstaki*, strain HD-1	21,651
4	E,E-8,10-Dodecadien-1-OL	21,029
5	*Myrothecium verrucaria*, dried fermentation solids & solubles	18,821
6	*Bt* (Berliner), subsp. *Kurstaki*, serotype 3a,3b	14,111
7	*Bt*, subsp. *Kurstaki*, genetically engineered strain EG7841 lepidopteran active toxin	12,809
8	*Bt* (Berliner), subsp. *Aizawai*, serotype H-7	10,421
9	*Bt* (Berliner), subsp. *Kurstaki*, strain SA-11	8,719
10	*Bt*, var. *Kurstaki* delta endotoxins Cry 1A(C) & Cry 1C (genetically engineered) encapsulated in Pseudo-monas fluorescens (killed)	7,B00

Source: Compiled by the authors from the California Department of Pesticide Regulation, Pesticide Use Databose, 2001.
Note: *Bt* = *Bocillus thuringiensis*

5.4 Trends in the Use of Pesticides Risky to Human Health or the Environment

The DPR tracks the use of a number of broad categories of pesticides. These categories and the 10 most widely used chemicals in each category are listed in Table 5.1. Data on the quantities of active ingredients used since 1991 in these categories can also be found in Table 4.3a. Poundage, however, as mentioned previously, indicates neither toxicity, environmental persistence, nor frequency of exposure.

We placed the chemical categories tracked by DPR in four broad groups: 1) human health hazards (reproductive toxins, carcinogens and cholinesterase inhibitors), 2) environmental health hazards (toxic air contaminants and potential groundwater contaminants), 3) reduced-risk pesticides, and 4) biopesticides. Some chemicals appear in more than one group or category.

The implications of reproductive toxins and carcinogens for human health are obvious. Pursuant to the California Safe Drinking Water and Toxic Enforcement Act (Proposition 65), the Office of Environmental Health Hazard Assessment (Cal-EPA) lists chemicals known to cause reproductive toxicity and known to cause cancer. The DPR' s list of cholinesterase inhibitors includes all chemicals in the carbamate and organophosphate chemical families as well as a few others not in these families. These chemicals tie up cholinesterase, an important enzyme of the nervous system. As insecticides they work by causing uncontrolled firing of electrical nerve impulses, leading to seizure and death. Without proper precautions, some of these chemicals can also lead to paralysis and respiratory failure in humans and other mammals (Ware 2000, EXTOXNET 1993). Not only must employees be warned about these chemicals, the chemicals may not be discharged in a concentration posing significant risk to a source of drinking water.

Groups of pesticides that are environmental health hazards are listed in the California Code of Regulations. Pesticides on the Groundwater Protection List "a," plus norflurazon, are those designated as having been detected in groundwater or soil (CA Code of Regulations, Title 3, Division 6, Section 6800(a)). Pesticides on the toxic air-contaminant list are those that have been found in ambient air in concentrations higher than established levels. The established levels for air contaminants differ for pesticides that are believed to have adverse health effects and those that are not (CA Code of Regulations, 6890).

Two groups of less toxic chemicals are specifically tracked by DPR: reduced-risk pesticides and biopesticides. Reduced-risk pesticides are those that have been given reduced-risk status by the U.S. EPA during the expedited registration process since 1994 because they are perceived as posing less risk to people and the environment than pesticides not requesting this classification. Even if by today' s criteria they might be considered as reduced-risk, chemicals registered prior to 1994 did not receive such a classification and are not tracked by DPR as such. Reduced-risk pesticides may be highly toxic to biocontrol organisms, however. DPR tracks biopesticides in a category distinct from the reduced-risk category. Their list of biopesticides consists of some microorganisms (such as *Bacillus thuringiensis*, which was first used in 1938), naturally occurring compounds, and synthetic compounds that are essentially identical to naturally occurring compounds. It also includes chemicals that are not toxic to the target pest (such as pheromones that disrupt mating, or scents that lure to traps).[16]

Human Health Hazards

Between 1991 and 1999 the use (in pounds) of chemicals known to the state to cause cancer or reproductive toxicity increased significantly, while use of cholinesterase-inhibiting pesticides decreased slightly after peaking in 1995.[17] Pounds of chemicals posing environmental health hazards (toxic air contaminants and groundwater contaminants) increased slightly. There were dramatic increases in the use of reduced-risk chemicals and bio-pesticides, but they represented a miniscule share of the total pounds applied.

The use of pesticides that are known carcinogens (excluding mineral oil and petroleum products) trebled between 1991 and 1999 (Figure 5.1 and Table 4.3a). This increase came almost entirely from increased use of metam sodium. About 16.7 million pounds of this pesticide were used in 1999, up from 4.9 million pounds in 1991.[18] Use of another chemical in this category, 1,3 dichloropropene, increased from 0.14 million pounds in 1991 to 3.3 million pounds in 1999.

As a broad group, The Safe Drinking Water and Toxic Enforcement Act lists oil pesticides as known to cause cancer. However, the DPR tracks them separately from other carcinogens because the act does not separately identify the more-distilled oil products that may not qualify as carcinogens and that serve as alternatives to highly toxic pesticides (DPR 1999). Annual use of oil pesticides increased by about one-half amid wide annual fluctuation.

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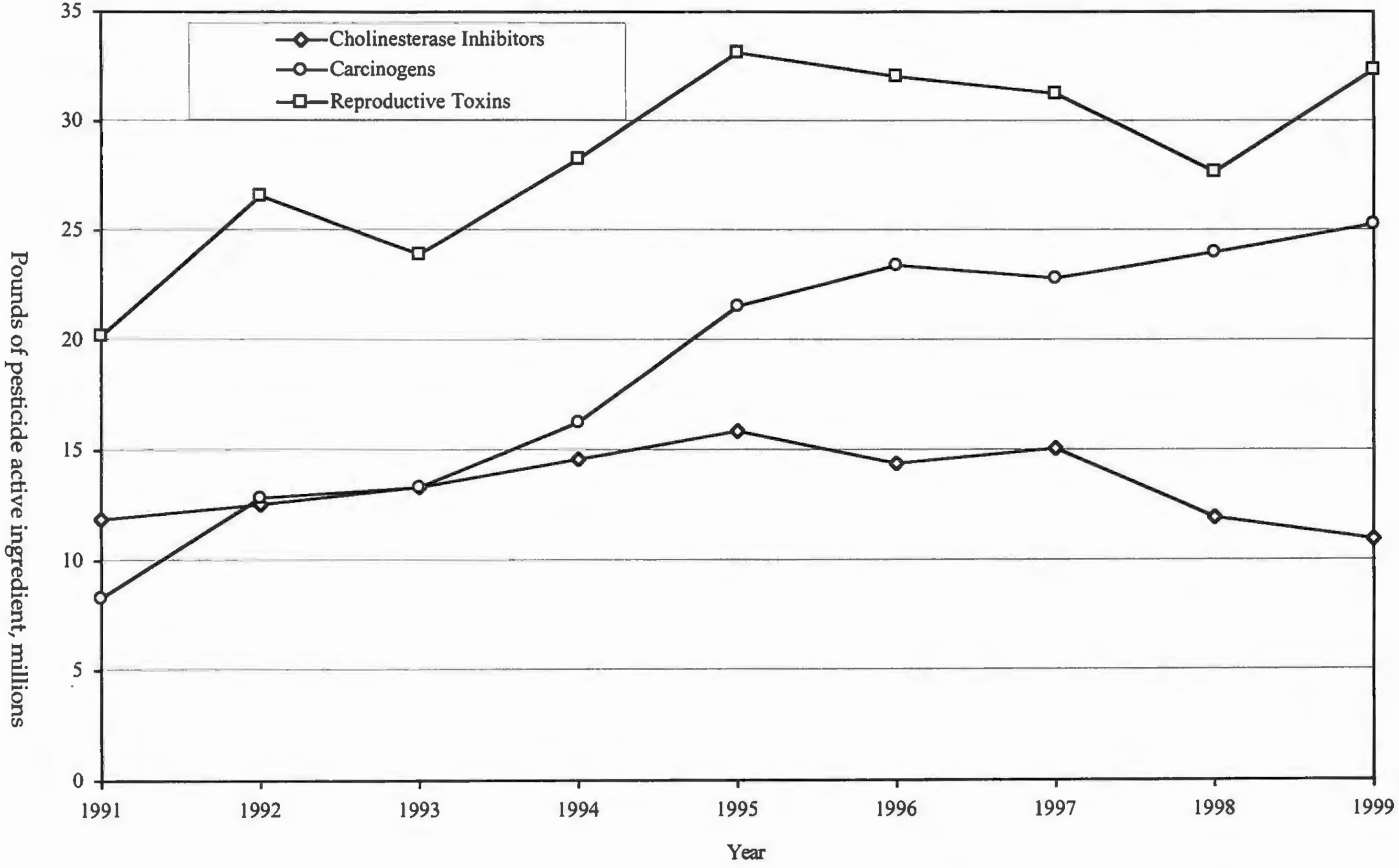
[16] http://www.epa.gov/pesticides/biopesticides/what_are_biopesticides.htm, 1999.

[17] Listing by OEHHA is pursuant to Proposition 65, The Safe Drinking Water and Toxic Enforcement Act, 1986.

[18] Wilhoit et al. (1999) note that the increase in use of metam sodium between 1991 and 1996 reflected both more pounds applied per application and more acres treated. Two possible reasons for the increase are 1) metam sodium is a broad-spectrum preplant fumigant that is still available, while other broad-spectrum pesticides have been more heavily regulated, or are being phased out; 2) we know that metam sodium is mainly used on land used for vegetable production, and we also know that for many vegetables the average number of harvests on a single field increased from three to four during the 1990s because of increased use of drip systems and starting young plants in greenhouses before transplanting them to the fields (Alexander and Kuminoff 2000).



Source: Compiled by the authors from the California Department of Pesticide Regulation, PUR database, 2001.

Fig. 5.1 Pesticide use by California agriculture: human health, 1991–1999

Pounds of pesticide active ingredients that are listed by The Safe Drinking Water and Toxic Enforcement Act as known to cause reproductive toxicity increased by 50 percent, from 20.2 million pounds to 32.3 million between 1991 and 1999. Like the change in carcinogens, the increase in chemicals known to cause reproductive toxicity came almost entirely from increases in the use of metam sodium, which accounted for about one-half of the poundage in this category in 1999.

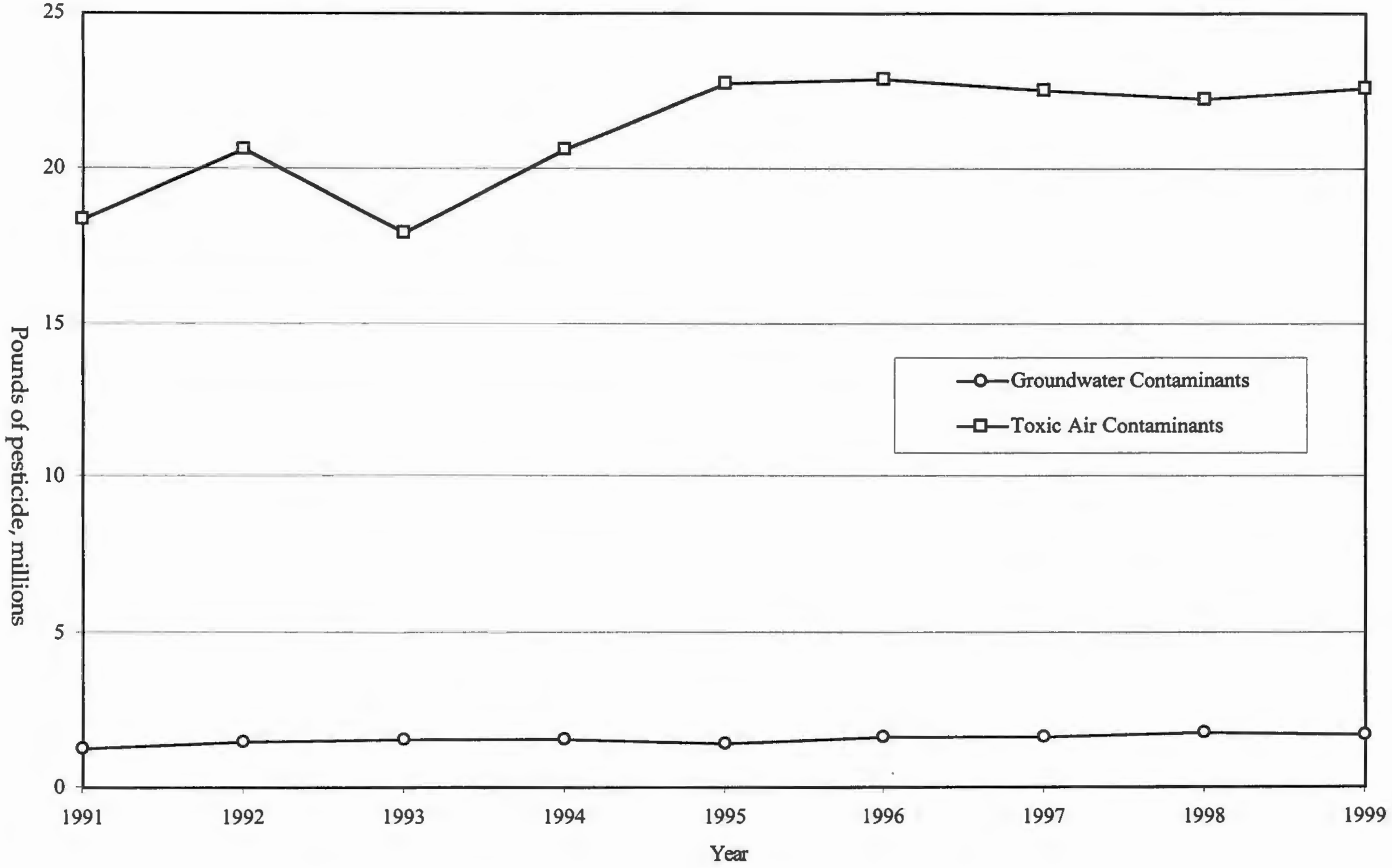
In terms of weight, two-thirds of the cholinesterase inhibitors used were organophosphates, and about one-third were carbamates. Both categories saw a rise in active ingredients applied during the early and mid-1990s and then a decrease toward the end of the decade that eclipsed earlier increases and led to a slight decrease overall. Unlike the carcinogen or reproductive toxicity categories, no single carbamate or organophosphate pesticide accounts for a majority of the total use of cholinesterase inhibitors, nor for most of the decrease. The most-used cholinesterase-inhibiting pesticide in 1999 was the organophosphate chlorpyrifos, with 1.5 million pounds being applied.

We cannot say whether society is better or worse off as a result of the decreased use of cholinesterase inhibitors and the increased use of chemicals associated with cancer and reproductive toxicity, although organophosphates and carbamates seem to be the focus of regulatory attention at present to prevent toxicity to aquatic species from organophosphate runoff to surface waters. To make this judgement we would need to know 1) how the use of these chemicals translates into human disease incidence, with exposure and duration dependent in part on the adequacy of protective clothing and equipment during application, and how food products are handled after harvest and 2) the costs associated with the different human health problems.

Environmental Health Hazards

Between 1991 and 1999, the annual use of toxic air contaminants increased by 23 percent (Figure 5.2 and Table 4.3a). The main toxic air contaminant is methyl bromide. Other widely used contaminants include captan, maneb, 1,3 dichloropropene, and trifluralin. Although its use decreased, methyl bromide accounted for the majority of pounds of toxic air contaminant applied throughout the decade. The slight overall increase was due to increases in the use of 1,3 dichloropropene, captan, and maneb.

Three selective herbicides, diuron, norflurazon and simazine, account for over 93 percent of the pounds of pesticides belonging to the groundwater protection list "a" (so designated because they have been detected in groundwater or soil, independent of whether they have been proven harmful to health). As mentioned above, their use is now subject to restriction, and



Source: Compiled by the authors from the California Department of Pesticide Regulation, PUR database, 2001.

Fig. 5.2 Pesticide use by California agriculture: the environment, 1991–1999

some may not be used at all on certain soils or in certain areas. This group of pesticides increased in use by about 32 percent between 1991 and 1999, with the largest individual increases coming from diuron and norflurazon. Aggregate use of these pesticides that potentially could contaminate groundwater is shown in Figure 5.2.

We have no measure of the costs to society of the increased level of contamination (nor of the private benefits from the use of these pesticides) and hence no way to judge the net benefits or costs to society from increased use of toxic air or groundwater contaminants.

Less Toxic Chemicals

Among the categories of pesticides tracked by DPR, by far the largest percentage increases in use during the past decade have been in biopesticides and in reduced-risk pesticides. Use of biopesticides increased from 47,000 pounds in 1991 to 250,000 pounds in 1999. About one-half of the total pounds of biopesticides used in 1999 was hydrophobic extract of neem tree oil, which had not been used at all prior to 1996. *Bacillus thuringiensis* (a naturally occurring bacterium) was the next most heavily used biopesticide. Reduced-risk pesticides were not registered as such prior to 1995, but after that their use increased dramatically. However, to put the increases in use of biological and reduced-risk pesticides in perspective, total pounds of these pesticides applied in 1999 represented about one-tenth of one percent of total pesticide use by California agriculture.

5.5 Pesticide Residues on Food

A California program to test for pesticide residues on marketplace produce was first established in 1926, after the U.S. Bureau of Chemistry established allowable levels of arsenic on apples and pears in interstate commerce. Monitoring efforts were originally conducted by the California Department of Food, and have more recently been continued by the DPR (California EPA 2000a). Technological advances have allowed the monitoring process to evolve from tracking residues of a few specific pesticides individually to using multi-residue screens that can detect hundreds of pesticides, metabolites and breakdown products, with the results available in about eight hours (DPR). Many of these advances are relatively recent. For example, in 1988 CDFA residue program chemists were using screens that could detect 108 pesticides, while today, the DPR Marketplace Surveillance Program uses screens that detect over 200 pesticides.

Even with the advances in residue detection technology, the results have been consistent over time. Most pesticide residue on crops in the marketplace is below detectable levels. Table 5.2 shows that while testing results between 1987 and 1997 have shown an increasing share of produce with any residue detected, the share of samples with illegal residue has hovered between 0.7 percent and 1.6 percent. Most samples with illegal residue were

Table 5.2 Market surveillance program sampling results, 1987–1997

Year	Total	No detectable residue	Illegal residue	Any detectable residue as percentage share of total
1987	7,010	5,591	104	20
1988	9,293	7,262	108	22
1989	9,403	7,329	67	22
1990	8,278	6,609	65	20
1991	7,446	5,582	70	25
1992	7,319	5,044	68	31
1993	6,066	3,898	95	36
1994	5,588	3,688	84	34
1995	5,502	3,557	90	35
1996	6,097	3,683	94	40
1997	5,660	3,515	70	38

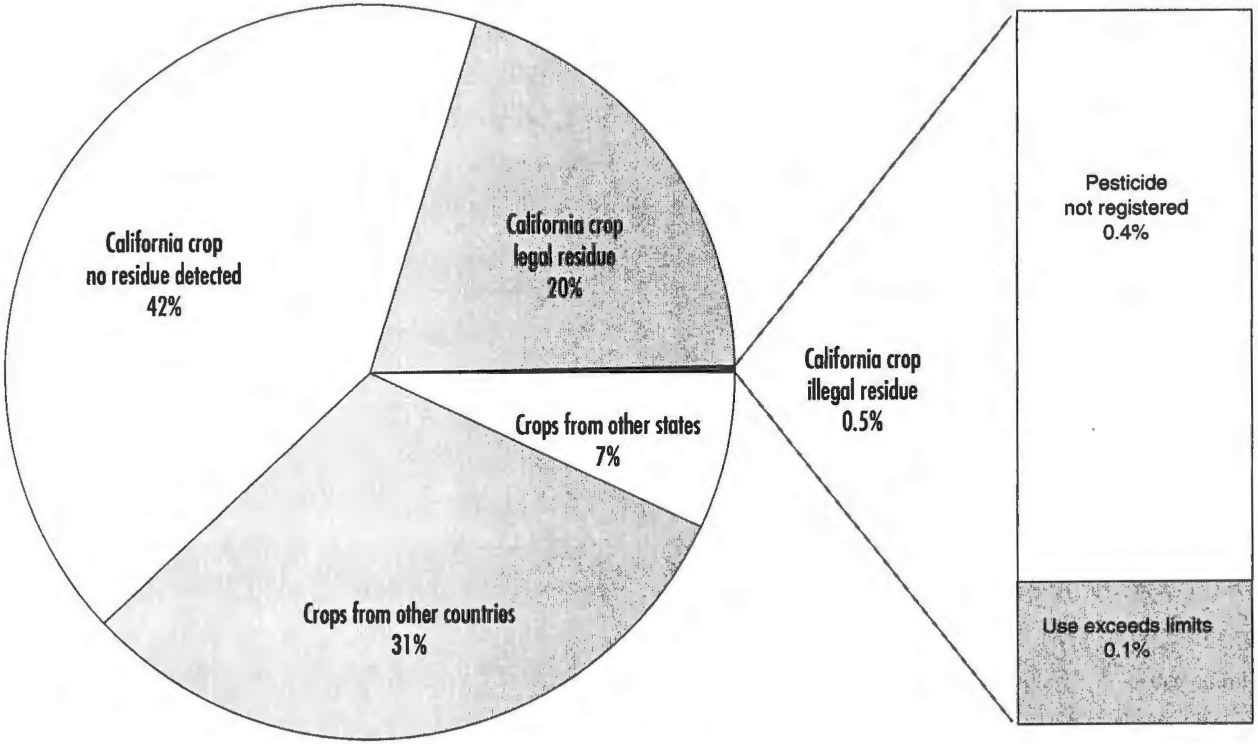
Source: Compiled by the authors from the California Department of Pesticide Regulation, Market Surveillance Program, online data.

from crops grown in other states and countries. In most cases of illegal residue on California-grown crops, the detected residues were of pesticides not registered for use on that particular crop. The DPR noted that this is usually a result of pesticide drift from nearby fields, rather than from deliberate illegal use. In 1997 the DPR took 5,660 samples of 170 different commodities. Of these, 3,519 samples were of crops grown in California. Twenty-six of the samples from California had illegal residue, and of these, 22 were from pesticides not registered for that crop, while four were residues that exceeded legal limits. Figure 5.3 shows these statistics in percentage form.

Although the share of samples with illegal residue is small, DPR noted two reasons why they believe the actual health risk might be even lower than indicated by the illegal-residue data: 1) sampling methods tend to emphasize areas with more pesticide use and, therefore, may lead to a higher frequency of finding illegal residues than if they used a random sample; 2) since the standards include a safety margin, illegal residues rarely present a health risk.

5.6 Illness and Injury due to Agricultural Pesticides in California

Each year the DPR works with county agricultural commissioners to investigate illnesses and deaths that may have been caused by pesticides (California EPA 2001b). The DPR obtains reports of pesticide-related illness from health departments and worker compensation reports, the California Poison Control System, and news reports. Since 1971, California law has required doctors to contact the local health officer within 24 hours of examining a patient who they believe may have been injured or became ill from pesticide exposure. The health officer then informs the county agricultural



Source: Compiled by the authors from California Department of Pesticide Regulation, Marketplace Surveillance Program, online data, 2001.

Fig. 5.3 California marketplace pesticide residue sampling, 1997 (5,660 total samples)

commissioner and proceeds to investigate the incident, collecting samples and reporting the results to the DPR for further analysis. DPR also investigates cases reported in worker compensation reports that mention pesticides as a possible cause of illness or injury. After investigating a reported case, the DPR often concludes that pesticides were unlikely to be the cause of injury, or the data are not adequate to support any conclusion about the cause of injury.

In 1999, the DPR received reports of 1,629 people whose health may have been affected by pesticide exposure. The DPR' s investigation of the evidence concluded that pesticide exposure had been at least a possible contributing factor to 1,201 of those 1,629 cases (195 definite, 635 probable and 371 possible). Less than half (555) of the 1,201 possible cases of pesticide illness or injury were due to agricultural use of pesticides. Evidence established an unlikely or unrelated relationship to pesticide exposure for 311 of the 1,629 cases, while data were insufficient to evaluate 177 cases. Violation of safety regulations accounted for almost half (594) of the 1,201 definite, probable or possible cases related to pesticide exposure. Drift exposures (570) accounted for the largest number of pesticide exposures in 1999, with drift from agricultural applications responsible for two-thirds of the drift exposures.

In 1999, field workers incurred 15 percent of the confirmed pesticide illness and injuries attributable to agricultural pesticide use. That year, 134 cases involving field worker illness and injury were reported. Of these, exposure to residue was implicated for 82 field workers—11 from illegal reentry—and drift exposed another 42 while working in the field. As a result of changes made in 1998 to California' s Pesticide Illness Surveillance Program' s (PISP) computerized data collection, in the future it will be possible to track activities of those exposed, mechanism of exposure, and types of equipment used, together with types of formulation and application dates.

The past few years have seen a downward trend in the total number of reported injury and illness cases related to agricultural and nonagricultural pesticide use, along with the number of cases where pesticides were found to be at least a possible contributing factor. However, the percentage attributable to agricultural pesticide use has increased. Table 5.3 shows these statistics from 1995 through 1999. DPR notes that a few events can account for a large number of the illnesses or injuries related to pesticide use, making it difficult to generalize about statewide health trends. For example, in 1999, three different episodes accounted for 286 of the health complaints, with 170 cases linked to a single incident where a breakdown product of metam sodium, which was used to fumigate an agricultural field, drifted into a town. In comparison, the largest group episode of 1998 involved 34 field workers who unknowingly entered a sprayed cotton field prior to expiration of the restricted entry interval.

Although the pesticide-related illness data are relatively consistent over

Table 5.3 Number of illnesses and injuries caused by pesticide use in California, 1995–1999

Type	1995	1996	1997	1998	1999
			(number of cases)		
Total reported cases of health affected by pesticide use	2,401	2,229	1,806	1,481	1,629
Cases with pesticides found to be at least a possible contributing factor	1,593	1,580	1,319	998	1,201
Cases due to agricultural use of pesticides as a possible contributing factar	656	696	545	366	555
			(percentage)		
Agriculture as a percentage of all cases where pesticides were at least a possible contributing factor	41	44	41	37	46

Source: Compiled by the authors from the California Environmental Protection Agency, Department of Pesticide Regulation, Worker Health and Safety Branch, Summary of Results from the California Pesticide Illness Surveillance Program, annual reports, 1995–1999, online data.

time, the DPR notes two significant factors that may cause the data to understate the true extent of pesticide-related illness and injuries. One is that people injured by pesticides who do not seek medical attention will not be counted in the data. The second factor is that the reporting requirements emphasize acute injuries, rather than chronic illnesses such as cancer caused by prolonged exposure.

Some of the economic issues involved in farm worker safety and the use of pesticides are reviewed in Antle and Capalbo (1994) and Sunding and Zivin (2000).

CHAPTER 6

Economic Issues Related to Pest Management

6.1 Introduction

We have argued that research and extension by the UC system has generated information about the biology of agricultural pests that has been valuable in assisting farmers and the community to make decisions about the profitable use and appropriate regulation of pest control strategies.

Decisions about pest control strategies are complex because of the mobility of pests and their ability to respond to control strategies and because many control strategies, particularly those of a chemical nature, have adverse impacts, sometimes distant in time, on nontarget species and nontarget sites. These nontarget impacts, sometimes referred to as externalities, come in many forms. They range from pest control issues, such as the loss of natural enemies of target species, secondary pest outbreaks, and the emergence of resistant pest strains, to health risks to farm labor and the consumers of farm produce, as well as risks to environmental resources such as air and water quality.

Our goal in this chapter is to review issues that may explain the demand for pest control services (chemical and nonchemical) by farmers and, hence, shed further light on the type of information about the biology of arthropods that is valuable to farmers and the community. Pesticides are costly, and their use by farmers is driven by their contribution to increasing net farm income and reducing its variability. Hence, we review the theory and limited empirical evidence about the profitability of pesticide use by farmers and whether farmers are using too much or too little pesticide. We also explain more fully the nature of externalities associated with pest control strategies. We explore the implications of these issues for UC research and extension in pest management, particularly with respect to the development of IPM programs and appropriate regulatory responses.

6.2 Econometric Analyses of the On-Farm Efficiency of Pesticide Use

The demand by farmers for pesticides and the efficiency with which they use pesticides are continuing areas of economic research. More thorough reviews of this research can be found in Lichtenberg, Zilberman and Archibald (1990), Norton and Mullen (1994) and Fernandez-Cornejo, Jans and Smith (1998). Important issues have been the marginal value of pesticides, the specification of pesticides in input demand equations, and the impact of IPM technologies on farmer exposure to risk. These issues are briefly reviewed.

One area of research has been in estimating the marginal value product (MVP) of pesticide use in agriculture, hence contributing to the debate as to whether pesticides are being efficiently used. This research was reviewed by Lichtenberg, Zilberman and Archibald (1990) and Carrasco-Tauber (1990). Early research was conducted by Headley (1968), Pimental et al. (1978, 1980), and Roth, Martin and Brandt (1982). The general conclusion of these studies, which treated pesticides as a conventional input in a traditional production function, was that marginal productivity was high with a benefit-cost ratio of around 4:1, and that farmers were underutilizing pesticide. This finding was in sharp contrast with the widely held view that farmers were using too much pesticide.

Teague and Brorsen (1995) observed that estimates of the marginal value product of pesticides had generally been in the range of \$3 to \$6 per dollar of pesticide expenditure. They pointed out that these estimates were averages or snapshots of MVP, either over a number of years or in a particular year for studies based on cross sections. They estimated a random-coefficient production function that allowed changes in the MVP of pesticides to be traced through time. They estimated their model over the 1949 to 1991 period for the 10 largest agricultural states in the United States, including Texas, Iowa and California, the states whose results they reported. They used data on agricultural output and inputs from the USDA Economic Research Service publication, *Economic Indicators of the Farm Sector, State Financial Summary*. As a dependent variable they used the value of agricultural output for the state, deflated by the index of prices received by farmers. Inputs were aggregated into three categories—pesticides, other material inputs and machinery—and their values were deflated by the index of prices received. A Cobb-Douglas functional form was used.

They found that while the MVP of pesticides had fallen over the observation period in Texas and Iowa, this was not the case for California where the MVP of pesticides was generally in the range of \$3 to \$9 per dollar of expenditure on pesticides (1991 dollars), similar to that found in previous studies. This may help explain the continuing strong demand for pesticides in California.

Reasons why the specification of pesticides as a conventional input in a traditional production function framework may lead to an upward bias in estimates of the marginal value product of pesticides include the misspecification of the production function and inadequate consideration of health risks to farm families and workers. Additionally, farmers are unlikely to account fully for the impacts of their use of pesticides on neighbors and the community, and hence their demand for pesticides is likely to be higher than the demand for pesticides by the community. These issues are discussed in turn.

Lichtenberg and Zilberman (1986) argued that the standard specification of pesticides as a conventional input in a production function was inappropriate and resulted in the marginal product of pesticides being overestimated. They argued that, unlike other inputs, pesticides do not enhance productivity directly. Rather, they contribute to the crop achieving its potential output by controlling damaging agents such as pests. When damage control is effective, actual output reaches potential output. This specification has the added attraction of being able to explain why farmers use more rather than less pesticide when resistance starts appearing. This original work has been generalized in a number of papers, including Chambers and Lichtenberg (1994). An important empirical application was a study of pest control in apples (Babcock, Lichtenberg and Zilberman 1992) which also attempted to disaggregate the contribution of pest abatement into quality and yield components.

The damage-control specification is not a panacea. Carrasco-Tauber (1990) used this specification but found little change in the estimate of the marginal value product. Fox and Weersink (1995) warned that empirical results from damage function specifications are sensitive to the functional form used.

Beach and Carlson (1993) pointed out that the demand for pesticides is driven not just by farm profitability considerations but also by health risks to those who are exposed to pesticides on the farm. The implication is that the observed behavior of farmers concerning pesticide use is unlikely to be entirely consistent with simple profit-maximizing behavior by a firm, but to be influenced by broader measures of family or employee welfare.

Lichtenberg, Zilberman and Archibald (1990) reviewed a number of other areas of pesticide economics. At the farm level, much effort has been devoted to modeling optimal pesticide usage under conditions of pest mobility, resistance development, predator-prey interactions, risk, and managerial constraints. One focus has been on comparing IPM programs with fixed-schedule pesticide applications. The general conclusion is that, were farmers to account fully for off-site effects, they would use less pesticide. In the next section, the nature of off-site effects and externalities are more fully explained, and their implications for pesticide use by farmers and for UC research and extension activities are explored.

6.3 Pest Management Strategies and the Exposure to Income Risk of Farm Firms

A concern in the literature has been the impact of pest management strategies, particularly IPM strategies, on risk. Here, the term risk is used in a very general sense. We talk, for example, about risks to health and the environment when we mean a change in the likely incidence of health problems or environmental contamination. Such externalities associated with pesticide use are explained more fully below.

In this context of farmer decisions about pesticide use, risk has a more narrow interpretation related to the variability of farm income through time, as distinct from other characteristics of the distribution of income, such as its average. Some of the literature relating to this issue was reviewed by

Fernandez-Cornejo, Jans and Smith (1998). The common perception is that pesticides are used as insurance to reduce income variability and, hence, that IPM programs are more risky because mistakes in monitoring, for example, on some occasions result in pest populations exceeding the economic threshold. Grafton-Cardwell (2000) argued that the use of selective pesticides was more risky because it left growers exposed in the event of an exotic pest invasion.[1] Fernandez-Cornejo et al. (1998), however, pointed to theoretical (Moffit 1986, Horowitz and Lichtenberg 1994) and empirical (Hurd 1994, Gotsch and Regev 1996) analyses suggesting that the relationship between risk and pesticide use was ambiguous.

6.4 On-Farm and External Effects of Pest Management

Standard production economics theory prescribes that inputs should be used to the point where the value of their marginal product equals the marginal cost of using them, such that an additional dollar spent on inputs gives rise to an additional dollar's worth of output. This clear prescription is based on a number of assumptions including profit- maximizing behavior by farmers, competitive markets for inputs and outputs, certainty about the outcomes of production decisions, and no off-site effects from production decisions in either spatial or temporal dimensions. Under these conditions farmer decisions about input use are of no concern to the welfare of neighbors or the community.

However, many pest management strategies are likely to have off-site impacts and, more broadly, externalities and, hence, do affect—positively or negatively—welfare of neighbors. The simple resource allocation rule above (equating marginal private benefits and costs) needs to be generalized to recognize that the cost of applying pesticide, for example, may comprise costs imposed on other parts of the farm, on neighbors and on the community, as well as the cost of the chemical and its application. In general, higher rates of pesticide are used when these off-site effects are ignored than when they are fully taken into account as a reflection of the fact that the off-site effects are more often costs than benefits. It will be in the interests of farmers to consider some of these costs in their decisions about pest management, but it is unreasonable to expect farmers to bear the entire cost of community preferences about environmental outcomes or to fully consider the impact of their actions on neighbors when property rights are attenuated. The concepts of off-site effects and externalities were explained in Mullen, Helyar and Pagan (2000), and the discussion below draws heavily on their paper.

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[1] Perhaps she ignored the option of farmers quickly returning to a broad-spectrum pesticide, providing broad-spectrum pesticides are not all withdrawn.

Off-site effects arise when resource use decisions on a particular unit of land at a point in time have impacts on other units of land—the spatial dimension—or on the same unit of land at different points in time—the temporal dimension. Spatial off-site effects arise because pests and their natural enemies and pesticides are rarely confined to the target site. Temporal off-site effects may arise if pest management strategies this year influence pest problems later in the season or next year through a carryover of the pest population or because a nontarget pest is released by the destruction of natural enemies. Resistance to pesticides has both spatial and temporal dimensions.

Some of these off-site effects occur within the farm boundaries—on-farm effects—and others impose costs or benefits on neighboring farms or the community more broadly, and these are referred to as externalities. These two types of off-site effects, reviewed in turn below, provide different incentives for the use of pest management strategies by farmers. Much of the discussion below will focus on the use of pesticides and the on-farm and external off-site costs they may impose. However, some pest management strategies, including pesticide use, may deliver on-farm and external off-site benefits.

On-farm Effects

Pest management can have effects on production and profit on the rest of the farm and, where chemicals are involved, potential effects on the health of the farm family and farm workers. It is in the interest of farmers to consider these types of on-farm, off-site effects in making decisions about pest management on any area of the farm. However, uncertainty about these effects makes decision-making complex.

On-farm production effects occur, for example, when pesticide drifts to a neighboring crop, when pests and beneficials are encouraged to move to a neighboring crop by pest management strategies, or when pests become resistant to chemicals. Farmers have incentives to manage these effects in a way that optimizes total farm income rather than the returns from particular fields. For instance, a farmer is unlikely to use pesticides on one part of his farm if the damage on another part of the farm caused by the loss of natural enemies of pests is greater than the benefits from using the pesticide. Similarly, cotton growers, for example, may find it profitable to maintain an area of alfalfa as a sink for lygus and a haven for its predators, even though that area of land could earn higher returns in cotton.

Some temporal off-site effects, such as the development of a weed population resistant to herbicides, may be borne by the current owners in the future and are, therefore, not externalities. These potential costs should be considered by farmers in decisions about weed management. However, when temporal off-site, on-farm effects impose costs on future owners that are not reflected in land values, externalities arise. As noted above, Beach and Carlson (1993) found empirical evidence that health risk and environmental concerns influenced the demand by farmers for pesticides.

Externalities

Externalities are a subset of off-site effects under this terminology and arise if spatial and temporal off-site effects are not confined to the farm boundaries and farmers are not obliged to meet the full costs of their actions (or do not receive the full benefits). Negative pesticide externalities can arise when farmer pesticide choices—either to over-use or under-use pesticides or alternative pest management technologies—have an impact on neighbors and the community whose property rights are attenuated in the sense that they cannot choose the extent to which they are exposed. In the presence of externalities, there emerges a divergence in the interests of individual farmers, their neighbors, and the community in how pests are best managed. For example, a pest control strategy expected to have widespread benefits to the community in the form of reduced pesticide use may prove to be unprofitable to growers and not be adopted.[2]

It seems useful to distinguish between two types of externalities—those that take the form of production costs and health risks to neighboring farms, such as those associated with spray drift, the loss of beneficials or the development of resistant pest populations; and environmental impacts that affect the broader community through changes in air and water quality.

Externalities are the consequence of market failure associated with attenuated property rights.[3] In the minds of some, market failure is an automatic signal for some form of government intervention. However, it is difficult to generalize about how externalities influence pest management decisions by farmers. Randall (1999a, p.30) used the term isolation paradox to describe situations where everyone can enjoy a net benefit from coordinated action, but farmers acting alone have little incentive to consider their neighbors.[4] The attraction of expressing the problem in this way is that it points to a much broader range of responses that recognize the incentives facing farmers and their neighbors. According to Randall (1999a, p.31), "The isolation paradox concept, then, suggests an openness to solutions that invoke a variety of institutional forms: private enterprises, voluntary associations, and government from the most local to the national scale and beyond. Given the centrality of information and coordination, the array of feasible institutions is continually shifting as information, communication and exclusion technologies develop."

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[2] Some analyses of IPM programs fail to make clear whether the perspective of the analysis is that of the grower or of the community and the benefits and costs to growers and the community are inappropriately matched.

[3] Godden (1997) provides a good discussion of externalities and the role of institutions and technology in establishing property rights.

[4] Marshall (1999) expressed similar views.

This concept of isolation paradox would seem to be particularly helpful in pest management, where the concern is with the impact of one farmer's pest management strategy on pest and predator populations on neighboring farms. Pesticide drift and residues and the development of resistance also fall into the externality category. In these situations, growers in such close proximity that pests and their natural enemies travel easily between them, might gain from cooperation, with benefits in terms of some combination of lower costs and higher yields and quality from managing the pest problem as a common property resource.

Randall argued that, without any intervention by government, farmers were already engaged in a range of cooperative activities to reduce externalities. We came across a number of instances where farmers were cooperating in the harvesting of crops and in pest control practices to minimize consequences for neighbors.

Despite these benefits, the barriers to collective action are high. Management of resources where externalities arise often has the characteristics of a public good. In the case of pest management, it is not possible to exclude farmers who do not participate from the benefits of collective action by their neighbors. Further, the benefits of pest management are likely to be nonrival and enjoyed by many. Hence, while externalities require some form of collective action for their solution, any form of collective action is costly to negotiate and enforce. These costs threaten the adoption of IPM programs that rely on collective action. Some IPM programs may be viable at the farm level only if they are adopted by a neighborhood.[5]

Diverse mechanisms are being or may be used to achieve collective action in California agriculture. They range from informal voluntary agreements among small groups of close neighbors, through to industry groups with varying degrees of power to influence the pest management strategies of members. A selection of these arrangements is reviewed in Klonsky et al. (1998). They focussed on the Lodi-Woodbridge Winegrape Commission that began after a grower referendum in 1992. It is compulsory for the 650 growers in the Lodi area to financially support the commission, which conducts research and extension programs related to IPM in grapes with a view to reducing pest management costs in the area. However, the commission has no authority to prescribe or proscribe pest management strategies by individual farmers that are otherwise legal. Klonsky et al. (1998) were unable to provide empirical estimates of the extent of adoption of pest management strategies recommended by the commission, although the commission is

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[5] This discussion suggests that an important component of IPM research is the modeling of pest management strategies where pest (and predator) populations are alternatively treated as common property and open access resources to indicate the significance of the externality, as demonstrated by Quiggin (1991).

generally viewed as being successful and was supported by growers in a second referendum in 1996.

Klonsky et al. (1998) briefly contrasted the Lodi-Woodbridge Winegrape Commission with the operation of the Fillmore Citrus Protective District and the pink bollworm eradication program in the San Joaquin Valley cotton industry. Growers in the Fillmore district relinquished to the district all decisions about the management of red scale on their orchards and were taxed to provide funds for the district to undertake spray and predator release programs on their orchards.[6] According to Klonsky et al. (1998), cotton growers agreed to an even higher degree of regulation to keep the pink bollworm, reputed to have destroyed the industry in the Imperial Valley, from gaining a foothold in the San Joaquin Valley. They pay a production-based tax to fund eradication activities and are required to practice cultural practices, such as cotton plow-down that requires destruction of cotton crop residue by a specified date.

It would seem that these attempts at collective action by farmers were motivated solely by the prospect of increasing farm profitability. So far we have been unable to identify collective pest control action between farmers and the community designed to meet community preferences.

Despite opportunities for mutually profitable collective actions, there remain externalities for other neighbors or the broader community that will require more-intrusive intervention (probably in the form of a more formal specification of property rights) because mutually beneficial arrangements are not possible. In general, some tradeoff is required between the interests of farmers faced with pest problems, neighbors who do not share the same problem, and the community. Remedies may take the form of direct regulation of pest management practices or market-based mechanisms where farmers trade entitlements to use certain pest management practices, and which involve a clearer specification of property rights. Already there are clear legal remedies in the case of point-source pollution problems such as pesticide drift and the harboring of pests, but nonpoint sources of pest or pesticide externalities are more difficult to manage.

To date, the chief remedy has been the regulation of pesticide use. This process involves high costs, both when new pesticides are proposed for use and when existing pesticides are withdrawn from use. These costs (and the overhead costs of the regulatory apparatus) must be offset against the benefits to the community in the form of reduced health risks and better environmental outcomes. A review of pest management regulation in California can be found in Chapter 5.

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[6] Reviewed more thoroughly in Graebner et al. (1984).

6.5 The UC Contribution to Pest Management Revisited

Not only does the discussion of on-farm effects and externalities make clearer the incentives farmers and the community face in managing pests, it also suggests the type of information about the populations and life cycles of pests and their natural enemies that is most valuable in making decisions about pest management.

Both farmers and the community require knowledge about the off-site effects and marginal user costs of pest control strategies. Farmers can use this information to make decisions that account for the whole-farm impact on profitability and family health of pest control strategies. This type of information will also assist them in making better decisions about cooperation with their neighbors to reduce external costs (or increase external benefits). Government can use this information to choose regulatory mechanisms more likely to deliver outcomes that meet community preferences but with less infringement on the choices of farmers.

We have already noted that the provision of information about the biology of pests and interactions between pests, their natural enemies, and control strategies was likely to have the characteristics of public goods to a high degree. The public good nature of research and extension about off-site effects, both on and off the farm, would seem to be even more pronounced because, particularly for effects external to the farm, there is little opportunity for farmers, and even chemical suppliers, to appropriate the benefits from investments in these activities.

CHAPTER 7

Framework for the Benefit-Cost Case Studies

7.1 Introduction

The broad objective of this study is to estimate the benefits and costs of investments by the UC system in research and extension activities related to pest management. One component of a broader strategy is to evaluate the impact of these activities in the almond, cotton, orange, lettuce and processing tomato industries and to compare the results from these case studies with the aggregate analysis from Chapter 2.

In this chapter the benefit-cost framework used in the study is described, key assumptions are identified, and important caveats are stated. An extensive literature has been published on benefit-cost analysis. A subset of that literature dealing with natural resources issues (Randall 1987 and 1999a, for example) is especially relevant because some of the issues relating to pesticide use are dynamic, long-lasting and involve externalities. In addition, we draw specifically on another subset of the literature that deals with the benefit-cost evaluation of public investments in agricultural research and extension, as discussed in detail by Alston, Norton and Pardey (1995) and in summary by Alston et al. (2000).[1]

7.2 Conceptual and Measurement Problems and Corresponding Caveats

The measurement of the returns to agricultural research and extension is never easy. As pointed out by Alston, Norton and Pardey (1995), many research projects fail to generate useful results, and for the few that succeed, it may take a long time before any benefits are obtained, owing to lags in development of technology and eventual adoption by farmers; then the benefits may flow for a very long time, perhaps indefinitely. These uncertainties about whether and when particular research investments will yield any benefits, make the assessment of the total benefits in present-value terms inherently difficult. This is true regardless of whether we are evaluating past benefits from past research, *ex post*, or conducting a forward-looking

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[1] Some people object to the philosophy behind benefit-cost analysis, particularly when it comes to valuing projects that have consequences for human lives or future generations. Benefit-cost analysis is based on a utilitarian philosophy: that actions are good if they result in the satisfaction of preferences. Randall (1999b) pointed out that there is another branch of Western moral philosophy which argues that consequences and preference satisfaction ought to play a subordinate role to some "universal moral imperatives," and hence some natural entities ought to be protected by constraint. Some are also concerned about the distribution of gains and losses when resources are reallocated. The point remains that every time a resource-use decision is made by an individual or by society, a benefit-cost judgement has been made either implicitly or explicitly.

assessment, *ex ante*. Further difficulties are encountered when we set out to measure the benefits accruing to a particular group—such as farmers alone, or farmers and consumers in a particular country or state. Such assessments typically involve measuring not just the total benefits globally, but the distribution of the benefits between the group of interest and others. In turn, this entails knowledge of the pattern of adoption among different sets of farmers (in California and elsewhere), the distribution of production and consumption of the affected commodities, and measures of research-induced changes in prices. Alston, Norton and Pardey (1995) provide details on how having to deal with distributional implications makes the measurement problems very much greater.

It is one thing to measure the benefits, another to match streams of benefits to corresponding streams of costs. Alston and Pardey (2001) refer to this as the "attribution problem" in benefit-cost evaluation of agricultural research investments. It is difficult to identify which research investments, made (and paid for) by whom, and in particular when, are responsible for a particular research-induced productivity improvement. The alternatives among whom we have to attribute responsibility for new technologies and improved agricultural productivity in California include private firms in California, other states and internationally; state and federal public institutions in the United States (including the USDA and agricultural experiment stations in other states, as well as the California Agricultural Experiment Station, and nonagricultural research institutions); and international public research efforts. Improved productivity might also have its origins in private and public investments in education and infrastructure, and in other improvements in inputs used by farmers.

Alston et al. (2000) discuss the role of this attribution problem in giving rise to distorted (generally, upward-biased) estimates of returns to agricultural research investments. A related issue is defining the relevant counterfactual alternative, since it is sometimes difficult to define a relevant representation of what the world would have been like in the absence of a particular technological innovation (in many cases, alternative innovations would have been developed and adopted if the technology of interest had not been invented or had been disallowed by regulation).

These general problems of measuring agricultural research benefits and attributing them among different investments in agricultural research apply with full force to agricultural pest management technologies. In addition, there are some problems and issues that are unique to (or, if not unique, particularly problematic in) evaluating pest management research. First, some of the benefits from pest management research are of a nonmarket form (such as the benefits from reduced environmental pollution) and are not reflected in the conventional commodity market measures of research benefits. Different types of measures are needed for these benefits, and the necessary data are typically not easy to come by. More generally, pest management research benefits ought to be measured as arising in the context of distorted markets and, while the approaches are worked out (see Alston, Norton and Pardey 1995), the data requirements are onerous.

Second, the dynamic nature of the interaction between pests themselves and the pest control technology, through resistance development and pesticide impacts on predators and other beneficials, adds a range of complications. In particular, the potential for inter-farm externalities is exacerbated, and maintenance research becomes more important, which adds to the difficulties of defining the relevant counterfactual alternative and defining benefits. Third, regulation of pesticides changes the potential streams of benefits from a particular technology, and the regulations and the technologies are mutually endogenous, evolving together with changes in information and attitudes about the technologies, as well as science. This mutual endogeneity has ramifications for how we think about and measure the benefits from new technology. For the most part, data are not available to implement approaches to deal with any of these issues, even where the approaches have been worked out in principle.

One reason why benefit-cost analyses are conducted is to assist in the allocation of resources towards projects that earn higher rates of return than alternatives. Resources devoted to project evaluation should be subject to similar scrutiny. As will become obvious as the limitations of the present study are explained in more detail, the resources available for this study meant that we were often forced to use pragmatic approaches in valuing the benefits of pest management research and extension. It must also be said that some of the outcomes of changes in pest management technology, particularly those related to human health and the environment, are so inherently difficult to evaluate (partly because of the lack of scientific data) that a much greater effort would have been required to significantly increase our confidence in the results.

7.3 The Perspective of the Analysis

Our analysis is conducted from the perspective of taxpayers in California who provide a large share of the funds to finance the research and extension. Ideally, we would like to estimate the benefits from new pest management technologies not only to agricultural industries in California, but to the broader community in California in terms of reduced risks to human health and the environment.

As reported in Chapter 5, we have been able to do little more than report on trends in the use of chemicals of significance to human health and the environment, in reported concentrations of pesticide residues on foods, and in reported incidence of illness (the majority from drift from agricultural applications) related to the use of pesticides. No attempt has been made to translate these changes into some monetary measure of changes in human health costs or even into some physical measure such as the incidence of cancer or morbidity. This deficiency is not unique to this study.

Our study is of an *ex post* rather than *ex ante* nature in that we have attempted to estimate the benefits that have flowed from research and extension since 1950. We have only recognized benefits up to 1999, which means that benefits from past research continuing beyond 1999 have been ignored. Just how long the benefits from particular investments continue is an empirical question. We have argued in this report that, because of the ability of pests to react to control strategies, a large component of the investment stream goes to maintenance activities, without which pest management technologies quickly become obsolete. On the other hand, some knowledge about the biology of pests may never become obsolete.

In Chapter 3, we noted that estimates of expenditure on research and extension in pest management by the UC system were available only from 1970 until 1997. No doubt much of the research into the biology of insects and mites that contributed to later IPM programs was undertaken prior to 1970. To this extent we have underestimated investments in pest management research.

Our estimates of benefits relate to industry benefits, which come in the form of reduced pesticide costs, reduced damage to crops, higher yields, increased production, and lower prices to consumers. Industry beneficiaries include consumers and processors of produce as well as farmers.

In the conduct of these case studies, our approach has been to ask what elements of the broad industry advances with respect to yields, product quality, and production costs can be attributed to technologies based on information generated by the UC system about the biology of arthropods and their interactions with natural enemies and control strategies since 1950. We have made judgements about the impact of these IPM technologies that are based on expert opinion, past evaluations of the technologies, industry trends in yields and product quality associated with reduced pest damage, and historical cost of production budgets prepared by UC Cooperative Extension staff.

Generally, it was not possible to value advances other than key advances in the management of arthropods widely adopted by growers. We repeat our caveat that the University of California has made contributions in other areas of pest management. For some crops, such as lettuce and processing tomatoes, it is in these other areas, such as breeding for disease and nematode resistance, that the most significant gains in pest management may have been made. Where appropriate and possible, we have estimated the benefits from such technologies.

Within each case study commodity, we compared the benefits from the key advances identified with an estimate of the total investment in pest management research and extension for that commodity. In general, benefits exceeded costs. Our strategy was to compare total benefits from the case studies with total investment in pest management research and extension for California as a whole, in the expectation that the benefits from key advances in a number of commodities would be large enough to exceed total investment, recognizing that we had not attempted to value all benefits. In practice, we conducted too few case studies to generate this level of benefits. The five case studies accounted for only 16 percent of the total pest management research and extension budget.

7.4 Estimating Industry Benefits

The UC system has been investing in pest management in agriculture at least since 1875 when professor E.W. Hilgard identified phylloxera in Sonoma vineyards. Our interest is in the period since 1950. Even since that time, the UC system has funded hundreds of projects in pest management.

One approach to evaluating this stream of investments is to evaluate a selection of these individual projects and aggregate the results. Conceptually, quite sophisticated econometric or programming modeling techniques can be used to estimate the farm-level impacts of new pest management strategies. Some of the literature concerning empirical analyses of the marginal value product of pesticides was reviewed by Fernandez-Cornejo, Jans and Smith (1998). It is also worth noting the growing interest in using crop models to provide data for economic models of the cost of pest damage that can be used to measure benefits from different pest management strategies. These models quickly become quite complex as attempts are made to model the response of farmers to issues, such as resistance, as well as allow them an adequate capacity to respond to changes in the prices of inputs and outputs (e.g., Monjardino, Pannell and Powles 2001). We have not followed an approach of modeling the impact of specific projects, partly because of the size of such a task and partly because of the difficulty of attributing benefits and costs to specific projects over such a long period of time.

An alternative approach in benefit-cost analysis of agricultural research investments is to use econometric analysis of the relationship between agricultural productivity growth and past investments in research and extension. The econometric approach to evaluating technology is most useful for the analysis of returns to all public research on agriculture in aggregate, at the level of nations or states, and is not easily applicable to the estimation of the returns to pest management research. In between these two extremes is the analysis of returns from research at a commodity level—aggregating across projects and programs, but staying within the context in which an individual commodity market model is applicable, as outlined by Alston, Norton and Pardey (1995). However, a comprehensive analysis of commodity-specific pest management research impacts is not feasible given available data, and in view of the difficulty of isolating returns from pest management as opposed to other types of technological change.

This study combines elements of these various approaches in a simplified framework that considers the nature of available data while drawing as much as possible on theoretical underpinnings from the literature. In the commodity case studies, we measured approximate benefits associated with increased yields or reduced unit costs resulting from improved pest control technologies, to which the UC system has contributed, related to the major pest problems faced by the case study industries. In Chapter 2 we estimated the aggregate returns to investments by the UC system on research and extension based on hypotheses (assumptions) about the sources of the growth in productivity in California agriculture as a whole. The general approach here has been used in many studies, beginning with Griliches (1958), and is similar to that used by Alston, Pardey and Carter (1994).

In both the case studies and the aggregative analysis, the gross benefits from a research-induced improvement in technology are estimated as being approximately equal to either the proportional increase in yield times the value of California's production (for yield-enhancing technologies) or the proportional savings in per unit costs times the value of California's production (for cost-reducing technologies) of the relevant commodity. If, at the same time, the new technology led to an improvement in average quality, we would add to the other benefits the proportional increase in unit value of the commodity multiplied by the value of production. As discussed in Alston, Norton and Pardey (1995), this approach is a reasonable approximation for the gross annual research benefits.[2] But these are *global* benefits, including any benefits to producers, processors and consumers in other states and other countries, as well as those accruing within California from California's adoption of the technology in question. Benefits will accrue to consumers outside of California if California's production is sufficiently important to significantly influence the market price of the commodity in question. In cases where California's production influences world prices for the production question—almonds is the only case study where this effect is large enough to warrant a specific adjustment—we need to partition the benefits between producers and consumers and partition the consumer benefits between California and elsewhere to derive an aggregate benefit to California.

Also, if producers in other states or other countries can adopt improved technologies as a result of UC pest management research, there will be additional benefits. At the same time, however, if the foreign adoption of the technology appreciably affects foreign production and, thus, prices, the returns to California producers will be commensurately reduced. In the work that follows, we do not allow for any price feedback effects from technology spillovers to other states or countries resulting from UC pest management research. In the case of almonds alone, we allow for price effects of UC pest management research.

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[2] See Martin and Alston (1997) for a defense from a different theoretical perspective.

7.5 Defining the "With" and "Without" Scenarios

The critical step in any evaluation of technology is to define how the industry would look if the technology had been adopted—the "with new technology" scenario—and how the industry would look if the technology had not been adopted—the "without new technology" scenario. Marshall and Brennan (2001) provide a good discussion of the issues involved in carefully defining "with" and "without" scenarios.

In our situation of an *ex post* analysis, we observe the "with new technology" scenario and have to make judgements about how the industry would have developed in the absence of UC investments in research and extension in the management of insects and spider mites. It is tempting to assume that the "without" scenario is simply the industry as it was before IPM technology was introduced and attribute all changes related to pest management to the UC investments. This still requires judgements about the contribution of pest management to yield increases relative to other sources of yield increase.

One problem with this approach is that, in general, we do not have data on pest management strategies, their costs and distribution at the time of the introduction of IPM in each of these industries.[3] Nor do we have much information on the rate and extent to which it was adopted. A second major problem is that this naive "without" scenario assumes that pest management practices would not have changed in the absence of the UC activities. The technologies farmers employ come from a range of sources. Some they learn over time from their own experimentation, some they acquire from neighbors, some are developed by other research agencies, and some come embodied in inputs they purchase. In some cases, the UC activities speed up by a few years the adoption of technologies that farmers would have discovered for themselves from these other sources. The payoff to the more rapid adoption of technology can be very high. For example, it may have been the case that farmers themselves would have realized the futility of continuing to increase the number of insecticides in the late 1970s, and hence the University of California made a major but relatively short-lived contribution in educating farmers about the effective use of pesticides and about interactions between pests, predators and climate.

In some cases the knowledge generated by UC activities may be useful for many years. The detailed knowledge about the life cycles of pests and predators that has allowed more effective timing of pesticides, the use of biological and cultural control methods, and the development of pest moni-

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[3] A drawback in looking back to 1950 is that most of those who were working in the UC system in the 1960s are now retired. The institutional memory of the current faculty and staff is short for our purposes, and there is a risk we have overlooked some key early developments.

toring techniques, are innovations that farmers may not have been able to learn by themselves, and may have elements that are specific to the California environment, requiring, at the very least, extensive adaptation of knowledge developed elsewhere. Biological and cultural innovations that lower what Stern et al. (1959) refer to as the "permanent general equilibrium pest population," are particularly valuable. As already noted above, the UC system is credited with having made a major contribution in this knowledge-based IPM approach.

A further difficulty in defining the "without" scenario in this area of pest management arises from the ability of arthropods and diseases to react to control strategies. One view is that a continuing series of short-lived innovations is required to protect yields and pest management costs. Another view is that many strategies to lower the general equilibrium pest population, particularly those whose effects are temporary, such as pesticides, require a high level of maintenance research to protect their efficacy.

As noted in Chapter 3, a major UC contribution has been the development of IPM technologies based on information about arthropod pest populations and their interaction with the target crop, pesticides, natural enemies, day length, and weather that allows farmers to make more profitable pest management decisions, either because they lower pest management costs or because they result in increased yields of higher-quality produce. These technologies appeared in the late 1970s and early 1980s as a result of research that began in the 1960s, and earlier, when problems with the calendar application of pesticides started to appear. Maintaining the efficacy of these technologies has required an ongoing stream of maintenance research. This information about arthropod pest populations has also allowed the community to make decisions about the regulation of pest management strategies that lower risks to the health of farm workers, consumers, and neighboring communities, and to the environment more broadly.

7.6 Assumptions Common to the Five Case Studies

- Revenue and cost streams were expressed in year-2000 real dollar values using the GDP deflator for the U.S. economy.
- Real revenue and cost streams were compounded forward to 2000 at a real interest rate of 2 percent, reflecting to some degree the return these funds could have earned in alternative investments. Weitzman (2001) suggested that 2 percent was an appropriate discount rate for planning periods of 26 to 75 years.
- Prices received by farmers were used to value agricultural products, which may mean that the value to the community of UC activities is overstated to the extent that prices to farmers have been supported under farm programs, although, with the notable exception of cotton, this has not been an issue for most crops grown in California.
- In each of the case studies we used the estimates of investments in

research and extension in pest management from 1970 to 1997, derived in Chapter 3, as estimated costs in the benefit-cost analyses.

7.7 Sources of Data

The following sources of information were helpful in defining "with" and "without" scenarios and in valuing benefits and costs:

- Industry data collected by federal and state authorities on production, value of production, yield and price
- Farmer association data on quality change in the cases of almonds and tomatoes
- Pesticide-use data from the Department of Pesticide Registration for all chemicals since 1991 and for restricted-use chemicals for some longer periods
- Previous evaluations of pest management practices
- Crop budgets back to 1953 prepared by UC Cooperative Extension, which were used in valuing changes in pesticide use, yield and crop quality.

Some appreciation of the relative importance of pest management and changing technologies in pest management can be gained from review, of commodity cost-of-production budgets prepared over many years by UC Cooperative Extension staff. Recent practice has been to represent in the budgets, procedures and materials typical of a well-managed enterprise in the region under consideration. The budget publications warn that there will be considerable variation across the region from the enterprise defined in the budgets. We tried to identify trends in pest management costs, but our observations should be interpreted cautiously for a number of reasons. Foremost is the likelihood that the budgets have not been prepared on a consistent basis since 1953. We know that earlier budgets were based on survey data, whereas recent budgets reflect practices on a typical (but hypothetical) well-managed farm or orchard. It is also likely that the treatment of noncash costs has varied over the period.

An important noncash cost in recent budgets has been an opportunity cost (or capital recovery cost, to use the same terminology as the budgets) for capital invested in the orchard. In 1998 the basis of this cost was an estimated (by the USDA-ERS) long-run nominal rate of return to production assets in agriculture in California of 7.81 percent per year. This opportunity cost amounted to over $800 per acre in the 1998 budget for almonds in the northern San Joaquin Valley, for example. It is highly unlikely that this procedure was followed over the entire period, and, hence, we have deducted this cost in the budget information presented in the following chapters. Similarly, some earlier budgets included an allowance for renting land, which we have deducted.

CHAPTER 8

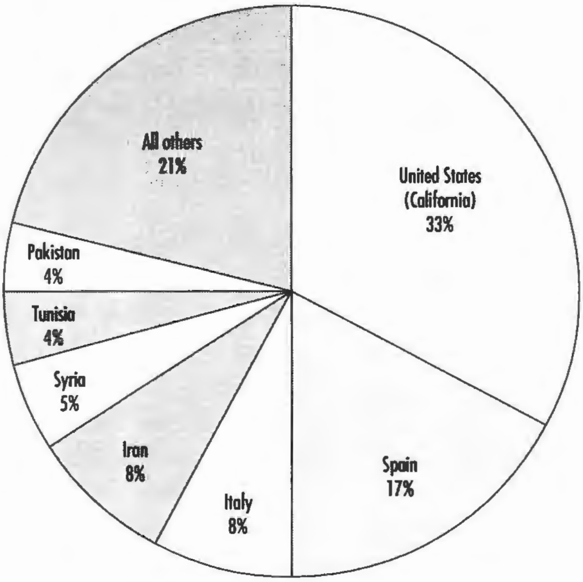
An Evaluation of Pest Management R&D in Almonds

8.1 The Almond Industry in California

California accounts for about one-third of the world's almond production (Figure 8.1) and virtually all of the almonds grown in the United States. Almonds have been California's highest value tree nut since 1970 and in recent years a billion dollar commodity. Among all of California's agricultural commodities, almonds ranked tenth in cash receipts in 1999. About 75 percent of the state's almonds are grown in five counties in the San Joaquin Valley—Stanislaus, Kern, Merced, Fresno and Madera—each of which accounts for over 10 percent of total production.

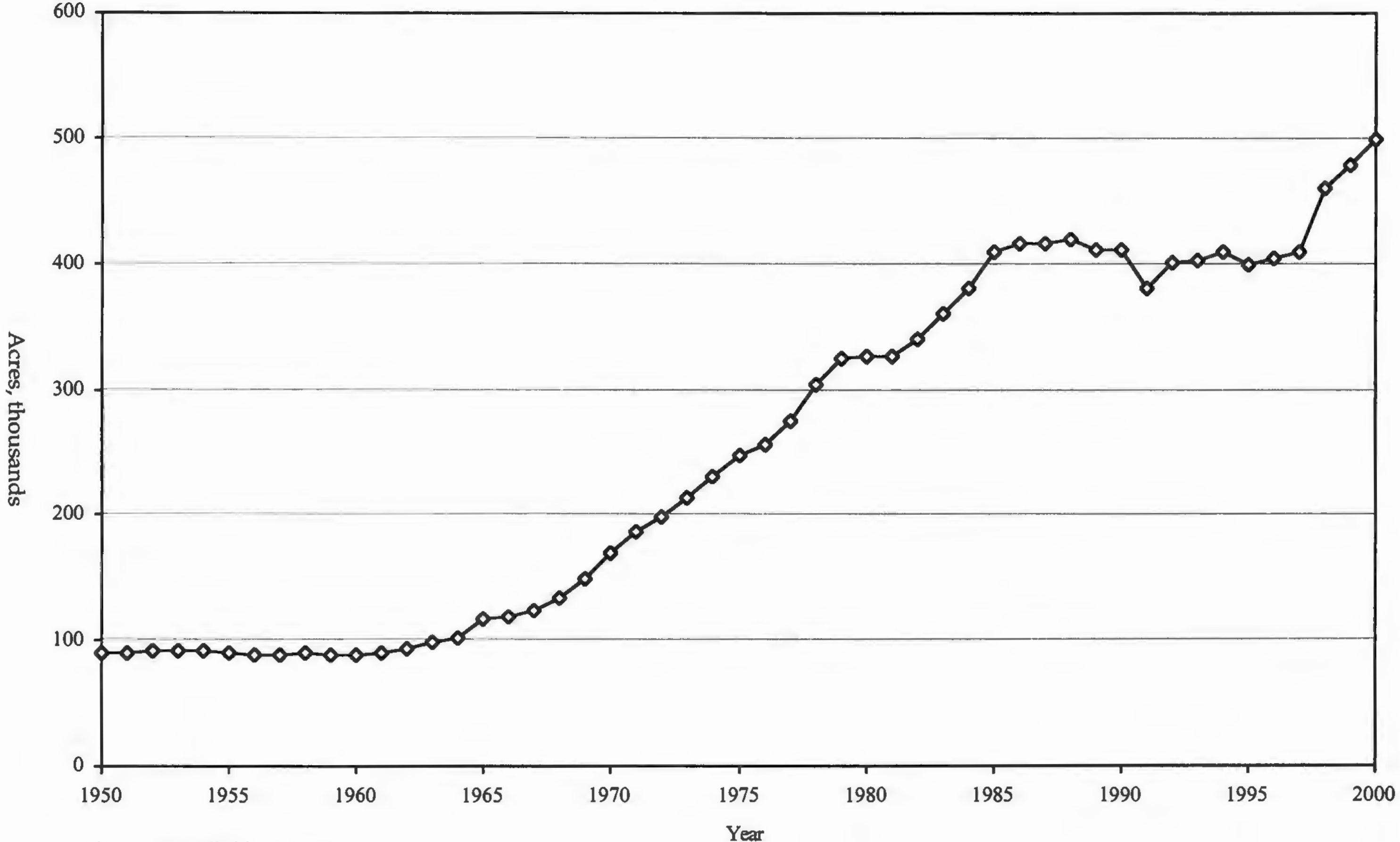
Acreage

Between 1950 and 1963 California had almost 100,000 bearing acres of almonds (Figure 8.2 and Table 8.1). In 1950, about one-half of this acreage was in the Sacramento Valley, with the other half divided between the San Joaquin Valley and a few coastal counties (Contra Costa, Monterey, San Luis



Source: Compiled by the authors from Food and Agriculture Organization, United Nations, online data, 2001.

Fig. 8.1 World almond production, 1999



Source: Compiled by the authors.

Fig. 8.2 California almond harvested acreage, 1950–2000

Table 8.1 California almond production, 1950–2000

Year	Harvested acres	Yield	Production	Price	Value of production	Real price	Value of production
				(nominal dollars)		(year-2000 dollars)	
	(thousands)	(shelled lbs/acre)	(million lbs shelled)	(dollars/lb)	(millions)	(dollars/lb)	(millions)
1950	90.5	417	37.7	0.55	20.6	3.35	126.1
1951	90.7	471	42.7	0.47	20.2	2.70	115.2
1952	91.4	398	36.4	0.46	16.9	2.61	95.0
1953	92.2	419	38.6	0.48	18.4	2.64	102.1
1954	92.6	466	43.2	0.50	21.5	2.74	118.3
1955	89.4	428	38.3	0.86	33.0	4.66	178.3
1956	88.6	661	58.6	0.80	47.1	4.20	246.3
1957	88.2	425	37.5	0.51	18.9	2.56	95.8
1958	89.5	221	19.8	0.77	15.3	3.82	75.5
1959	89.2	929	82.8	0.47	38.6	2.28	188.6
1960	89.1	595	53.0	0.53	27.9	2.53	134.3
1961	89.3	744	66.4	0.56	37.3	2.67	177.5
1962	93.1	516	48.0	0.67	31.9	3.13	150.1
1963	97.8	610	59.7	0.59	35.3	2.75	164.0
1964	101.8	741	75.4	0.63	47.5	2.89	217.6
1965	117.3	622	72.9	0.62	45.0	2.77	202.3
1966	118.3	720	85.1	0.61	51.9	2.67	227.0
1967	124.6	615	76.6	0.58	44.6	2.47	189.1
1968	135.1	551	74.5	0.60	44.5	2.43	180.8
1969	149.0	819	122.0	0.61	73.9	2.35	286.5
1970	169.9	730	124.0	0.65	80.1	2.38	294.8
1971	187.8	714	134.0	0.65	87.1	2.28	305.1
1972	198.9	628	125.0	0.79	98.1	2.64	329.7
1973	213.6	627	134.0	1.49	199.7	4.74	635.4
1974	231.2	817	189.0	0.90	170.1	2.63	496.7
1975	248.8	643	160.0	0.74	118.4	1.98	316.2
1976	256.7	908	233.0	0.81	188.7	2.05	477.0
1977	275.4	926	255.0	1.05	267.8	2.49	635.9
1978	303.6	582	176.6	1.44	253.4	3.18	561.8
1979	324.1	1,248	404.4	1.38	558.7	2.83	1,143.4
1980	326.8	1,060	346.3	1.37	473.3	2.56	887.3
1981	326.2	1,345	438.8	0.68	299.5	1.17	513.5
1982	339.3	1,100	373.2	0.83	311.1	1.35	502.1

(continued)

Table 8.1 Continued

Year	Harvested acres	Yield	Production	Price	Value of production	Real price	Value of production
				(nominal dollars)		(year-2000 dollars)	
	(thousands)	(shelled lbs/acre)	(million lbs shelled)	(dollars/lb)	(millions)	(dollars/lb)	(millions)
1983	360.0	723	260.3	0.89	231.9	1.38	360.0
1984	381.0	1,665	634.5	0.70	446.1	1.05	667.8
1985	409.2	1,222	500.1	0.72	360.6	1.05	523.3
1986	416.0	646	268.9	1.72	461.6	2.44	655.3
1987	417.0	1,702	709.8	0.91	648.0	1.26	893.1
1988	419.0	1,514	634.5	0.95	600.1	1.26	799.9
1989	411.0	1,282	527.0	0.91	480.9	1.17	617.5
1990	411.0	1,727	709.8	0.84	598.0	1.04	739.1
1991	380.0	1,387	527.0	1.07	564.2	1.28	672.8
1992	401.0	1,470	589.3	1.17	691.3	1.37	804.8
1993	402.0	1,311	527.0	1.77	930.6	2.01	1,058.0
1994	409.0	1,933	790.4	1.22	965.2	1.36	1,075.0
1995	400.0	925	370.0	2.48	880.9	2.70	960.1
1996	405.0	1,260	510.0	2.08	1,018.4	2.22	1,088.9
1997	410.0	1,850	757.0	1.55	1,126.9	1.63	1,181.9
1998	460.0	1,130	520.0	1.41	703.6	1.46	728.8
1999	480.0	1,740	833.0	0.86	687.7	0.88	701.9
2000*	500.0	1,420	710.0	1.25	852.0	1.25	852.0

Source: Compiled by the authors from the California Agricultural Statistics Service, *Fruit and Nut Report*, 1950–1992; and USDA, National Agricultural Statistics Service, *Non-Citrus Fruits and Nuts Report*, 1993–2000.

*Preliminary

Obispo and Los Angeles). At that time, production began to decrease in the coastal region and to increase in the San Joaquin Valley, so that while these two regions had roughly the same acreage in 1950, the San Joaquin Valley share was significantly larger by 1960.

During the next 20 years, almond acreage increased dramatically, more than quadrupling to 417,000 bearing acres in 1985. Most of the new acres were planted in the San Joaquin Valley as water became available from the Central Valley Project. San Luis Obispo was the only coastal county still reporting significant bearing acres in 1985, although it had decreased from 8,000 acres in 1950 to 5,000 acres in 1985.

Between 1985 and 2000 almond acreage increased by another 80,000 acres to about 500,000 bearing acres. Most of the acres that came into production in the late 1980s and 1990s were in the San Joaquin Valley, which now accounts for about 80 percent of total acreage. Although the Sacramento Valley has a comparatively small share of almond production, the number of bearing acres in that region more than doubled between 1950 and 1999, from 44,000 to 99,000 acres. San Luis Obispo County no longer reported any almond acreage in 1999, and only 1,500 bearing acres were reported in regions other than the Sacramento and San Joaquin valleys.

Yield, Production, and Value

Almond yields increased almost as dramatically as acreage (Figure 8.3 and Table 8.1). During the 1950s the average almond yield (in-shell) was roughly 500 pounds per acre. By the 1990s it had increased to over 1,500 pounds per acre. The most significant growth occurred during the late 1970s and early 1980s. Average yields during the 1980s were about 45 percent higher than in the previous decade. The increase in yields can be attributed to a number of sources, including higher rates of irrigation, better soils, better pollination techniques and improved varieties.

Annual production increased from almost 40 million pounds (shelled) in 1950 to 830 million pounds in 1999 before decreasing to 710 million pounds in 2000 (Table 8.1 and Figure 8.4). Production fluctuated more widely from about 1980 on than it did during previous years, and this fluctuation was reflected to some degree in prices and the value of production. Most of this variability can be explained by the fact that almond production is inversely related to the amount of rainfall in February.

Almond prices, in nominal terms, were about 55 cents per pound in 1950 and rose to almost $2.50 per pound in 1995 before falling to $1.25 per pound in 2000 (Table 8.1). In real (year-2000) dollars, almond prices fell from about $3.35 per pound to $1.25 per pound between 1950 and 2000. In most of the 1980s, prices were relatively low. They rose in the early 1990s, no doubt encouraging the expansion of the industry in that decade (Figure 8.5).

Almonds have accounted for an increasingly large share of the state's total agricultural cash receipts. In 1999 almonds were the state's tenth-ranked commodity in terms of cash receipts. In constant (year-2000) dollars, cash receipts increased from almost $126 million in 1950 to over $1 billion in a few years in the 1990s (Figure 8.6 and Table 8.1) before declining to $852 million in 2000. The increase was largely due to increased acreage.

As the world's largest almond producer, California depends on international export markets, and almonds are one of the state's top export commodities. For 1999 and 2000 the annual ratio of the quantity of exports to production increased from 53 percent to 71 percent[1] and in both years almonds were the first-ranked crop by export value.[2] In 1999 almond exports

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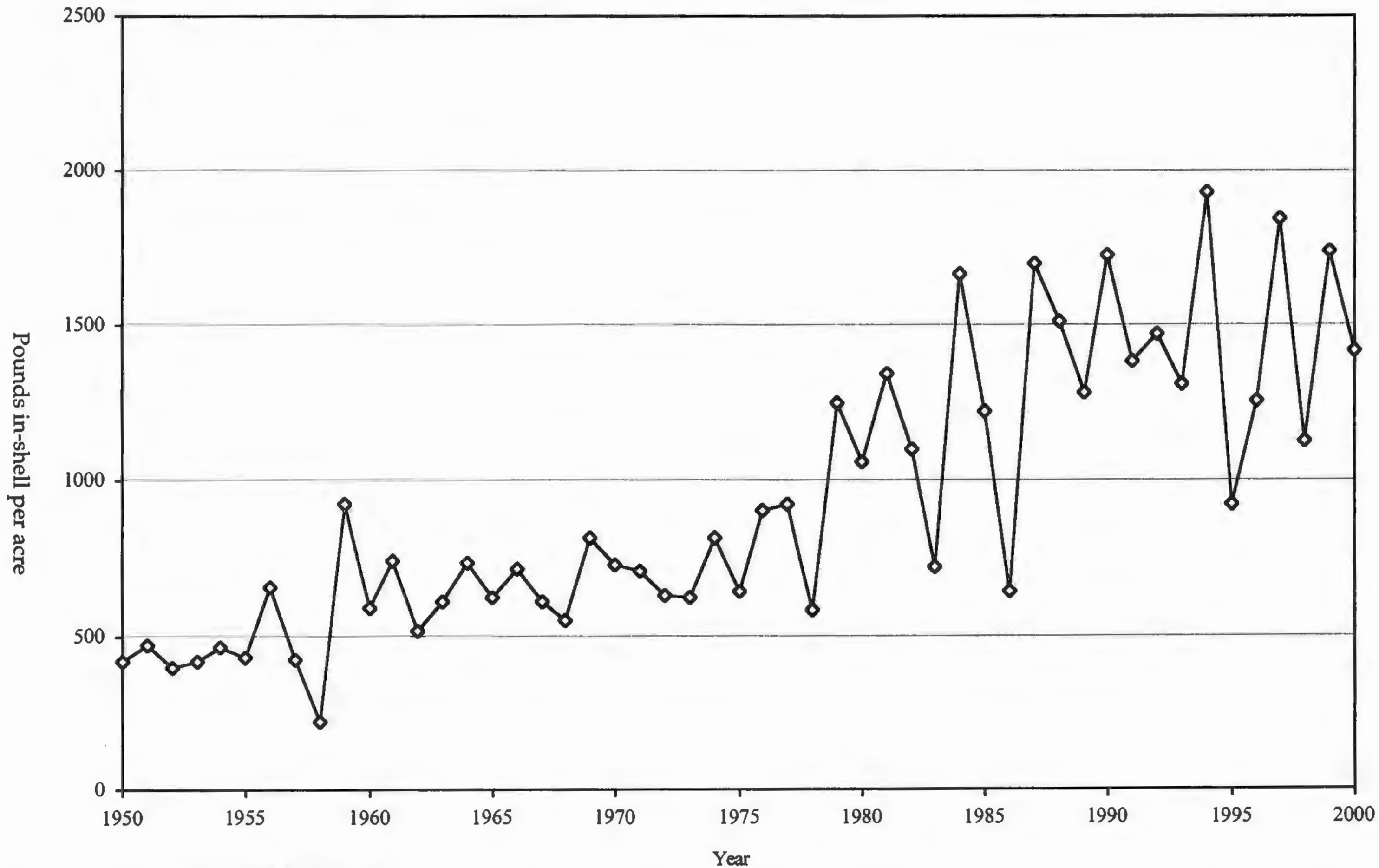
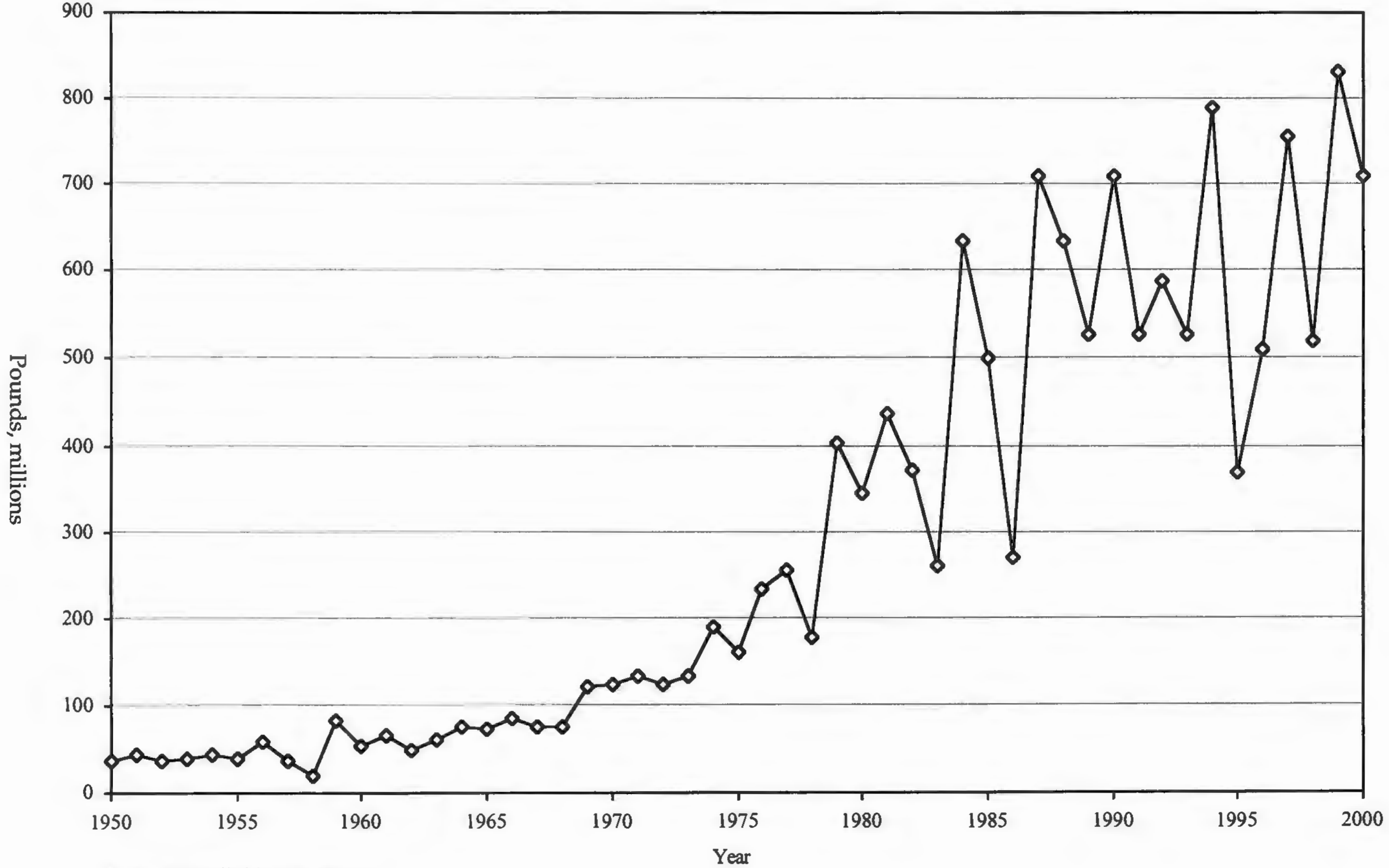
[1] aic.ucdavis.edu/pub/ratio.pdf.

[2] Although these ratios give a general indication of the importance of international markets to the California almond industry, they are not precise measures of the share of production exported, which is more difficult to determine due to storage (Kuminoff, Bervillo and Sumner 2001).



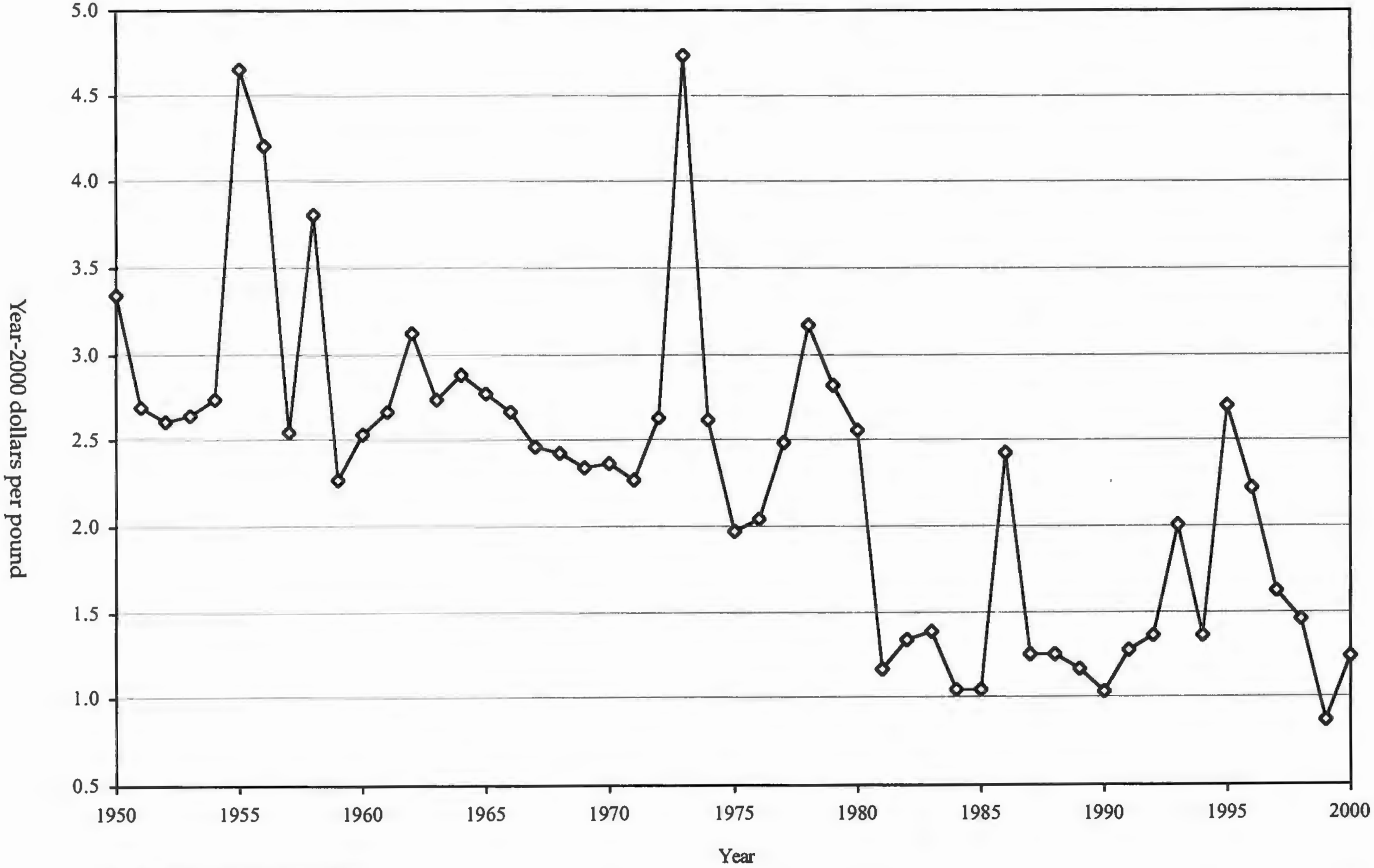
Source: Compiled by the authors.

Fig 8.3 California almond yield, 1950–2000



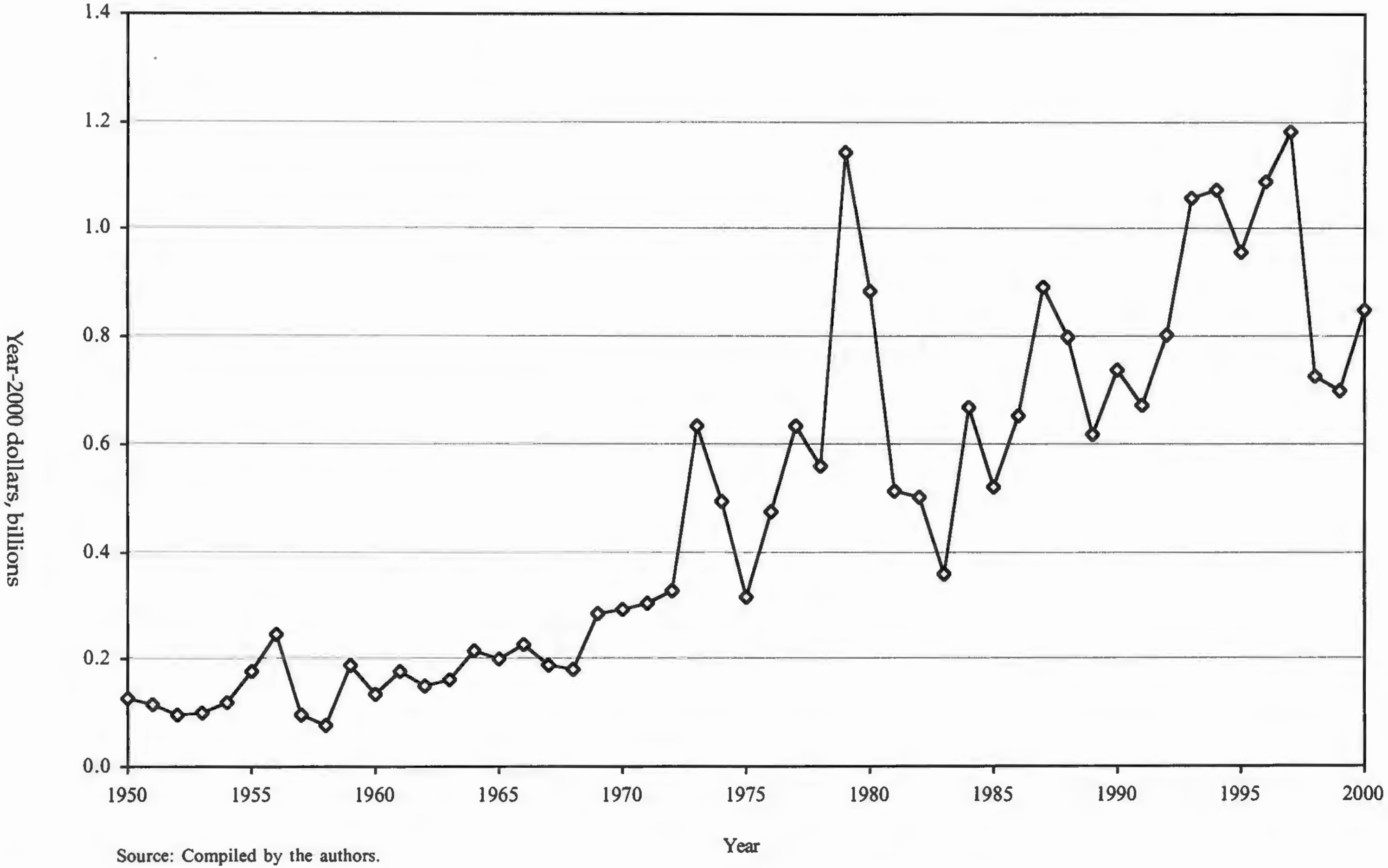
Source: Compiled by the authors.

Fig. 8.4 California almond production, 1950–2000



Source: Compiled by the authors.

Fig. 8.5 California almond price, 1950–2000



Source: Compiled by the authors.

Fig. 8.6 California almond value of production, 1950–2000

were worth about $624 million. Germany, Spain, Japan, Netherlands, India and Canada were the top export destinations. In 2000 the export value was $662.4 million.

8.2 Significant Pests in the Almond Industry

The main arthropod pests requiring routine management include navel orangeworm, peach twig borer, San Jose scale, several mite species, oriental fruit moth, southern fire ant and pavement ant (Rice et al. 1996). Diseases associated with rain at flowering, such as brown rot, shot hole, anthracnose and leaf blight, require routine application of fungicides, especially in northern growing areas. Herbicides are commonly used to manage the orchard floor. The usual approach is a strip treatment down the tree row, although some growers use complete orchard floor applications. Prior to planting, soil nematodes and fungi are sometimes controlled with soil fumigants.

Navel orangeworm (*Amyelois transitella*) is the most significant pest of almonds. It appeared as early as 1947 and displaced peach twig borer as the most significant pest in the 1950s. Nuts left on trees or on the orchard floor provided a haven for navel orangeworm to overwinter.

The key management practice in controlling this pest is postharvest orchard sanitation—the removal of mummy nuts—to break the breeding cycle. The breeding cycle is also shortened by the early and prompt harvest of nuts, which reduces the prospects of a third generation of moths developing, overwintering and infesting next season's crop. Some almond varieties are less susceptible to navel orangeworm than others, and there has been a shift to these less susceptible varieties.

Peach twig borer (*Anarsia lineatella*) has typically been controlled with organophosphates applied during the dormancy period. At the same time, an oil is applied to control mites. Epstein et al. (2000) reviewed the management of these pests. When introduced in the 1970s, the use of an organophosphate spray during the dormant period instead of a number of sprays during the growing season was seen to be an environmentally friendly advance. However, there is now concern that winter rains may wash organophosphates into surface water. Since the early 1990s recommended management practices for the peach twig borer and mites include monitoring pest populations and greater use of pyrethroids or carbamates in either the dormant or growing seasons. These chemicals are also a source of surface water contamination but apparently are less of a concern than organophosphates. In recent years there has been some increased use of even "softer" alternatives such as *Bacillus thuringiensis*, spinosad and pheromones.

San Jose scale and mites do not directly damage nuts, but they do affect the vigor of trees and, ultimately, yield. San Jose scale is normally controlled by an oil spray during the dormant period when better coverage can be assured than during the growing season. While dormant sprays control some mites, Pacific two-spotted mites and strawberry mites require a miticide during the growing season. Predaceous mites also can provide effective control of these mites.

Oriental fruit moth has long been an important pest of peaches, nectarines and other fruit. Since the 1980s its economic significance to the almond industry has increased. The moth is controlled by the use of insecticides during the growing season based on a monitoring program. Parasites and predators do not provide satisfactory control.

Southern fire ants and pavement ants are controlled using insecticide baits applied to the soil in infested areas.

Teviotdale (1996) reviewed economically significant diseases of almonds but did not indicate the incidence and losses associated with these diseases. The diseases include brown rot, blossom blight, shot hole, scab, leaf blight, rust, hull rot, bacterial canker and blast, Ceratocystis canker, Armillaria root rot, crown and root rot, "aerial" Phytophthora, crown gall, Verticillium wilt and almond leaf scorch. Some of these diseases, including brown rot, blossom blight, shot hole, scab and leaf blight, are controlled by the use of fungicides during the growing seasons. There are no known treatments for most of the other diseases. Some enter the plants through lesions in the bark or roots, and hence care in handling trees is indicated. Some affecting the roots are treated by soil fumigation before planting. A disease of growing importance to the industry in the 1990s was the fungus Anthracnose, now treated with propiconazole or tebuconazole.

McKenry (1996) reviewed the management of nematodes but provided little information about the incidence of nematode damage. The problem is of concern during the establishment of orchards. Besides selecting for resistant varieties, cultural practices include four years of fallow or rotation through several field crops. Control using a fumigant such as methyl bromide is also a successful technique. Methyl bromide, soon to be disallowed, is being replaced by 1,3-Dichloropropene.

8.3 Eras of Pest Management in Almonds

The discussion of pest management in almonds follows our general classification of pest management into the presynthetic pesticide era, the synthetic pesticide era, and the IPM era. Much of the "historical" information about the management of pests in almonds is drawn from Zalom et al. (1987).

The Presynthetic Era through the late 1940s

Peach twig borer was the main pest at this time and was controlled by lead arsenate. Bailey (1948) reported 1.25 to 35 percent damage per year by this pest during the six years from 1937-1942. The crop was harvested by hand, and cultivation was the means of weed or orchard floor management.

The Synthetic Pesticide Era from the 1950s to the late 1970s

Some of the key developments during this period included:

- The emergence of navel orangeworm as the most significant pest of almonds
- The rapid increase in the use of synthetic pesticides, especially toward the end of the period when azinphosmethyl and carbaryl were registered for the control of navel orangeworm in almonds
- Problems with use of pesticides, including secondary pest outbreaks, the destruction of predators and pesticide resistance
- Increased knowledge of the biology of pests and predators that became important elements of the IPM program—particularly the use of pheromones and phenology models.

In 1976 insecticides (azinphosmethyl and carbaryl) were registered specifically for navel orangeworm control in almonds, and the use of these chemicals quickly grew to where over 90 percent of orchards were applying insecticide. Despite the increased use of sprays, there was still significant damage to the crop. Insect monitoring and mummy removal were not widespread practices. Repeated applications were made to ensure effectiveness, but this led to secondary pest outbreaks—mites and San Jose scale in particular.

The IPM Era in the 1980s and 1990s

As a result of a strong research and development program since the late 1960s by UC and USDA staff, the main elements of an IPM program in almonds had been developed by the 1980s. UC extension entomologist Clarence Davis began an IPM project funded by Smith-Lever funds and the Almond Board of California in 1979. Extension specialists, farm advisors and USDA staff extensively tested an IPM package in large-scale field trials on 33 different orchards in 1981 and 1982. The UC Division of Agriculture and Natural Resources published an IPM manual for almonds in 1985. The elements of the IPM manual for almonds included:

- Removal of mummies, orchard sanitation and early harvesting
- Regular monitoring throughout the growing season of navel orangeworm, peach twig borers, oriental fruit moths, and mites and application of pesticides only when economic damage was likely
- The release of predatory mites that could tolerate some organophosphates and carbaryl and a lower application rate for omite (propargite), the main miticide used at the time
- For most growers, an organophosphate and oil spray in dormancy for control of peach twig borer, scale and mites (a dormant spray was expected to reduce the need for growing-season sprays)
- An application of an organophosphate in May for navel orangeworm and peach twig borer control, particularly if an organophosphate had not been used in the dormancy period (If an organophosphate was not used in May, it would probably be used in July. In-season insecticides may also help control San Jose scale.)

- Application of a number of acaricides to control mites
- Two combined brown rot and shot hole treatments applied simultaneously in wet years, with additional shot hole sprays in high incidence orchards if the weather stayed wet
- Fumigation of nuts after harvest in the event of a navel orangeworm infestation.

In the late 1990s there was a significant change in IPM recommendations away from the use of dormant organophosphate sprays because of concerns about surface water contamination.

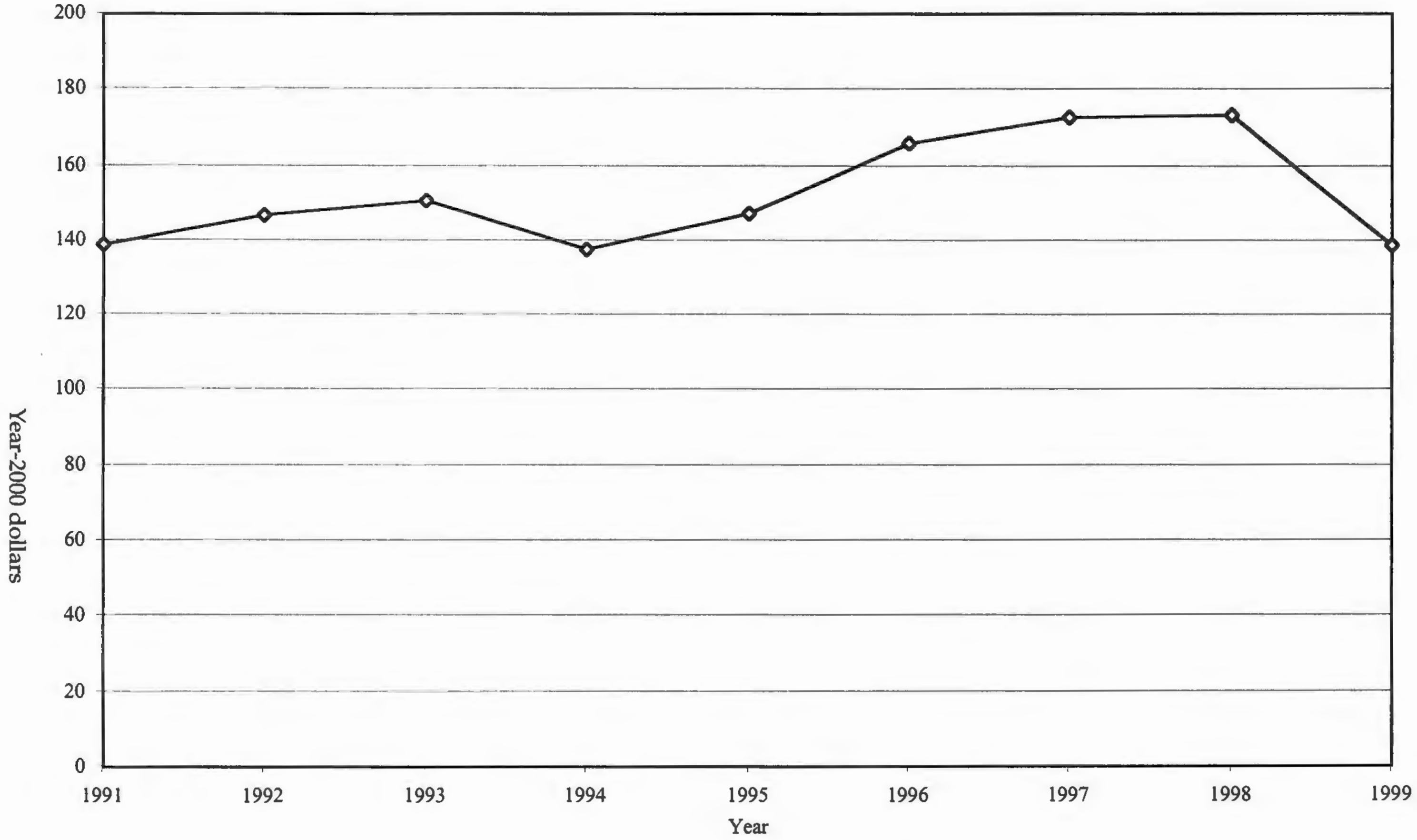
Several research projects during the synthetic era were important in providing the basis for this IPM program:

- UC Berkeley (Caltagirone et al. 1968) research described the biology of the navel orangeworm and the role of overwintering larvae in unharvested nuts.
- Engle and Barnes (1983) provided information on the level of mummy removal required for effective nonchemical control.
- After demonstrating that navel orangeworm insecticides also acted against the populations of beneficial predator mites, Hoy et al. (1982) developed two strains of a predatory mite, Metaseiulus occidentalis, which could tolerate some of the navel orangeworm insecticides. One strain was resistant to carbaryl, the other to permethrin (pyrethroid). Both strains had resistance to several organophosphates, including azinphosmethyl, diazinon and phosmet. Hoy's research also demonstrated that mites could be controlled using 10 percent of the recommended rates of miticide, and this practice was adopted widely.
- Zalom et al. (1984) provided empirical estimates of navel orangeworm damage under different mummy management regimes from monitoring a small sample of orchards. They observed that the cost of winter sanitation was equivalent to the cost of an insecticide application.
- In parallel to the navel orangeworm research, UC researchers developed pheromone traps and phenology models to allow more strategic use of pesticides in the control of peach twig borers, oriental fruit moth and San Jose scale.

8.4 The Use of Pesticides in the California Almond Industry

Real expenditure on pesticides in the almond industry grew from $52.8 million in 1991 to a peak of $79.8 million in 1998 before falling to $66.6 million in 1999 (Table 8.2b). No doubt some of the variation in pesticide use was weather related. Some was also related to the growth of the almond industry. In per acre terms, pesticide expenditure (in year-2000 dollars) was $139 per acre in 1991 and in 1999, with a low of $138 in 1994 and a high of $174 in 1998 (Figure 8.7).

Overall, during the 1990s aggregate pounds (active ingredient) of pesticides used on California almonds trended upward amid annual fluctua-



Source: Compiled by the authors from California Department of Pesticide Regulation, PUR database, 2001.

Fig. 8.7 Pesticide expenditure per acre on California almonds, 1991–1999

Table 8.2a All pesticide use on California almonds, 1991–1999

					Year				
Pesticide	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
				(thousand pounds active ingredient)					
Oils	6,670	6,583	7,206	7,509	5,042	7,014	7,702	8,028	8,504
Toxic air contaminants	809	1,353	1,198	868	1,687	1,753	1,815	2,230	1,400
Carcinogens	514	705	891	728	1,196	1,636	1,505	2,204	1,539
Organophosphates	688	901	851	788	723	754	795	680	626
Cholinesterase inhibitors	688	901	851	788	754	785	835	725	650
Reproductive toxins	368	1,088	784	579	882	630	911	565	340
Potential groundwater contaminants	108	59		93	94	100	104	92	100
Biopesticides		3		8	18	15	21	17	12
Carbamates					31	31	40	45	25
Reduced risk pesticides							1	4	25
Total pesticide use in almonds	12,390	12,797	13,370	12,640	11,617	14,006	14,379	15,991	14,750
				(lbs)					
Active ingredient per acre	33	32	33	31	29	35	35	35	31
				(percentage)					
Share of California total*	9.3	8.2	7.8	7.2	6.2	7.7	7.6	8.1	8.0

Source: Compiled by the authors from California Department of Pesticide Regulation, Pesticide Use Database, 2001.

*Total pesticide use = all pesticides used in production agriculture

Table 8.2b Use of 62 major pesticides on California almonds, 1991–1999[a]

	Year								
Class	1991	1992	1993	1994	1995	1996	1997	1998	1999
(thousand pounds active ingredient)									
Insecticides	7,577	7,789	8,349	8,496	5,903	8,001	8,801	8,984	9,372
Fungicides	2,698	2,376	2,789	2,123	2,924	3,279	2,442	4,029	2,680
Herbicides	834	933	872	882	933	1,017	1,155	1,243	1,245
Fumigants	354	1,067	749	533	812	650	916	650	490
Plant growth regulators								0	0
(percentage of total almond pesticide use, by weight)									
Insecticides	66.1	64.0	65.4	70.6	55.8	61.8	66.1	60.3	68.0
Fungicides	23.5	19.5	21.9	17.6	27.7	25.3	18.3	27.0	19.4
Herbicides	7.3	7.7	6.8	7.3	8.8	7.9	8.7	8.3	9.0
Fumigants	3.1	8.8	5.9	4.4	7.7	5.0	6.9	4.4	3.6
Plant growth regulators	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(year-2000 dollars, millions)									
Estimated expenditures[b]	52.8	58.8	60.6	56.4	58.8	67.3	70.9	79.8	66.6
(year-2000 dollars/acre)									
Estimated expenditures[b]	139	147	151	138	147	166	173	174	139

Source: Compiled by the authors from California Department of Pesticide Regulation, Pesticide Use Database, 2001.

[a] The 62 pesticides are listed in Table 4.5

[b] Estimated expenditures are for the 62 major pesticides

tions, for a net increase of about 10 percent between 1991 and 1999, and this is largely explained by the increase in the size of the industry. Pesticide use was 12.4 million pounds in 1991 and then rose to 16 million pounds in 1998 before falling to 14.8 million pounds in 1999 (Table 8.2a). On a per acre basis (Figure 8.8), the total amount of pesticides applied to almonds has fallen slightly since 1991, but there is no clear trend.

According to Wilhoit et al. (1999), insecticides account for about 60 percent of pesticides applied by weight but, in terms of numbers of applications and acres treated, herbicides account for about one-third of pesticide use, and insecticides and fungicides each account for about one-quarter. For our 62 pesticides, again by weight, the shares of use in 1999 were 68 percent for insecticides, 9 percent for herbicides and 19 percent for fungicides (Table 8.2b). In the wet years of 1998 and 1995, the share of fungicides rose to over 27 percent.

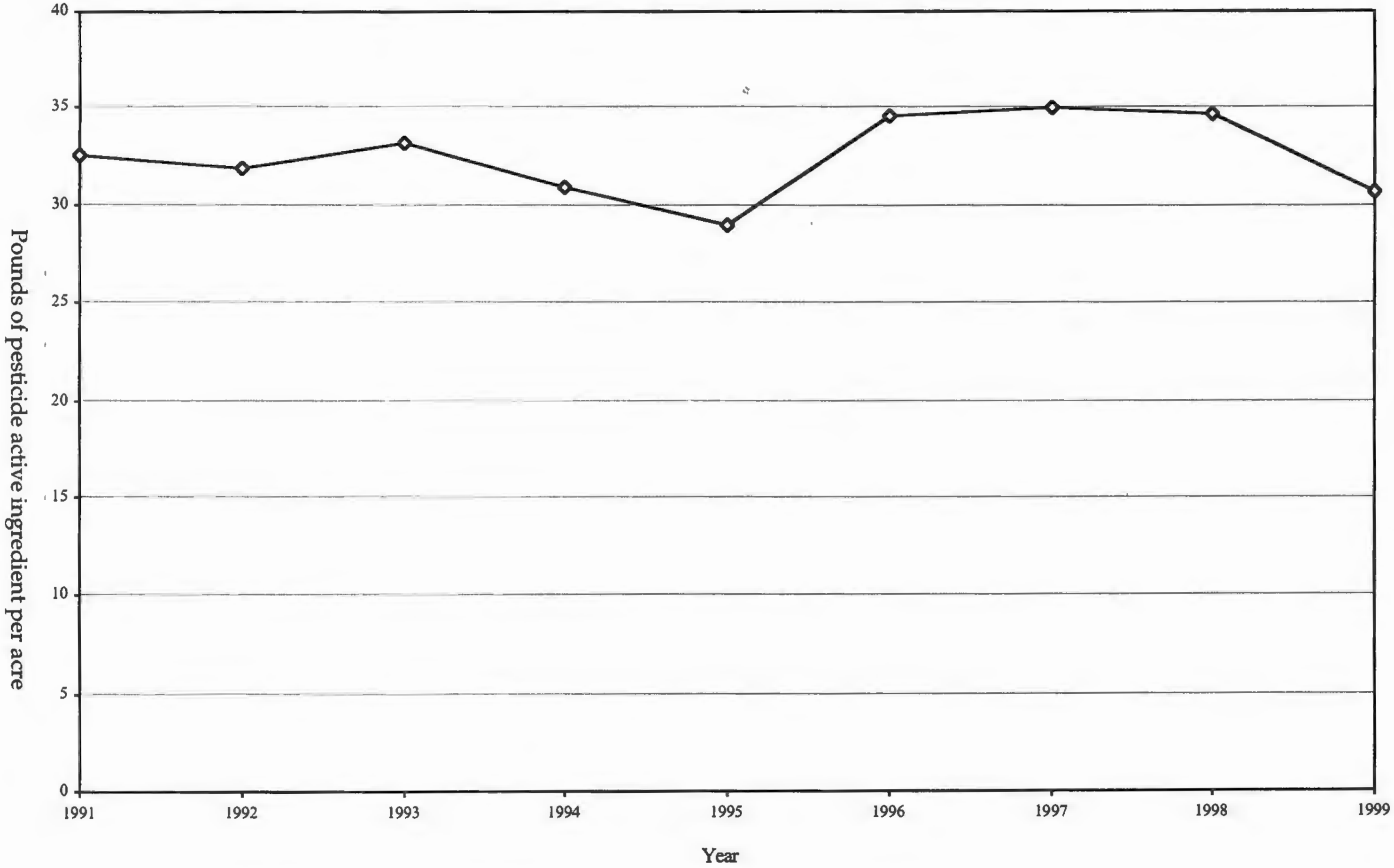
Ranked by total pounds applied in 1999, the top 10 pesticides used on almonds were petroleum products, mineral oil, copper hydroxide, glyphosate, ziram, captan, propargite, methyl bromide, maneb and 1,3 dichloropropene. Together, these 10 pesticides accounted for about 80 percent of the total pesticide use on almonds during the 1990s. The net increase in use of these pesticides more than accounted for the overall increase in pesticide use on almonds, indicating there were some partially offsetting decreases in other pesticides. Pounds of mineral oil use increased the most. Glyphosate, captan, maneb, and 1,3 dichloropropene also increased significantly. Use of ziram and methyl bromide decreased significantly during the 1990s.

The dip in pounds of pesticide use in 1995 is largely explained by a fall of one-third in the amount of petroleum oil products applied, and the dip in 1999 can be attributed to a decline in the use of fungicides and methyl bromide (Figure 8.9).

By most measures (Tables 4.4 and 4.7), the almond industry is a large user of pesticides relative to the other commodities covered in this report. In terms of total pounds of active ingredient applied, the almond industry was second to the grape industry in 1999. The high use is explained by the large acreage of trees and the widespread use of bulky oils. In terms of total expenditure, the almond industry was highest among the commodities, and second only to the cotton industry in terms of expenditure per acre in 1999.

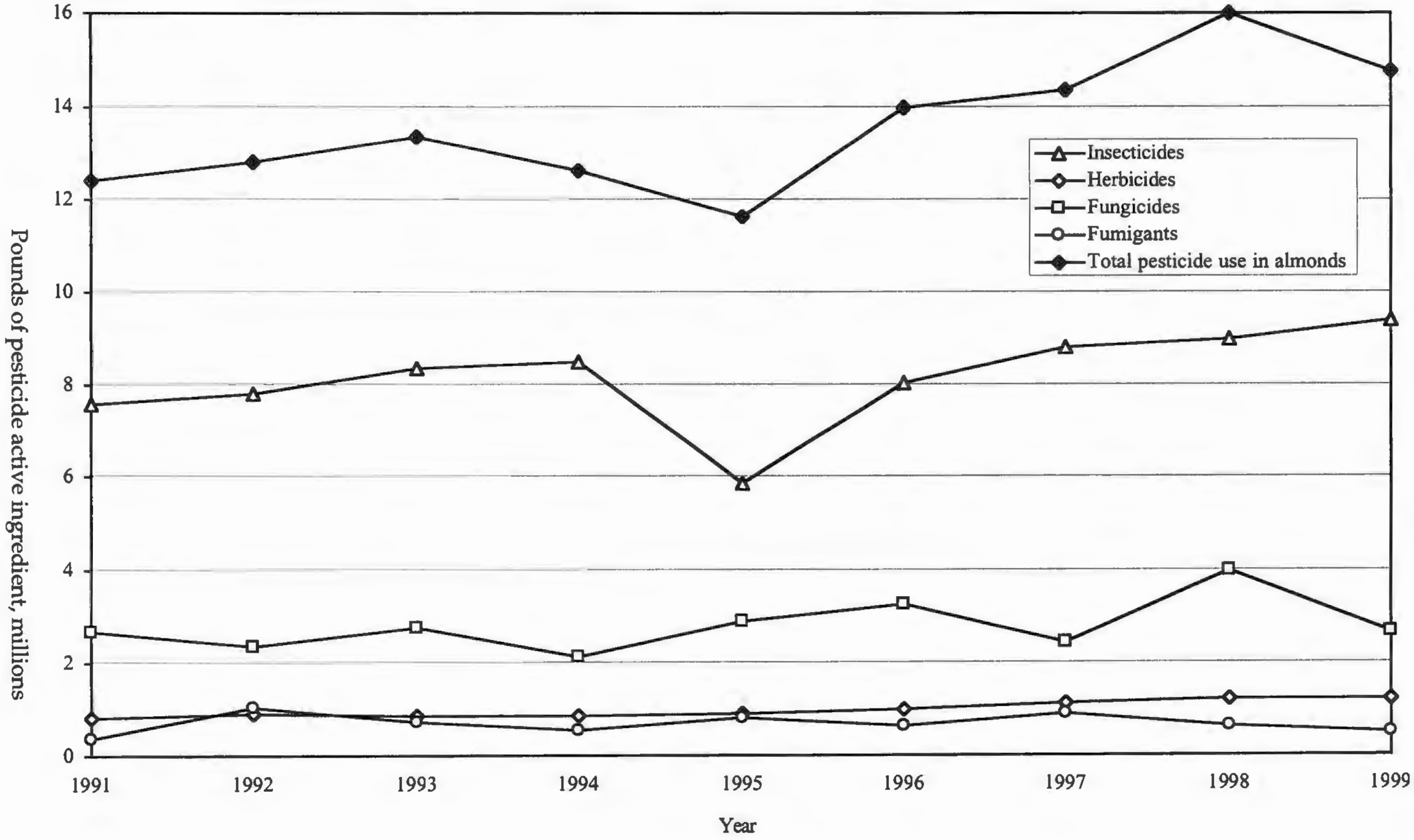
8.5 Changes in Pesticide Use: Environmental/Human Health Risk Perspectives

Of the chemical groups posing human health hazards, use of carcinogens and toxic air contaminants increased from 1991 through 1999, while use decreased for reproductive toxins and chlorinesterase inhibitors. Of the chemical groups posing environmental health hazards, use of toxic air contaminants increased, while use of groundwater contaminants decreased. (For a more extensive discussion of these categories as they are defined in California statutes, see Chapter 3 and the glossary.) Among the categories



Source: Compiled by the authors from California Department of Pesticide Regulation, PUR database, 2001.

Fig. 8.8 Pesticide use on California almonds per bearing acre, 1991–1999



Source: Compiled by the authors from California Department of Pesticide Regulation, PUR database, 2001.

Fig. 8.9 Pesticide use on California almonds, 1991–1999

of pesticide use tracked by the California Department of Pesticide Registration, by far the most significant percentage increases were in use of biopesticides and reduced-risk chemicals, although in terms of pounds very little of these chemicals were applied.

Human Health Hazards

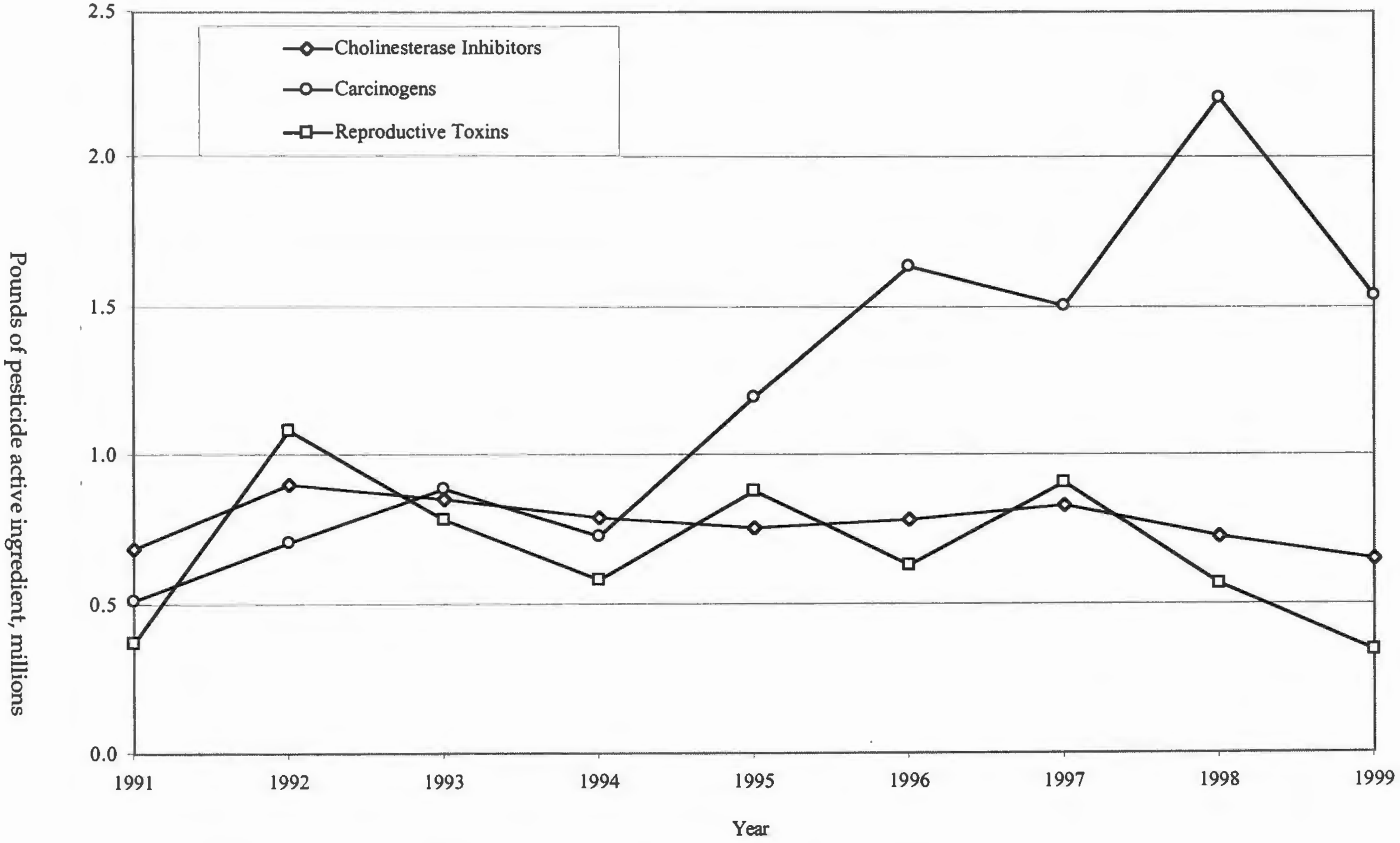
Figure 8.10 shows that the use of pesticides on almonds that are known carcinogens (excluding mineral oil and petroleum products) trebled between 1991 and 1999. This increase was mainly due to increases in four chemicals that, together, represented 90 percent of total carcinogens applied to almonds: maneb, captan, propargite and 1,3 dichloropropene.

Petroleum products and mineral oil accounted for about one-half of the total pesticides applied to almonds in each year from 1991 to 1999. As a broad group, these pesticides are listed as known carcinogens by California Proposition 65. However, the Department of Pesticide Regulation tracks them separately from other carcinogens because the more-distilled products in these categories do not qualify as carcinogens and are used as alternatives to more toxic chemicals (Department of Pesticide Regulation 2000). While use of carcinogens increased on almonds, the use of both pesticides that are listed by Proposition 65 as "known to cause reproductive toxicity" and cholinesterase inhibitors remained largely unchanged, although the use of pesticides associated with reproductive toxicity varied, and in some years was almost double the use in 1991.

Environmental Health Hazards

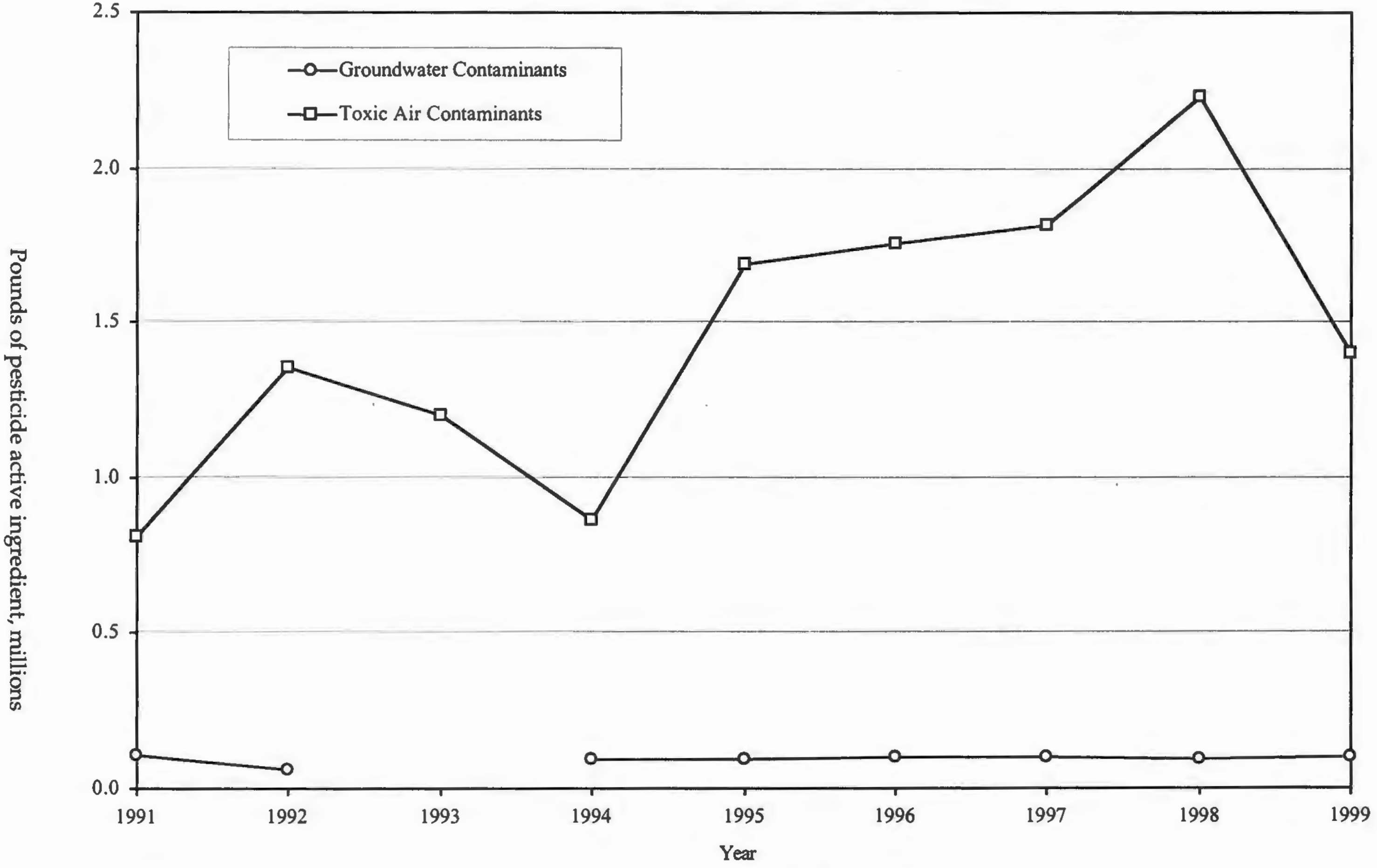
By 1995 the use of toxic air contaminants was double the use in 1991, while use of groundwater contaminants was largely unchanged amid annual fluctuation. Figure 8.11 shows annual pounds applied for pesticides in these categories. The main toxic air contaminants are methyl bromide, captan, maneb, and 1,3 dichloropropene. Methyl bromide accounted for the majority of pounds of toxic air contaminant applied in the early 1990s. As the use of methyl bromide on almonds decreased during the decade, use of the other three main contaminants increased. A contributor to the growth in the use of toxic air contaminants is likely to have been the use of fumigants in establishing new orchards during this time. Two selective herbicides, norflurazon and simazine, account for virtually all of the pounds of groundwater protection list pesticides used on almonds. These herbicides were used in similar quantities throughout the 1990s.

Epstein et al. (2000) analyzed PUR data from 1992 to 1998 and argued that the use of organophosphates had indeed declined. They estimated that the proportion of the total area of almonds treated using organophosphates as a dormant spray had declined from over 40 percent in 1992 to less than 20 percent in 1998. At the same time the proportion treated with pyrethroids rose to about 20 percent.



Source: Compiled by the authors from California Department of Pesticide Regulation, PUR database, 2001.

Fig. 8.10 Pesticide use on California almonds: human health, 1991–1999



Source: Compiled by the authors from California Department of Pesticide Regulation, PUR database, 2001.

Fig. 8.11 Pesticide use on California almonds: the environment, 1991–1999

These results are surprising from two perspectives. First, they suggest that less than one-half of the industry used organophosphates as a dormant spray in the early 90s, despite it being part of the IPM package for almonds. Second, it is not that clear why producers reduced their use of organophosphates to such an extent. Epstein et al. (2000) noted that some pyrethroids were less expensive than organophosphates, and this may have been an important factor. Another recommended alternative, the use of Bt sprays, was more expensive than either continuing with organophosphates or shifting to pyrethroids. The California Department of Pesticide Regulation and the Region 5 Water Quality Control Board were urging, but not compelling, growers to use fewer organophosphates during this time.

Less-Toxic Chemicals

Among the categories of pesticides tracked by Department of Pesticide Regulation, by far the largest percentage increases in use during the past decade were in biopesticides and reduced-risk pesticides. The Department of Pesticide Regulation data indicate that these pesticides emerged during the 1990s. Use of biopesticides increased from almost nothing in 1991 to more than 12,000 pounds in 1999. Almost all of the biopesticides used on almonds were various strains of bacillus thuringiensis, often used to control peach twig borer (Wilhoit et al, 1998). Reduced-risk pesticides have been applied to almonds only since 1997, but their use increased from 950 pounds in 1997 to about 25,000 pounds in 1999. However, to put the increases in use of biological and reduced-risk pesticides in perspective, total pounds of these pesticides applied in 1999 represented about two-tenths of one percent of total pesticide use in almonds.

8.6 Elements of Industry Benefits from UC Pest Management Research and Extension in Almonds

The UC system has made a steady stream of research and extension investments into pest management in almonds since 1950. We assumed that the broad objectives of these research and extension activities were to generate new information about the biology of pests and their interactions with predators and cultural and chemical control measures that would allow growers to make more profitable pest management decisions and also provide the community with better information on which to base responses to the externalities associated with pest management.

The challenge is to identify and value this new information. Clearly, many projects have contributed to this knowledge base since 1950. It is not feasible to evaluate these individually.

Some new knowledge may be of lasting value (e.g., knowledge about the life-cycles of pests) while some other knowledge (e.g., knowledge about response to a particular pesticide) might be of value only for a few seasons. This arises because of unanticipated impacts on other pests and predators and changing resistance on the part of the target pest and also from the loss of pesticides through regulatory action. It would seem that there is a high proportion of maintenance research associated with the use of pesticides to manage pests.

At the farm level, the information is valuable if it allows farmers to manage pests more profitably. The outcome is some combination of reduced costs of pest management and lower losses in terms of yield or product quality, but where on this spectrum is most profitable depends on the nature of the technology and the pests and whether the farmer was managing pests efficiently beforehand.

Hence, the approach adopted here was to identify trends in pesticide use and yields that could be attributable to better pest management. In the case of almonds, we have attempted to identify any savings in the cost of pesticide use over time and changes in the losses associated with insect damage to almonds.

The UC system has contributed significantly to efficiency gains in the management of arthropods in almonds. A greater understanding of the biology of insects and greater use of insect monitoring techniques has led to marked changes in how insect pests are managed in the almond industry. An ongoing program of research and extension has made possible a steady improvement in the quality of almonds despite a continuing need to adapt the pest management program as pests respond to the control environment. The management of diseases has continued to rely on the preventative application of fungicides, and it would seem that weed management in almonds has evolved in a fashion similar to weed management in other agricultural industries.

8.7 The Value of Reduced Nut Damage

Navel orangeworm, in particular, causes significant damage to almond kernels. Kernel damage by navel orangeworm is also a concern because it is associated with the fungus responsible for aflatoxins. One measure of this damage is provided by the percentage of the crop rejected by processors (Figure 8.12).[3] Data are available from the California Almond Board from 1974. In 1974, about 4 percent of the crop was rejected as being inedible, but this rose to 6 percent in 1976 and 1977 and then to almost 9 percent in 1978 before falling to around 4 to 5 percent until the mid-1980s. Since then the percentage rejected has steadily declined to about 1 percent in 2000.

Little information is available about kernel damage prior to 1974. Bailey's (1948) estimate that 1.35 to 35 percent of the crop was damaged by peach twig borer in each of the six years prior to 1943 has been noted. Hence it

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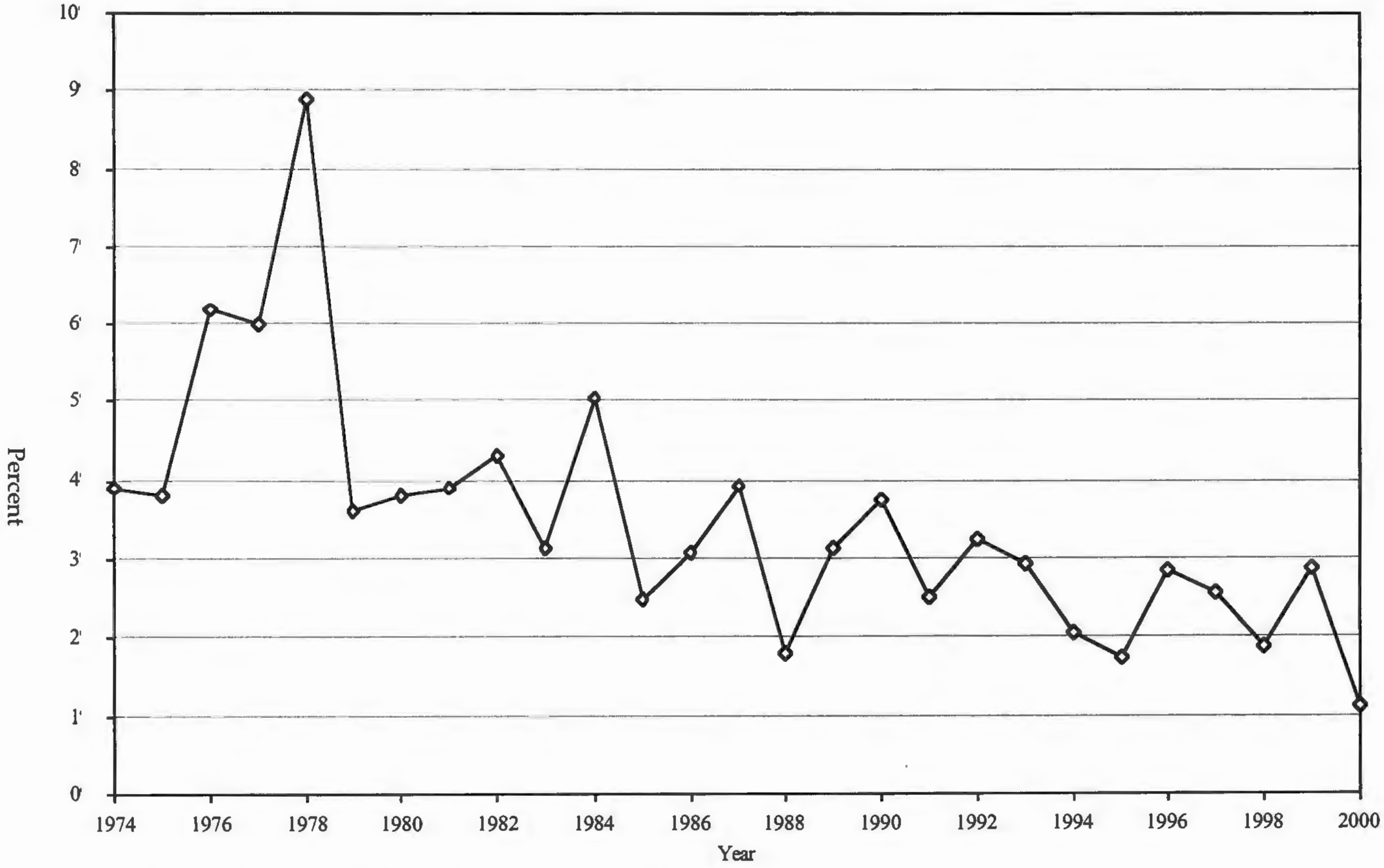
[3] This measure ignores damaged nuts left in orchards but includes damage from sources other than pests. On balance it is regarded as a reasonable estimate of the damage to kernels by pests.



Source: Compiled by the authors from Almond Board of California data.

Fig. 8.12 Inedible share of California almond crop, 1974–2000

seems reasonable to assume that kernel damage prior to 1974 was no lower than since 1974.

An important objective of pest management in almonds has been to reduce kernel damage. In their evaluation of IPM in almonds, Zalom et al. (1987) and Klonsky et al. (1990) identified reduced nut damage as a significant benefit of the IPM program. Using the Almond Board data in Figure 8.12, they estimated that the proportion of crop damage averaged 5 percent from 1974 to 1977. The proportion of the crop damaged was abnormally high in 1978, a poor crop year.

Research and extension associated with the IPM program increased in intensity in the early 1980s. The proportion of the crop damaged averaged 3.7 percent from 1980 to 1984, according to Zalom et al. (1987). Hence they attributed a reduction in crop damage of 1.3 percent to the almond IPM program. Klonsky et al. (1990) used a reduced damage estimate of 1.8 percent, presumably because they found that the crop rejection rate averaged 3.2 percent over the longer period from 1980 to 1988. Note that these rejection rates are average changes through time over the whole crop and not a comparison of crop damage suffered by those who adopted the IPM program and those who did not.

Klonsky et al. (1990) valued this reduction in crop damage by applying an average price for almonds of $1.07 per pound over the 1982–88 period (compared with $1 per pound from 1982 to 1984) to an average almond production of 449 million kernel pounds over this same period (compared with 380 million pounds per year from 1982 to 1984). The estimated value of the reduction in crop loss was $8.7 million per year (Klonsky et al. 1990) or $4.94 million per year (Zalom et al. 1987).

Almond growers receive price premiums or discounts based on the quality of the almonds they deliver. Discounts apply when the rejection rate is above 4 percent and premiums apply when it is below 3 percent. Zalom et al. (1987) also recognized as a benefit the savings in discounts of $3.33 million from a rejection rate of 3.7 percent rather than 5 percent. Klonsky et al. (1990) did not recognize this benefit, and neither have we.

The approach taken here has been to regard the rejection rate since 1980 as the "with" new technology scenario and to follow Zalom et al. (1987) in assuming that the rejection rate "without" the better pest management practices recommended by the IPM program would have continued at 5 percent. Hence the benefit of reduced almond damage has been estimated as the difference between the annual rejection rate and 5 percent valued at the real price of almonds in each year since 1980.

This approach underestimates the benefits of research and extension associated with the IPM program to the extent that the rejection rate was higher than 5 percent in years prior to 1974. It overestimates the benefits by assuming that without the program the rejection rate would not have fallen below 5 percent, implying that farmers would not have discovered these practices in some other way. Some support for this assumption can be found in the fact that after azinphosmethyl and carbaryl became available for the control of navel orangeworm, the rejection rate actually increased with pesticide use because the IPM package was not yet in place.

The implicit assumption of the approach used here is that without the ongoing stream of research and extension activities undertaken by the UC system, the rejection rate would have exceeded 5 percent in many years, as periodically growers had to change their pest management strategies in a dynamic world in which existing strategies quickly become obsolete. This obsolescence arises from the emergence of new pests, resistance, and changes in strategies required either by regulation or by pest issues elsewhere on the farm or neighborhood. A large component of research and extension resources is used to maintain existing levels of pest protection.

Ignoring for the moment price differentials, we have followed Zalom et al. (1987) in recognizing the reduced rejection rate since 1980. The stream of benefits from lowering the rejection rate below 5 percent since 1980 is presented in Table 8.3. In calculating this stream of benefits, the actual reduction in the rejection rate in each year was applied to the real value of almond production in each of those years (that is, 5 percent minus the observed rate of nut damage).

One of the difficulties of this approach is that the rejection rate is also a function of weather and crop size. Rejection rates are likely to be higher in low crop years unless the pest population is also lower in these years. Our approach assumes that these "weather" incidents even out, but it has meant that in 1984 benefits were negative because the rejection rate was higher than 5 percent. An alternative approach would be to fit a trend line to the rejection rate data and assume no benefits to the program in early years when the rejection rate was above 5 percent.

The real benefits of the reduction in the rejection rate grew from around $10.5 million in 1980 to $28.8 million in 1997 before falling to $14.8 million in 1999 (Table 8.3). The compound value of this stream of benefits in 1999 was $375 million (year-2000 dollars).

8.8 Changes in the On-Farm Costs of Pesticide Use

The other major potential benefit of the IPM program is a reduction in pesticide use, which is valued as a cost saving to growers. Studies by Headley and Hoy (1987), Zalom et al. (1987) and Klonsky et al. (1990) all identified reduced pest management costs as a benefit from IPM. The analysis was based on a survey of 236 growers in the Sacramento and northern and southern San Joaquin valleys.

Headley and Hoy (1987) evaluated a research and extension program to manage mites in almonds, which involved a reduction in the rate and number of acaricides but increased costs in the form of monitoring and the release of beneficial predators. They assumed that the rejection rate remained

Table 8.3 The benefits of UC pest management technologies in almonds

Year	Nut damage (%)	Damage saved (%)	Real value nuts saved	Real savings pesticides	Real savings Propagite
				(year-2000 dollars, thousands)	
1980	3.8	1.2	10,558	1,348	4,728
1981	3.9	1.1	5,649	1,286	9,532
1982	4.3	0.7	3,415	1,314	14,644
1983	3.1	1.9	6,733	1,397	18,381
1984	5.1	-0.1	-401	1,483	19,620
1985	2.5	2.5	13,239	1,603	21,620
1986	3.1	1.9	12,516	1,654	22,094
1987	3.9	1.1	9,557	1,667	21,989
1988	1.8	3.2	25,517	1,676	21,871
1989	3.2	1.9	11,424	1,636	21,960
1990	3.8	1.3	9,238	1,625	
1991	2.5	2.5	16,685	1,495	
1992	3.3	1.7	14,004	1,587	
1993	3.0	2.1	21,689	1,600	
1994	2.1	2.9	31,604	1,902	
1995	1.8	3.2	31,012	1,868	
1996	2.9	2.1	23,193	1,875	
1997	2.6	2.4	28,837	1,853	
1998	1.9	3.1	22,666	2,137	
1999	2.9	2.1	14,810	2,253	
Total value compounded forward to 1999			375,036	41,400	240,961

Source: Compiled by the authors from Almond Board of California data.

constant. They estimated that growers who adopted the program would receive benefits ranging from $24 per acre to $44 per acre and that the project earned a return over five years of between 280 and 370 percent, depending on the extent of adoption. With applications of propargite (omite) at only 10 percent of label rates, they found growers could halve the cost of control and still control spider mites. An added advantage was that the damage to natural enemies was much lower.

Focusing on the control of navel orangeworm, Zalom et al. (1987) and Klonsky et al. (1990) tracked changes in almond acreage treated with pesticides and in total pounds of pesticides used per 1,000 bearing acres of almonds. Using data from CDFA's Pesticide Use Report, they tracked the use of azinphosmethyl, carbaryl, diazinon, imidan and permethrin. They concentrated on the period 1974 to 1988 and noted an increase in both the area of almonds treated and the amount of insecticide used up to about 1981 and then a decrease in both to 1988. Over the period 1971 to 1974, about 21 percent of total bearing acreage was treated with these insecticides. In 1976 azinphosmethyl and carbaryl were registered for the control of navel orangeworm. The proportion of almond acreage treated with these insecticides peaked at 92 percent in 1981 and averaged 77 percent for the years 1979 to 1981. At about this time, the IPM program became very active. According to Zalom et al. (1987), the share of bearing acres treated averaged 53 percent from 1982 to 1984, a reduction of 24 percentage points compared with the average over 1979 to 1981. Note that Zalom et al. (1987) also presented data on the basis of pounds of insecticide per 1,000 bearing acres.

In valuing the savings in navel orangeworm pesticides attributable to the IPM program, Zalom et al. (1987) assumed that growers using pesticide to control navel orangeworm would continue to apply 1.43 sprays per acre, the average number of sprays used by the survey respondents. They noted that the total bearing acreage averaged 357,000 acres from 1982 to 1984 and assumed the cost of a spray averaged $32 per acre. Applying the 24 percent reduction in the acreage to which pesticides were applied to 357,000 acres and assuming an average number of sprays of 1.43 at $32 each gave an estimate of the annual value of pesticides saved of $3.5 million in Zalom et al. (1987). Using a similar approach Klonsky et al. (1990) valued the annual pesticide savings as $4.1 million.

Presumably the reduction in pesticide use was made possible by some other form of control, whether by the removal of mummies, monitoring of the pests for more timely spraying, early harvesting, or some combination of these three. These strategies have costs that were not estimated in either report. Zalom et al. (1987) noted that the cost of winter sanitation was equivalent to the cost of an insecticide application. There was also no attempt to evaluate how the management of other pests such as mites, disease and weeds changed at this time, either in response to elements of the IPM program or in response to the changes in the management of navel orangeworm.

We followed two approaches in trying to determine whether and for how long savings in pesticides persisted. One approach involved an examination of the CDFA-DPR dataset on pesticide use. The second approach examined through time enterprise budgets for almonds prepared by UC Cooperative Extension to identify trends in pest management costs.

The CDFA/DPR Dataset

The change from partial to full agricultural-use pesticide reporting in California in 1990 made it very difficult to judge the duration of the savings in pesticide use identified by Zalom et al. (1987). Azinphosmethyl has always been a restricted-use material, and hence reporting of its use has always been required. It was the predominant chemical used in the control of navel orangeworm. Tracking its use lends some support to the view that the IPM program has resulted in pesticide savings. By the early 1980s its use had risen to about one pound per acre (use averaged over harvested acres), and since that time the application rate has generally fallen. The organophosphate, parathion was an important chemical for dormant-season spraying until it was deregistered in the mid-1990s. However, it was not a restricted-use material for all this time, and hence trends in its reported use need to be interpreted more cautiously. Its use generally increased (to about one pound per acre) until 1991, but the use of organophosphates for dormant spraying was a component of the IPM package at that time.

Pest Management Costs in Mature Almond Orchards

Some appreciation of the relative importance of pest management and changing technologies in pest management can be gained from a review of a sample of enterprise budgets for almonds since 1953. Recent practice is to represent, in the budgets, procedures and materials typical of a well-managed orchard in the region under consideration, but the danger is that actual practice on many orchards may be different. The budget publications warn that there will be considerable variation in practice by growers from the enterprise defined in the budget.

The University of California Cooperative Extension (1998) estimated that the cost of cultural practices and harvesting almonds in an established orchard in the northern part of the San Joaquin Valley using micro-sprinkler irrigation was $1,491 per acre. Important pest control components of this total cost included:

• Weed control using herbicides	$87 per acre
• Mowing	$51 per acre
• Winter sanitation program to remove mummy nuts	$117 per acre
• Insect control in the dormant period	$66 per acre
• Other insect control measures during the growing season	$148 per acre
• Gopher and squirrel control	$41 per acre
• Disease control measures – fungicides	$73 per acre

From this review it would seem that pest management costs for almond growers have increased in real terms and as a share of operating costs. Increased use of chemicals, especially since 1953, appears to be the main reason for the upward trend in pest management costs. Mummy sanitation, a significant cost in recent budgets, was first reported as a cost in the 1980s. Herbicides were not listed in the budgets until the 1960s, but appear to have largely replaced mechanical cultural techniques as the primary means of weed control during the 1970s.

Since 1995 pest management costs have accounted for between 17 percent and 30 percent of total costs (including cash and noncash overhead costs) for conventional almond growers. Insect, nematode and rodent control generally have accounted for at least one-half of total pest management expenses. Weed control and mummy sanitation each accounted for about one-quarter of expenses, and some operators spend an additional small amount on pest consultants and leaf monitoring.

In reviewing the enterprise budgets for almonds prepared by Cooperative Extension over many decades, we found little evidence that the almond

IPM program has resulted in savings in the costs of managing pests. In fact it would seem that the real costs of managing pests as a share of the total operating costs of growing almonds might have risen slightly. Any savings in pesticide costs might have been offset by other costs, including orchard sanitation and monitoring.

8.9 UC Expenditure on Research and Extension in the Almond Industry

Estimates of expenditures by the UC system on research and extension in pest management in almonds were presented in Chapter 3 (Tables 3.6–3.8). In 1997 expenditures were $2.2 million for pest management research and $1.1 million for extension. The compound value in the year 2000 of the stream of UC investments in pest management research and extension for almonds from 1970 to 1997 was $65.3 million.

8.10 Financial Analysis of Benefits and Costs

The standard techniques of financial analysis were used to value some of the costs and benefits from the UC pest management research and extension activities in the almond industry. Streams of benefits and costs were expressed in year-2000 dollars using a GDP deflator and were compounded forward to 2000 from their starting dates using a real interest rate of 2 percent.

The greater difficulty is in specifying scenarios "with" and "without" changes in pest management technology (Marshall and Brennan 2001). Our approach was to assume that the main benefit to almond growers from pest management research and development (R&D) came through a reduction in the rejection rate of almonds to below 5 percent, which is a conservative estimate of the extent of nut damage before the introduction of the IPM program early in the 1980s. The reduction in the rejection rate was 1.2 percent in 1980 and grew to 2.4 percent in 1997 (Table 8.3), and this reduction in the rejection rate was multiplied by the real value of production of almonds to estimate the benefits. The compound value of these benefits in 1999 was $375 million. The implicit assumption is that the lower rejection rate is largely due to better pest management rather than such factors as resistant varieties.

An important benefit was the potential halving in the cost of Omite applications, shown by Hoy's research. The technology was most valuable in the southern San Joaquin Valley where mite control was more of a problem. Therefore, for the counties from Stanislaus south, we have assumed that 70 percent of the growers were able to save five pounds per acre of propargite valued at a real price of $22 per pound. We also assumed that adoption began in 1980 at 20 percent and increased by 20 percent per year until a peak adoption rate of 70 percent was reached in 1983. The technology became obsolete by 1990, largely because of the introduction of new chemicals. Growers also may have discovered that they could use lower rates by this time. The real value of these savings over 10 years in 1999 was $241 million.

We found it difficult to establish from industry data a trend in pesticide use as a result of the IPM program and other research and extension. Our view of the research and extension efforts is that their focus was on more profitable pest management strategies by almond growers. This does not necessarily imply that pest management costs decline. In fact there is evidence from the enterprise budgets and estimates of expenditure on pesticides that the real cost of pest management might have risen, offsetting to some degree the lower rejection rates. Savings in pesticide costs might have also been offset by the costs of monitoring pest populations and the use of nonchemical control mechanisms such as mummy removal and orchard hygiene. The technology has, however, allowed growers to time pesticide applications and choose control strategies that are likely to result in greater control of pest populations and a lower rate of nut damage.

Nevertheless, we followed Zalom et al. (1987) in recognizing some benefits from lower pest management costs. We assumed that since 1980 for one-quarter of the area planted, one less application of azinphosmethyl (at two pounds per acre active ingredient) was used. We valued this at the cost of the chemical (excluding application costs because we assumed that it would have been applied in conjunction with some other chemical). The real value in 1999 of this stream of cost savings was $41 million, about one-tenth of the value of the reduced rejection rate. Note that if these savings were doubled—either because growers were able to save two applications, or because half the growers were able to save one pesticide, or because there were savings in applications costs roughly equivalent to the cost of chemicals—there would be little impact on the benefit-cost ratios below.

Greater control of navel orangeworm has also meant a lower incidence of aflatoxins, for which market tolerances are becoming stricter. We have not valued this benefit.

A benefit of the research and extension effort that probably is not fully valued by our approach is the development of a greater knowledge base about the management of pests among almond growers and their advisers, although this knowledge base also has to be maintained as new people enter the industry.

The "without" new technology scenario has the following components:

- Growers would have been unable otherwise to reduce the rejection rate below five percent.
- The growth in yields and the size of the industry was not driven by improved pest management technology, but rather by the availability of water, improved pollination and by breeding programs.
- Weather influences, which led to the variation in production and rejection rates, are assumed to average out over our observation period.
- At present we have assumed that the lower rejection rate had no impact on prices.

The "without" new technology scenario is that without this knowledge of the biology of pests and their response to control mechanisms, growers' costs would be unchanged, and they would have experienced rejection rates of 5 percent as was the case prior to the introduction of the IPM program. Compounding forward the stream of research and extension costs at the rate of 2 percent implies that in the "without" scenario the opportunity cost of these funds is an investment earning a real rate of return of 2 percent per year.

A key assumption is that as pests respond to control strategies, pest management technologies have to evolve continually to maintain the low rates of nut damage. In this sense, much of the research and extension effort can be viewed as being of a maintenance nature. Were this effort to stop, rejection rates would again rise to 5 percent. Hence the research and extension effort may be viewed as a series of small projects, many of which only provide benefits for a short period either because the technology becomes obsolete or because growers "learn" the technology from other sources. Our aggregate approach is an attempt to capture the benefits of this series of short-run projects.

The estimated real value of the three sources of benefits identified above compounded forward to 1999 totals $657 million, which gives a benefit-cost ratio of 10.1:1.

Estimating the Benefits to California

To this point we have estimated the benefits to all producers, processors, and consumers of almonds grown in California. Some processors and consumers who enjoy these benefits are nonresidents of California and of the United States. Here we estimate the share of these benefits that are enjoyed by residents of California and the United States.

First, define the global gross annual research benefits (GGARB) as:

$GGARB = K(PQ)$

Where K is the proportional per-unit cost saving attributable to new pest management technology, P is the commodity price, and Q is the quantity produced in California. We have estimated that GGARB, in the form of reduced nut damage, savings in organophosphate pesticides and a short-term saving in miticide (Omite) which, compounded forward to 2000, meant a benefit of $657 million.

The proportional change in price associated with this technological change is $Z = \varepsilon/(\varepsilon+\eta)$, where ε is the elasticity of supply and η is the absolute value of the elasticity of demand. Then, GGARB can be partitioned into benefits to California producers, ΔPS (the change in producer surplus), and benefits to domestic and export consumers, ΔGCS (the change in global consumer surplus net of foreign producer losses), as follows:

$\Delta PS = (K-Z)(PQ)$

$\Delta GCS = Z(PQ)$

$GGARB = \Delta PS + \Delta GCS$

Of total California production of almonds, a fraction e is exported, and so a fraction e of the total consumer surplus accrues to "foreign" consumers (foreign could mean outside the United States, if we are measuring U.S. benefits, in which case e is about 0.7, or it could mean outside California, in which case e may be 0.9 or greater). Hence, the "domestic" gross annual research benefits, GARB, are given by the sum of domestic consumer benefits, ΔCS, and domestic producer benefits, ΔPS:

$$\Delta PS = (K-Z)(PQ)$$
$$\Delta CS = (1-e)Z(PQ)$$
$$\begin{aligned} GARB &= \Delta PS + \Delta CS \\ &= (K-eZ)(PQ) \\ &= K(PQ)(1 - e\,\varepsilon/(\varepsilon+\eta)) \\ &= GGARB\,(1 - e\,\varepsilon/(\varepsilon+\eta)) \end{aligned}$$

For instance, assuming 90 percent of production is shipped to other states or internationally, and that supply and demand elasticities are one (i.e., $e = 0.9$, and $\varepsilon = \eta = 1$), then California receives only 55 percent of the total global benefits—i.e., given global benefits of $657, some $362 million accrue to California. The ratio of benefits received in California to investments made by California is 5.5:1.

Community Benefits

We also tried to identify the benefits to the community from research and extension into pest management in the almond industry. Our approach was to track the use of classes of pesticides of significance as potential risks to either human health or to the environment.

Since 1991 there has been little change in use of most classes of pesticides in the human health and environmental risk classes. The exception is that the use of chemicals known to be carcinogens and toxic air contaminants has risen. Hence, while many categories of pesticide are being used at the same rate, two key groups are being used at a higher rate, and the community is bearing an additional cost as a result. This change has largely been driven by the increase in the size of the industry, and some consideration also needs to be given to the amount and type of pesticides that would have been used otherwise on the same land. We have not attempted to put a value on the additional cost being borne by the community.

CHAPTER 9

An Evaluation of Pest Management R&D in Cotton

9.1 The Cotton Industry in California

Cotton production has a long history in California (Bassett and Kerby, 1996a). Among California's agricultural commodities, cotton ranked 11th in cash receipts in 1999, with a value of $1 billion. While cotton is grown in the Imperial Valley, the San Joaquin Valley is by far the largest production area in the state, particularly Fresno, Kern, Kings, Merced, Tulare and Madera counties. Pima cotton, grown in California since the late 1980s, accounted for 20 percent of the cotton grown in 1999. Our analysis and the production statistics are based on upland cotton.

Since the 1950s, California upland cotton has gone through three distinct periods. The first period was from 1950 to the late 1960s. Cotton yield trended up, but harvested acreage and real price (year-2000 dollars) trended down. The second period was from 1970 to 1979. Cotton yield was rarely above 1,000 pounds per acre; however, real price and harvested acreage increased dramatically during this period. During the third period, 1980 to 2000, cotton yield increased but real price and harvested acreage decreased. Data on important industry parameters are presented in Table 9.1 and Figures 9.1 through 9.5.

Harvested Acreage

From 1952 to 1968, the amount of California upland cotton harvested fell significantly, from a high of 1.4 million acres to a low of 0.7 million acres. During the next 11 years, cotton acreage increased dramatically, more than doubling to over 1.6 million acres in 1979, after which it trended downward to a low of about 0.6 million acres in 1998 and 1999 before increasing to 0.8 million acres in 2000.

Yield, Production, Value, and Price

Cotton yields doubled over the last 50 years, increasing from about 650 pounds per acre in the early 1950s to 1,370 pounds per acre in 2000. Yields increased dramatically during the late 1950s to a plateau of about 1,100 pounds per acre from 1960 to the late 1980s before increasing again to yields of up to 1,300 pounds per acre in the 1990s. There were several poor crop years in the 1960s and 1970s.

Cotton production did not change much from 1950 to 1970, staying at an average of around 1.7 million bales. From 1970, cotton production increased significantly, reaching a high of more than 3.5 million bales in 1981, and then decreased to about 2.2 million bales after particularly poor years in 1998 and 1999.

Source: Compiled by the authors.

Fig. 9.1 California upland cotton harvested acreage, 1950–2000

Table 9.1 California upland cotton production, 1950–2000

Year	Harvested acres	Yield	Production	Price	Value of production	Real price	Value of production
				(nominal dollars)		(year-2000 dollars)	
	(thousands)	(lbs/acre)	(480-lb bales, thousands)	(dollars/bale)	(millions)	(dollars/bale)	(millions)
1950	581	805	978	206.19	201.7	1,263.45	1,235.7
1951	1,305	648	1,765	196.23	346.3	1,121.75	1,979.9
1952	1,386	628	1,818	161.08	292.8	906.43	1,647.9
1953	1,340	632	1,768	155.82	275.5	865.66	1,530.5
1954	883	806	1,487	166.56	247.7	916.17	1,362.3
1955	745	774	1,205	165.41	199.3	894.33	1,077.7
1956	749	924	1,446	163.23	236.0	853.16	1,233.7
1957	711	1,035	1,537	168.12	258.4	850.65	1,307.5
1958	732	1,049	1,604	170.32	273.2	841.76	1,350.2
1959	875	1,055	1,929	160.82	310.2	785.91	1,516.0
1960	946	981	1,939	154.43	299.4	744.10	1,442.8
1961	816	990	1,689	168.44	284.5	802.64	1,355.7
1962	809	1,132	1,912	164.69	314.9	774.31	1,480.5
1963	730	1,124	1,714	168.89	289.5	785.28	1,346.0
1964	743	1,133	1,760	167.28	294.4	766.31	1,348.7
1965	725	1,116	1,690	151.50	256.0	681.28	1,151.4
1966	618	952	1,228	134.79	165.5	589.35	723.7
1967	588	847	1,038	160.34	166.4	680.00	705.8
1968	687	1,097	1,569	119.08	186.8	484.18	759.7
1969	701	899	1,312	116.44	152.8	451.30	592.1
1970	662	841	1,160	121.65	141.1	447.63	519.2
1971	741	723	1,117	151.40	169.1	530.40	592.5
1972	863	982	1,765	149.73	264.3	503.16	888.1
1973	942	891	1,749	237.56	415.5	755.94	1,322.1
1974	1,238	1,006	2,595	227.51	590.4	664.30	1,723.9
1975	875	1,072	1,954	261.60	511.2	698.66	1,365.2
1976	1,120	1,064	2,482	325.92	808.9	823.82	2,044.7
1977	1,390	964	2,790	268.80	750.0	638.35	1,781.0
1978	1,455	640	1,940	305.28	592.2	676.83	1,313.1
1979	1,635	1,000	3,408	348.00	1,186.0	712.19	2,427.1
1980	1,540	969	3,109	373.44	1,161.0	699.99	2,176.3
1981	1,530	1,109	3,535	305.28	1,079.2	523.40	1,850.2
1982	1,370	1,077	3,073	321.12	986.8	518.24	1,592.6

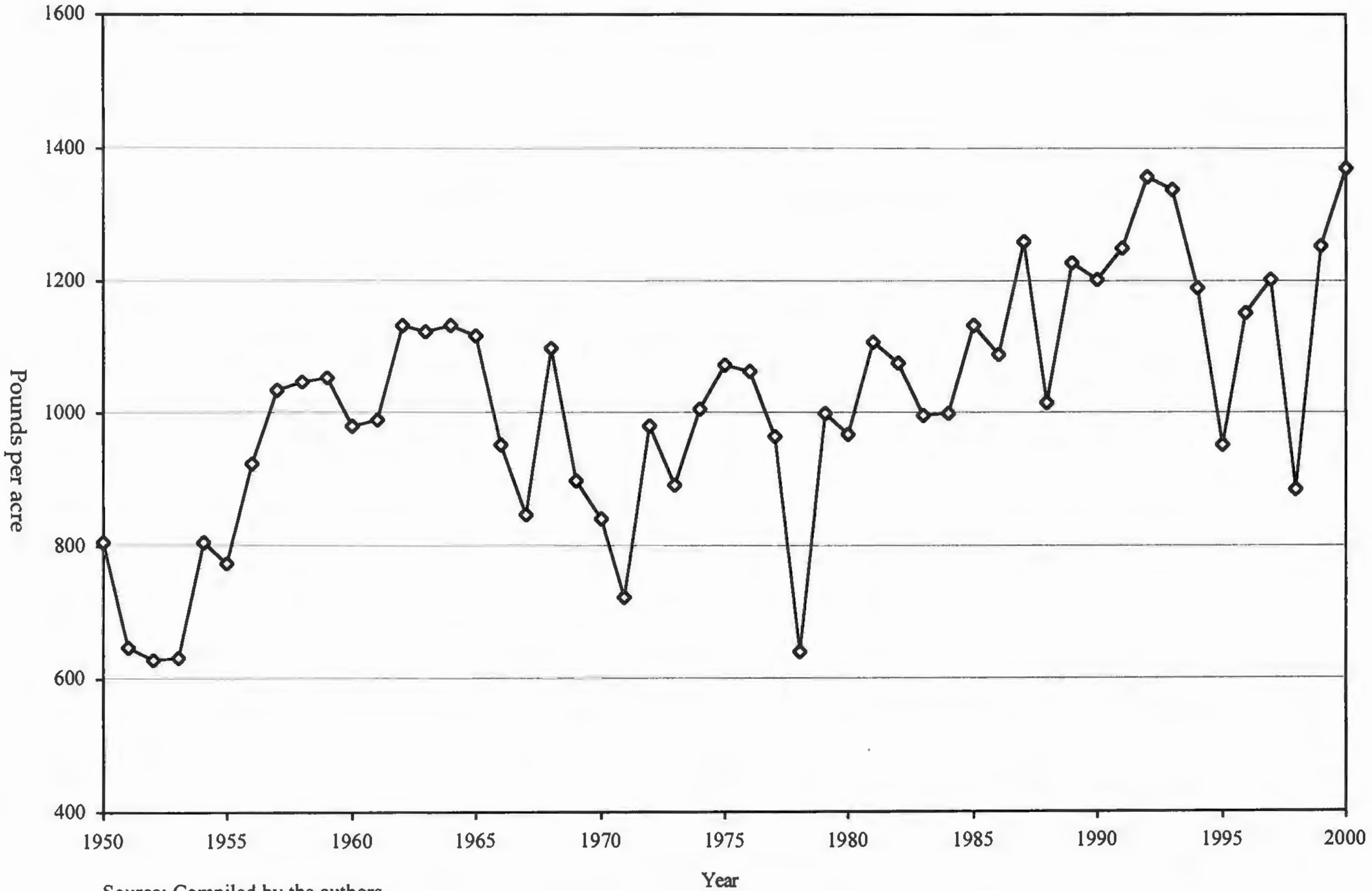
(continued)

Table 9.1 Continued

Year	Harvested acres	Yield	Production	Price	Value of production	Real price	Value of production
				(nominal dollars)		(year-2000 dollars)	
	(thousands)	(lbs/acre)	(480-lb bales, thousands)	(dollars/bale)	(millions)	(dollars/bale)	(millions)
1983	950	996	1,971	349.44	688.7	542.48	1,069.2
1984	1,400	999	2,913	320.64	934.0	479.92	1,398.0
1985	1,320	1,132	3,114	296.64	923.7	430.41	1,340.3
1986	990	1,088	2,245	283.68	636.9	402.74	904.1
1987	1,140	1,259	2,989	330.73	988.6	455.85	1,362.5
1988	1,335	1,015	2,824	310.56	877.0	413.97	1,169.1
1989	1,040	1,228	2,661	344.64	917.1	442.53	1,177.6
1990	1,090	1,204	2,734	369.12	1,009.2	456.20	1,247.3
1991	977	1,252	2,548	319.68	814.5	381.22	971.4
1992	995	1,359	2,817	290.88	819.4	338.64	953.9
1993	1,045	1,340	2,918	315.36	920.2	358.53	1,046.2
1994	1,095	1,191	2,717	385.44	1,047.2	429.27	1,166.3
1995	1,165	953	2,312	394.08	911.1	429.52	993.1
1996	995	1,153	2,390	367.20	877.6	392.62	938.4
1997	875	1,202	2,191	351.36	769.8	368.51	807.4
1998	620	887	1,146	325.44	373.0	337.11	386.3
1999	605	1,254	1,580	269.76	426.2	275.30	435.0
2000*	770	1,371	2,200	333.12	732.9	333.12	732.9

Source: Compiled by the authors from the California Agricultural Statistics Service, *Field Crop Report*, 1950-1992; USDA, National Agricultural Statistics Service, *Crop Production*, 1993-2000; and *Crop Values*, 1993-2000.

*Preliminary



Source: Compiled by the authors.

Fig. 9.2 California upland cotton yield, 1950–2000

Source: Compiled by the authors.

Fig. 9.3 California upland cotton production, 1950–2000

Source: Compiled by the authors.

Fig. 9.4 California upland cotton price, 1950–2000

Source: Compiled by the authors.

Fig. 9.5 California upland cotton value of production, 1950–2000

Cotton prices in nominal terms fell from $206 per bale in 1950 to $116 per bale in 1969 before increasing to $326 per bale in 1976. Nominal prices fluctuated around $320 per bale until 2000, with price spikes in 1980, 1990, and 1995. In real terms (year-2000 dollars), cotton prices fell from about $1,260 per bale in 1950 to about $450 per bale in 1970. Although real prices rose from 1970 to 1980, reaching a high of $824 per bale in 1976, real prices have been falling ever since. In 2000 cotton was about $333 per bale.

The statewide value of cotton production in nominal terms fluctuated between $350 million and $140 million from 1950 to 1970. During the 1970s, the value of cotton production trended up, reaching a high of about $1,200 million in 1979. Excluding 1998 and 1999, the value of cotton production has averaged around $900 million per year since 1980. In real terms (year-2000 dollars), the value of cotton production fell from $2 billion in 1951 to a low of around $520 million in 1970. From 1970 to 1980, the value of cotton production increased almost fourfold to $2.2 billion. Since 1979, however, the value of cotton production again decreased, reaching a low of $390 million in 1998 before recovering to $730 million in 2000.

9.2 Significant Pests in the Cotton Industry

Diseases and Nematodes

Verticillium wilt is a vascular disease caused by a soil-borne fungus. There are many strains, which vary in virulence. It is present to some degree in most fields. Hurd (1992) quoted estimates of reduced lint yields from this disease ranging from 2.5 to 7.6 percent. According to Bassett and Kerby (1996b, p. 125), "The combination of soils and climate in the San Joaquin Valley is evidently much more favorable for the development of the organism than anywhere else in the Cotton Belt, with the possible exception of New Mexico." While the organism is widespread, its virulence and eventual impact on yield in any year are uncertain. One of the difficult choices growers have faced is between varieties that are high yielding in the absence of strong wilt pressure but are not tolerant of wilt and those that are more tolerant of wilt but lower yielding when wilt is not such a problem. In recent years, more varieties have a higher tolerance of wilt, and there is now a soil test for the presence of the fungus (Bassett and Kerby, 1996b, p. 128).

An important reason for the decline in cotton production from the 1950s through 1970 was related to the impact of verticillium wilt on yields. In 1967 the San Joaquin lines with a broader genetic base began to be released. While they were higher yielding and good quality, they did little to overcome the verticillium wilt problem. The USDA released varieties with better wilt tolerance in 1974. These new varieties, SJ4 and SJ5, were partly based on genetic material from New Mexico. Bassett and Kerby (1996a, p.115) observed that "California has unquestionably received far greater benefits than has the state of New Mexico itself" from the New Mexico breeding programs. The USDA had sole responsibility for cotton breeding in the San Joaquin Valley until it abandoned this role in 1978. Further improvements in wilt tolerance came from varieties released by private breeders. While the San Joaquin Valley is no longer a "one-variety district," new varieties are still scrutinized by the San Joaquin Valley Quality Cotton Growers Association, the successor to the Acala Cotton Board.

The introduction of varieties with wilt tolerance is probably one of the factors explaining the growth of the industry from the late 1970s, but there have been criticisms that the USDA breeding program based at the Shafter Experiment Station in Kern County developed varieties more suited to the western side of the valley.[1]

Fusarium wilt, another important cotton disease, is controlled by managing nematodes that increase cotton's susceptibility to wilt. Aldicarb and metam sodium are used for nematode control, although metam sodium is relatively ineffective (Wilhoit et al., 1999). Fungicides are also used routinely to protect cotton from a number of soil-borne fungi to which young slow-growing seedlings are susceptible, particularly when the early growing season is cool and wet.

Lygus Bug and other Insects

Insect and mite pests of cotton are reviewed in a number of sources. Leigh and Goodell (1996) noted that about 30 insects and spider mites attacked western cotton but less than a dozen required regular control. Hurd (1992) reviewed economic pests of cotton and their management. Goodell et al. (1997) pointed out that in California growers have to manage a range of pests rather than a dominant pest, and the incidence of each pest varies among seasons in response to both climate and pest management strategies.

The Lygus *hesperus* (Knight) bug is a highly mobile insect that damages cotton by feeding on squares (fruiting structures) and terminal buds. Control measures are indicated if monitoring over several days in the six-week period from the start of squaring identifies a population level sufficient to exceed an economic threshold. According to Hurd (1992), some entomologists have suggested that the yield losses caused by lygus are sometimes small relative to the problems of secondary pest outbreaks and lygus resurgence arising from insecticide control of lygus.

Lygus can be controlled by a range of chemicals, but resistance has developed to some of these, and problems can arise from the destruction of natural predators with some of the broad-spectrum chemicals. Some control of lygus can be achieved with natural predators and trap crops such as alfalfa, but there are serious economic limitations to this control method.

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[1] Constantine, Alston and Smith (1994) analyze the impacts of the one-variety cotton law.

Spider mites damage leaves, reducing photosynthesis and the supply of energy to developing cotton bolls. The usual economic threshold is for one-half of the leaves sampled at any time between plant emergence and late July to be infested with mites. Some argue that the threshold should be 80 percent (Hurd, 1992), but growers often lower the threshold to 20 percent. Although there are natural predators for mites, generally one or two chemical treatments are used. Resistance has developed to some chemicals.

Wilhoit et al. (1999) reported that cotton aphid became a serious pest during the 1990s. It reduces yields and quality.

The Pink Bollworm

The pink bollworm has been a significant pest a number of times in the history of the cotton industry. It reemerged as a problem in Arizona and California in the mid-1960s and was largely responsible for the contraction of the industry in the Imperial Valley (Bassett and Kerby, 1996a). In 1967 growers in California accepted a compulsory Eradication and Suppression Program, which levies a tax of $2 per bale (Hurd 1992) to support intensive mapping and monitoring for early detection of the pest, the rearing and release of sterile male moths (and hence interference with reproduction), pheromone treatments and, if necessary, pesticide applications. The program also requires growers to plow down crop stubble to provide a 90-day, host-free period. The program, administered by CDFA and USDA-APHIS, has been quite successful. Each year pink bollworms (fly-ins and natives) have been trapped in the San Joaquin Valley, but serious outbreaks have been prevented, with 1990 being the last time either pheromone treatments to confuse mating or pesticides were used. Reestablishment of the bollworm in the San Joaquin Valley would require 6.13 million pounds of pesticides annually[2] at a cost of $90 to $100 per acre, to control the bollworm and related secondary pests. The 2000-01 statewide program cost about $6 million. Slightly less than $0.5 million came from the USDA for the production of sterile males, and $5.5 million came from grower assessments (Dechoretz 2002). Hurd (1992, p. 84) found that growers strongly supported the program. When van den Bosch (1978, p. 170) raised doubts as to whether pink bollworm had the capacity to develop to significantly injurious status in the San Joaquin Valley, the eradication campaign was costing $1.25 million per year.

Weeds

Weeds can be as economically significant as insects as pests of cotton. According to Hurd (1992), 10 weeds account for about 75 percent of the cotton losses caused by weeds, with morning glories, pigweed, Johnson

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[2] Based on October 2000 information obtained from California Pink Bollworm Program manager Jim Rudig (personal communication) and the program's website at www.cdfa.ca.gov/phpps/ipc/pinkbollworm/pbw_hp.htm.

grass, nutsedge and Bermuda grass being prominent.

Vargas et al. (1996) reviewed weed management in cotton, but there is not much weed management history in the literature. Clearly, the advent of cheap synthetic herbicides such as the dinitriles and trifluralin has had a major impact on the industry. Weed control is a major cost to the industry. In the 1950s and 1960s, prior to these chemicals, hand hoeing and weeder geese were important means of weed control. While weeds have not developed the resistance to pesticides that insects have, resistance is a potential problem that influences the use of pesticides in the industry. An important development has been the use of genetics to breed cotton varieties that are not susceptible to such herbicides as Roundup and Buctril. However, the routine use of Roundup allowed by "Roundup Ready" cotton varieties increases selection pressure and hence the likelihood of weed and grass species developing resistance.

Respondents to Hurd's (1992, p. 62) survey used an average of 1.3 herbicide and 3.2 cultivation treatments per year for an average annual cost in 1990 of $45 per acre for machinery, materials and labor.

9.3 Eras of Pest Management in Cotton

An historical perspective on insect management in cotton can be found in Leigh and Goodell (1996), Moore et al. (1996) and Bradley (1996). We applied the same three-era pest management classification system to cotton as we did to other crops, although the IPM era started earlier in cotton, an industry where much of the early IPM research began.

The Presynthetic Era through the Late 1940s

Before the introduction of DDT, Leigh and Goodell (1996) pointed out that lygus bugs, strawberry mite, cotton aphid, and bean thrips were the main pests of western cotton. The few pesticides available, including arsenate and sulfur compounds, were not broadly effective, and hence the emphasis was on cultural and biological practices, particularly the management of weeds and alfalfa. Some of these practices later became components of IPM packages, but important components were undeveloped at this stage. For example, Smith and Smith (1949) described groups of cotton growers in the late 1940s employing graduate entomologists over the summer to monitor such pests as alfalfa caterpillar, allowing more timely use of insecticides.

The Synthetic Pesticide Era from the 1950s to the Late 1970s

Once synthetic organic insecticides became available, they dominated pest control strategies. According to Bradley (1996), during the 1950s and 1960s many growers adopted "womb-to-tomb" or "wash-day" insecticide programs in which pesticides were applied on a schedule without regard to the pest population, and known ecological principles were largely ignored. Because the insecticides were relatively cheap, this was a profitable strategy for most of the industry. Moore et al. (1996, p.744) noted that by the mid-1960s, automatic treatment programs from planting until harvest were being advocated.

However, within a few years the weaknesses of this simple chemical control strategy began to appear in the form of secondary pest outbreaks and the development of resistance. The new insecticides were highly toxic to the predators of cotton pests, and hence spider mites and bollworm became significant pests of cotton. Falcon et al. (1968) wrote of insecticide resistance in cotton pests in the San Joaquin Valley, as did van den Bosch et al. (1971), some time after Roussell and Clower (1957) had found pesticide resistance in Louisiana cotton fields. More particularly, Leigh and Goodell (1996) noted that severe infestations of bollworm were associated with the use of insecticides to control lygus bugs and other pests. The initial response was to use more applications of mixtures of insecticides (Bradley 1996). This scenario is also described in Goodell et al. (1997).

Resistance has proven to be an even more enduring problem. Leigh and Goodell (1996, p. 262) noted that "most pests exhibit resistance to a majority of the available pesticides." Details of when resistance developed can be found in Bradley (1996), but generally as chemicals were released in the 1950s and 1960s, resistance followed a few years later. Moore et al. (1996) noted that in 1977 and 1978 there were serious yield losses, largely because of tobacco budworm developing resistance to methyl parathion. The pyrethroids introduced in 1978 now have a resistance problem. Because actions by individual growers that affect resistance have the characteristics of a public good (the consequences are not confined to individual growers), the widespread voluntary adoption of resistance management protocols is difficult to achieve.

The IPM Era from the 1970s

Extension material outlining an IPM program for cotton (Black 1976 and van den Bosch 1978) refers to economic thresholds for IPM in California cotton. An identifiable IPM package likely became available to cotton growers in the early 1970s, about 10 years before IPM was available to almond growers.

The "pesticide treadmill" in cotton described by van den Bosch was similar to the experience of pest management in other commodities and, in similar fashion, led to renewed interest in cultural and biological control mechanisms which formed the basis of IPM programs developed for the cotton industry in the 1970s. Bradley (1996) noted that a number of research findings during the late 1960s and early 1970s, including the ability to raise pests in laboratories and understanding diapause and the role of pheromones, were important steps in the development of IPM packages in the cotton industry in the 1970s.

An important component of IPM in cotton is the understanding that alfalfa is the preferred host for lygus and is also a reservoir for lygus predators (Leigh and Goodell, 1996, p. 268-269). Hence management of pests in alfalfa, especially where alfalfa is grown in close proximity to cotton, has important implications for pest management in cotton.

Cotton IPM programs have features similar to IPM programs for other commodities including:

- Twice weekly monitoring for lygus, mites, aphids and whitefly using defined protocols and threshold guidelines
- Plant monitoring for appropriate growth and development
- Integration of decisions about plant growth and insect control
- Preserving and fostering indigenous biological control agents by avoiding the use of broad-spectrum pesticides before July and the use of selective pesticides where possible
- Choosing pesticides consistent with resistance management practices.

An important development in 1996 was the availability of transgenic cotton varieties containing the *Bacillus thuringiensis* (Bt) gene, which provides protection against the major lepidopteran pests (Leigh and Goodell 1996, p. 271). Growers pay a premium for these varieties and agree to a management protocol designed to preserve resistance in the varieties. At present, Bt cotton is not widely used in California because bollworm is not a problem. However, the technology may become more valuable in California if protection against lygus can be incorporated. *Bacillus thuringiensis* has also been used as an insecticide for the control of a range of insects in cotton. A potential risk of the widespread use of Bt cotton and other transgenic varieties is that resistance to Bt will develop in various crop pests. This is a particular concern of organic farmers.

Leigh and Goodell (1996, p. 262) suggested that as a result of IPM, overall pesticide usage on cotton has declined "from as many as three to six applications per season to an average of a little more than one application." In their cotton enterprise budgets, Klonsky et al. (1996) allowed for only one miticide and one insecticide. Pesticides, including herbicides, accounted for about $100 of total operating costs of about $600 per acre.

Hurd (1992, p. 85) suggested that the average number of pesticide treatments had fallen from 10 to 12 per season in the 1970s to three to five treatments in 1990. While he did not provide evidence to support the estimate of the number of treatments in the 1970s, the average number of treatments for his surveyed fields in 1990 was 2.4, with a range from zero to eight. Survey fields received on average 1.3 treatments with herbicides (trifluraline), 0.05 with nematicides, 0.11 with fungicides and 2.2 with defoliants. This reduction in pesticide applications was largely the result of improved monitoring techniques and the development of threshold guidelines.

The program relied in part on organophosphates that worked well until the late 1980s when once again pesticide use increased. Goodell et al. (1997) suggested that growers switched from organophosphates to pyrethroids to treat lygus because of increasing resistance problems. However, the switch to pyrethroids seems to have resulted in severe aphid problems. They quoted studies suggesting that insecticide/miticide applications increased from 1.5 per season to as many as six, with consequent increases in costs. At a series of grower meetings in 1995 and following years, the IPM program was tailored to reflect current problems, and growers were asked to delay the use of broad-spectrum pesticides until later in the season. Pesticide use again declined.

By 1982, according to Baker (1988), the Imperial Valley Cotton Pest Abatement District reduced organophosphates and pyrethroids, considered to be broad-spectrum pesticides, by relying heavily on pheromone traps integrated with chlodimeform (since removed from the market). Other IPM techniques included late planting, early harvesting, plow-down of stubble, host-free periods, and staggered cuttings of adjacent alfalfa stands.

Fernandez-Cornejo and Jans (1999) concluded that cotton producers in general, and California growers in particular, had adopted IPM practices to a far higher degree than the producers of major field crops and selected fruit and vegetable crops. About 60 percent of the cotton growers in California and Arizona (the authors' western region) in 1996 compared pest-scouting data with recommended thresholds in determining whether to apply an insecticide (Fernandez-Cornejo and Jans 1999, p. 54). They based their study on a survey of pest management practices among a sample of growers who were part of either the Agricultural Resource Management Survey (ARMS) or the chemical use surveys conducted by the USDA.

Further information about the extent of IPM adoption by cotton growers in California can be found in Hurd (1992, p. 53), who randomly sampled field managers. Hurd estimated that IPM methods were applied at least partially on 70 percent of the fields surveyed. Further information about knowledge and use of particular IPM practices can be found in Hurd (1992). He observed that California used fewer insecticides and herbicides but more fungicides and growth regulators than other cotton growing areas.

Hall (1977) assessed the profitability of IPM in cotton (and citrus) in the San Joaquin Valley. He found that pesticide use was reduced by between one-third and two-thirds, that the per acre savings in total pest management expenditures were $7.19 (almost $20 in year-2000 dollars) and that yields were not reduced. However, he concluded that there was no difference in profit between IPM and conventional pest management.

Another source of data on insecticide applications in the cotton industry is a site maintained at Mississippi State University, titled *Cotton Crop Loss Data*, where industry specialists estimate crop loss from particular pests and the average number of treatments for these pests (http://www.msstate.edu/Entomology/Cotton.html). The data are not based on surveys of actual farmer practice; rather they are based on the judgement of industry specialists. The estimates for California are available from 1986 to 1999, when the average number of applications in the San Joaquin Valley ranged from 0.4 per acre in 1987 to 3.9 in 1995.

9.4 The Use of Pesticides in the California Cotton Industry

Data on pesticide use in the cotton industry are presented in Tables 9.2a and 9.2b and Figures 9.6 to 9.10. Our expenditure estimates are based on a group of 62 major pesticides[3] for which we were able to get prices and are expressed in year-2000 dollars. The quantity data came from the DPR database. Estimated expenditure on pesticides in cotton rose from $96 million in 1991 to a maximum of almost $200 million in 1995 before falling $98 million in 1999. Shifts in per acre expenditure were not so dramatic because there was also an increase in acres harvested over this time. Expenditure per acre increased from $92 per acre to $155 per acre between 1991 and 1995 and remained around $150 per acre from 1995 until 1998, long after the industry had begun contracting in size. As cotton price fell, pest management costs remained high, perhaps because it took two or three seasons for growers to adjust to new control strategies before pest management costs fell again. In 1999 pesticide expenditures declined to $115 per acre.

The quantity data from the DPR database are for all pesticide use rather than a subset of 62 chemicals. Our discussion on the use of pesticides in cotton draws heavily on Wilhoit et al. (1999). DPR data shows total use of pesticides in the industry increased from 9.6 million pounds in 1991 to 17.1 million pounds in 1995 before declining to 8.4 million pounds in 1999 (Table 9.2a). Some of these changes in use can be explained by changes in area harvested, which peaked at 1.2 million acres in 1995 before declining to 0.6 million acres in 1999, but the amount of pesticide applied per acre followed a similar (if damped) trend to total pesticide use (Figure 9.7).

Turning to the use of the 62 pesticides that we tracked, in 1999 the share of pesticide use on cotton by weight of active ingredient was 50 percent for herbicides, 25 percent for insecticides, and 10 percent for fumigants (Table 9.2b). Working with total pesticides, Wilhoit et al. (1999, p. 18) found that in 1996, by weight, herbicides accounted for about 60 percent, followed by insecticides at 25 percent and fumigants at 15 percent. In terms of numbers of applications or acres treated, they found that herbicides also accounted for close to 60 percent, insecticides accounted for nearly 40 percent and fumigants for less than 1 percent. The aphid problem caused a sharp increase in the use of chlorpyrifos from 57,000 pounds in 1991 to 1.3 million pounds in 1995. In 1996 the cotton industry accounted for almost 30 percent of all agricultural use of this chemical (Wilhoit et al. 1999, p. 19). Aldicarb was the second most widely used insecticide in cotton (against nematodes, thrips, aphids and lygus), and its use increased to a peak of 0.5 million pounds in 1996. Aphid control primarily uses chlorpyrifos and imidacloprid, while aldicarb, imidacloprid and several pyrethroids are the main chemicals used to control lygus. Avermectin, dicofol and propargite are the main chemicals used to control mites.

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[3] See Table 4.5 for the list of 62 chemicals.

Table 9.2a All pesticide use on California cotton, 1991–1999

					Year				
Pesticide	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
					(thousand pounds active ingredient)				
Cholinesterase inhibitors	2,086	2,019	2,367	3,434	4,910	3,615	3,927	2,723	2,069
Organophosphates	1,172	1,291	1,330	2,379	3,525	2,062	2,358	1,267	1,001
Toxic air contaminants	1,149	1,081	1,376	1,284	1,295	1,103	922	724	654
Reproductive toxins	487	1,441	1,760	2,254	1,890	2,313	1,855	682	762
Carcinogens	390	1,436	1,603	2,137	1,783	2,144	1,617	632	720
Oils	193	266	276	293	627	674	616	248	192
Carbamates	190	154	227	261	467	668	731	754	415
Biopesticides	0	1	0	0	2	1	3	4	1
Potential groundwater contaminants					5	8	13	13	12
Reduced risk pesticides					0		3	1	1
Total pesticide use in cotton	*9,569*	*11,464*	*13,009*	*14,013*	*17,148*	*14,383*	*13,279*	*9,455*	*8,445*
					(lbs)				
Active ingredient per acre	9	10	11	12	13	12	12	11	10
					(percentage)				
Share of California total*	7.2	7.3	7.5	8.0	9.1	7.9	7.0	4.8	4.6

Source: Compiled by the authors from California Department of Pesticide Regulation, Pesticide Use Database, 2001.

*Total pesticide use=all pesticides used in production agriculture

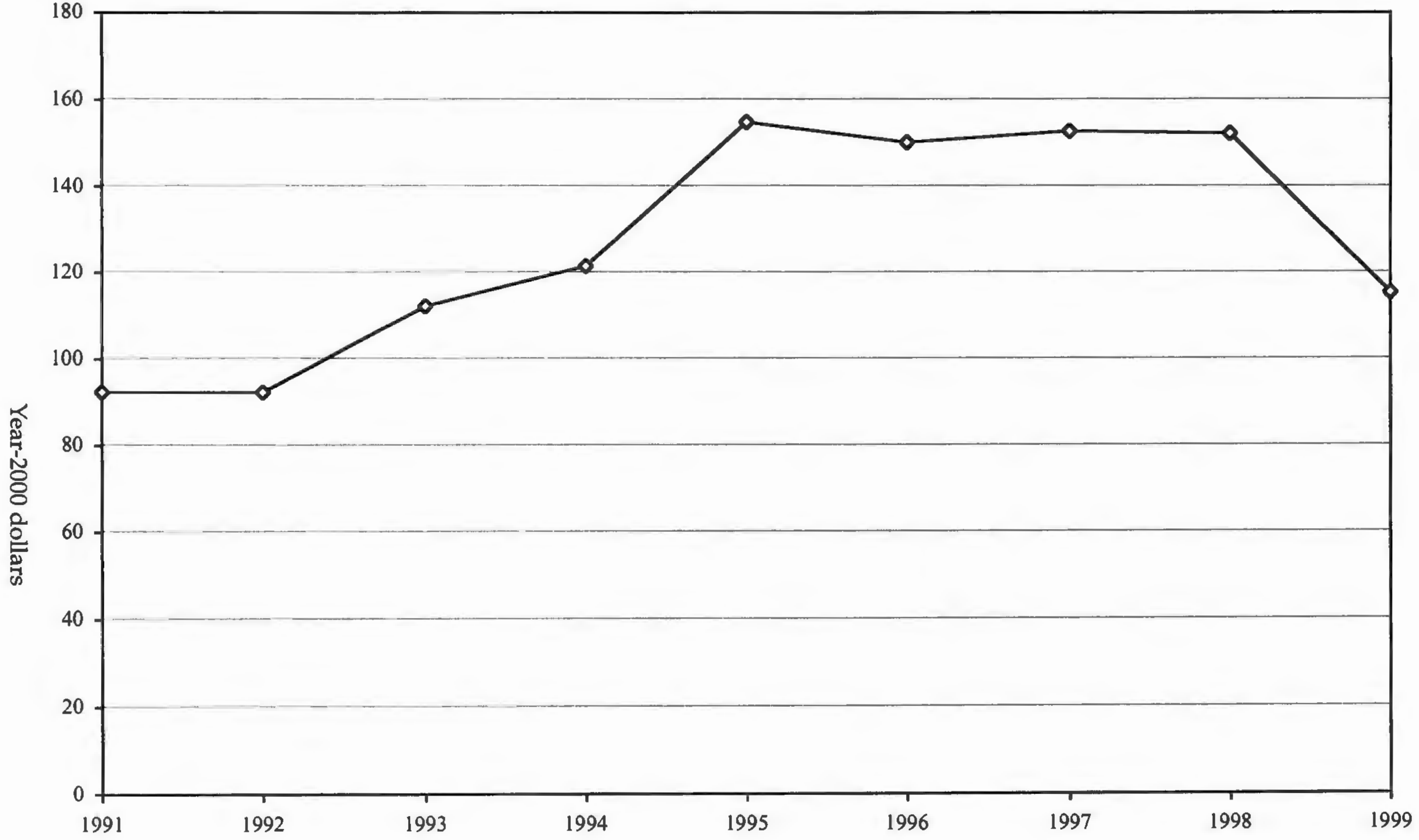
Table 9.2b Use of 62 major pesticides on California cotton, 1991–1999[a]

	Year								
Class	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
	(thousand pounds active ingredient)								
Herbicides	3,349	4,956	5,717	5,031	5,632	4,738	4,225	3,570	2,997
Fungicides	1,979	434	321	241	463	357	271	179	194
Insecticides	1,826	2,027	2,257	3,083	4,477	3,455	3,328	2,037	1,482
Plant growth regulators	737	591	831	816	947	911	864	734	677
Fumigants	234	1,133	1,300	1,698	1,214	1,780	1,333	418	601
	(percentage of total cotton pesticide use, by weight)								
Herbicides	41.2	54.2	54.8	46.3	44.2	42.1	42.2	51.5	50.4
Fungicides	24.4	4.8	3.1	2.2	3.6	3.2	2.7	2.6	3.3
Insecticides	22.5	22.2	21.7	28.4	35.2	30.7	33.2	29.4	24.9
Plant growth regulators	9.1	6.5	8.0	7.5	7.4	8.1	8.6	10.6	11.4
Fumigants	2.9	12.4	12.5	15.6	9.5	15.8	13.3	6.0	10.1
	(year-2000 dollars, millions)								
Estimated expenditures[b]	96.5	102.5	128.4	143.6	199.2	174.9	162.5	129.6	98.1
	(year-2000 dollars/acre)								
Estimated expenditures[b]	92	92	113	122	155	150	153	152	115

Source: Compiled by the authors from California Department of Pesticide Regulation, Pesticide Use database, 2001.

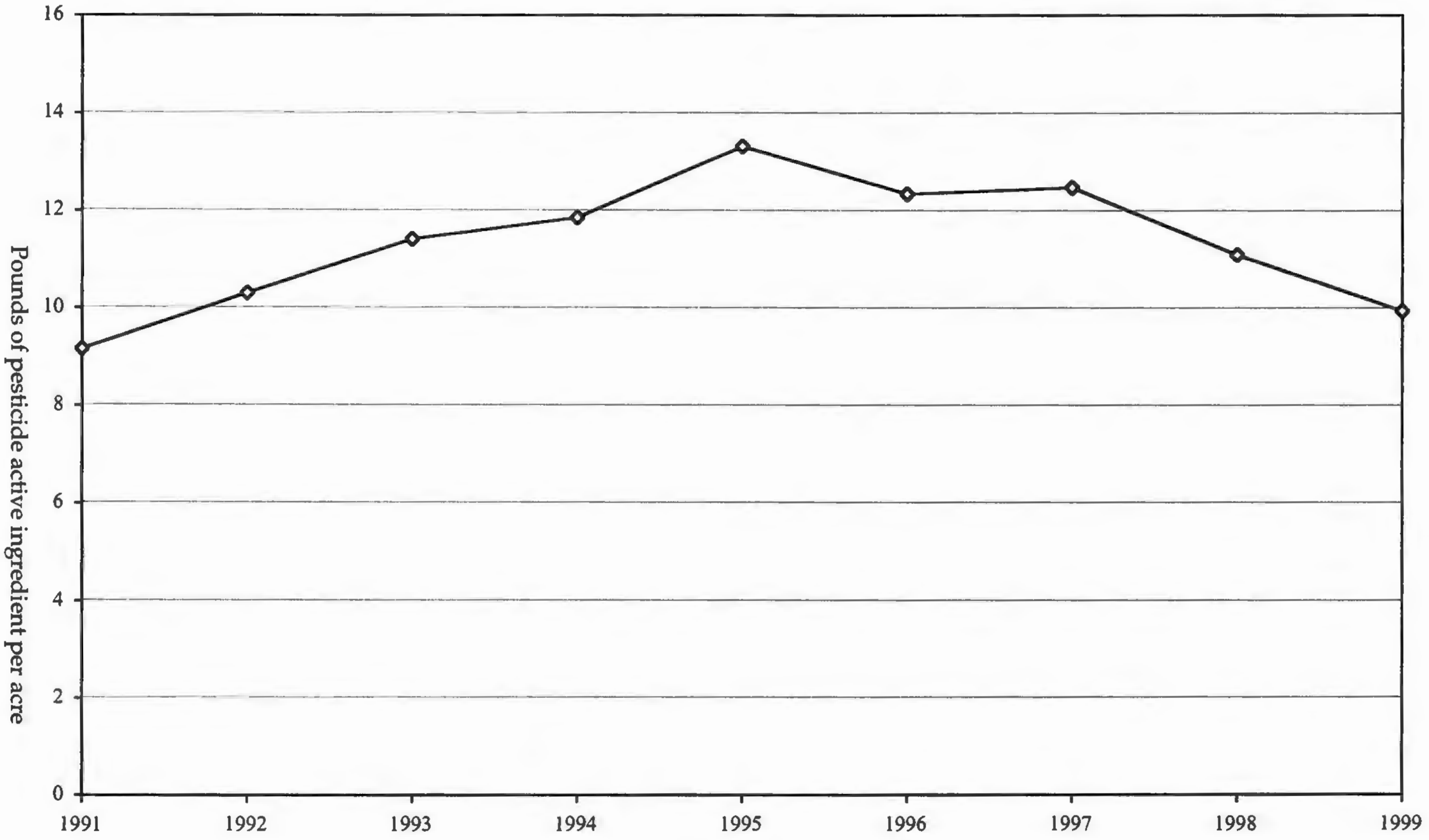
[a] The 62 pesticides are listed in Table 4.5

[b] Estimated expenditures are for the 62 major pesticides



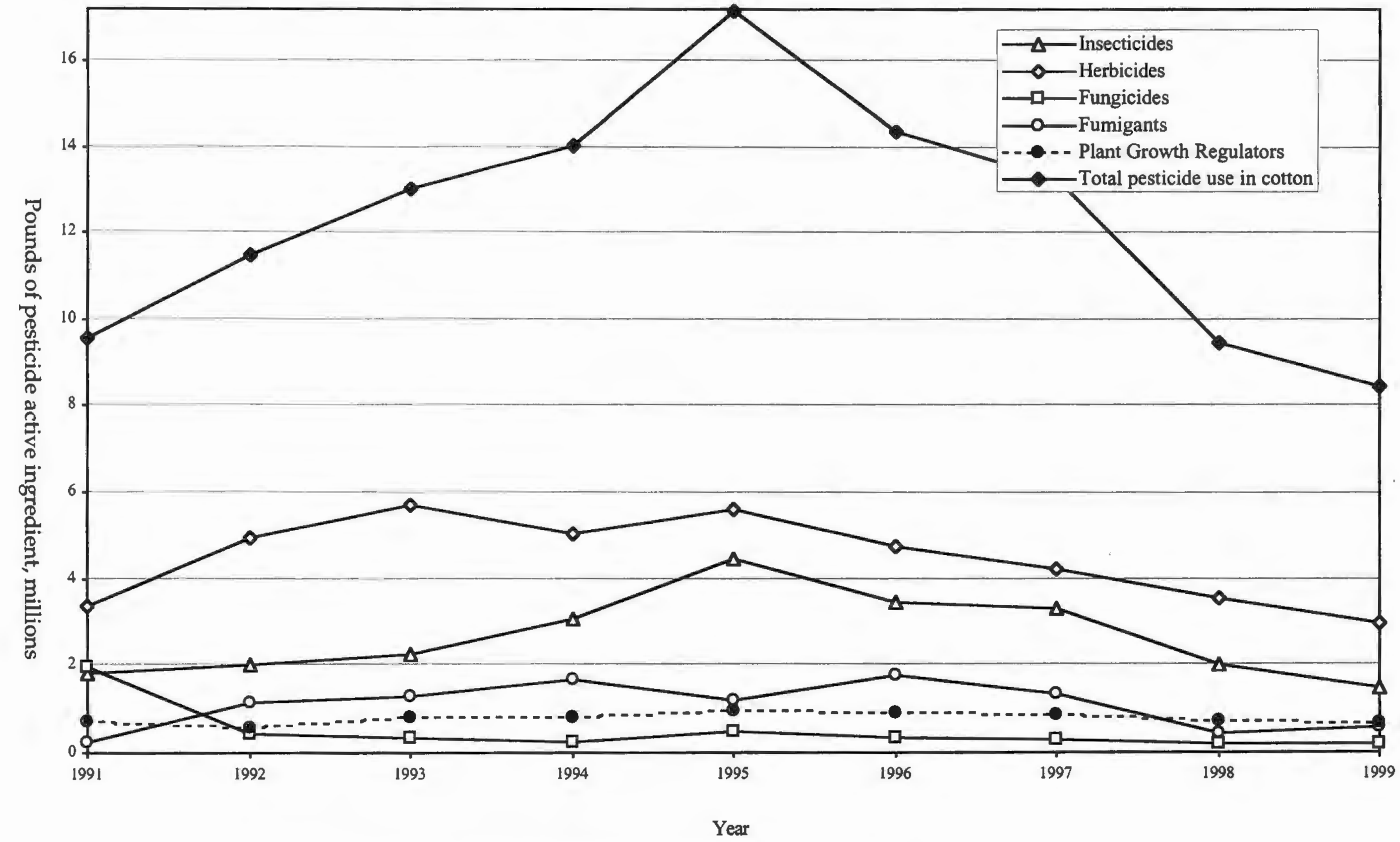
Source: Compiled by the authors from California Department of Pesticide Regulation, PUR database, 2001.

Fig. 9.6 Pesticide expenditure per acre on California cotton, 1991–1999



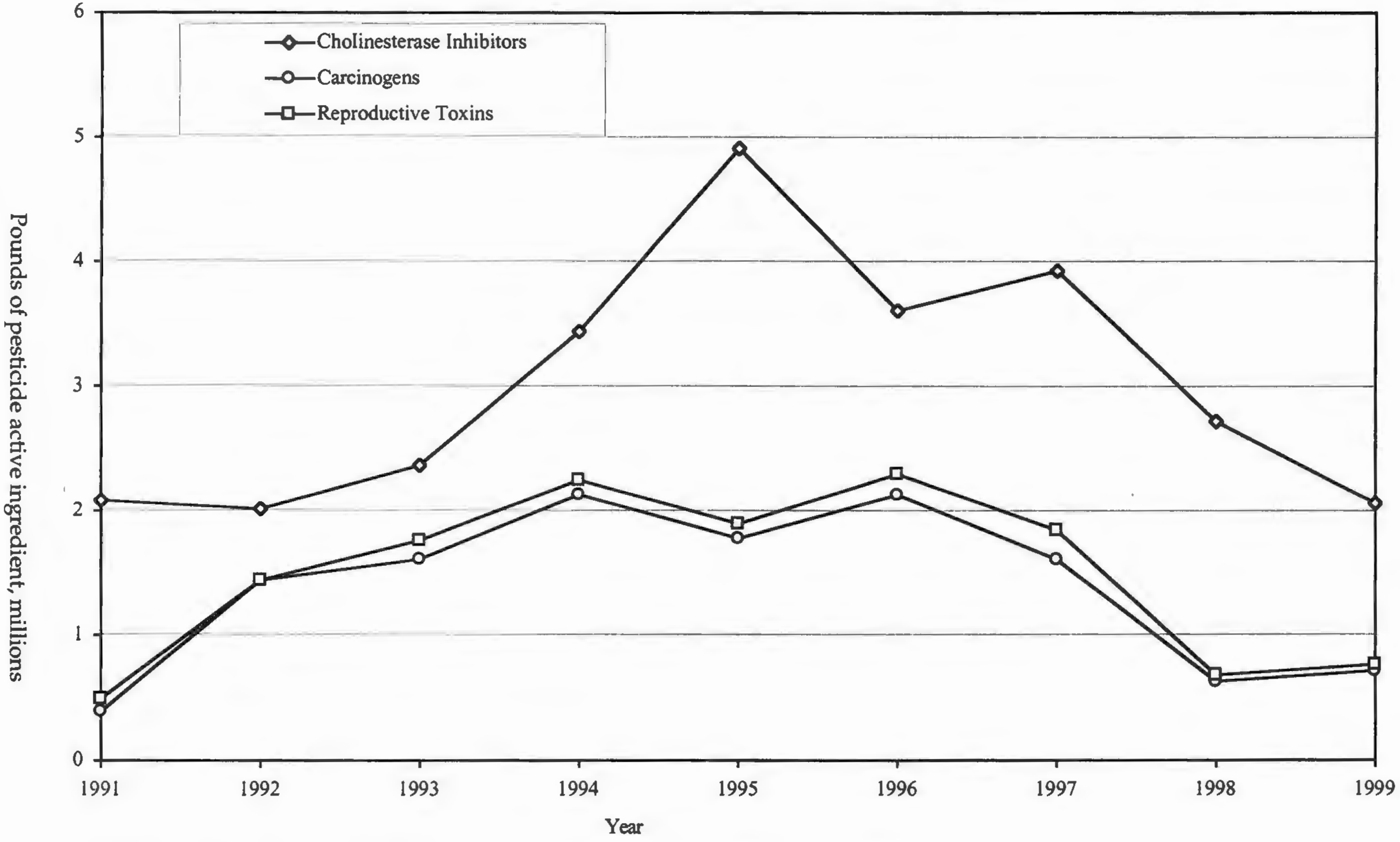
Source: Compiled by the authors from California Department of Pesticide Regulation, PUR database, 2001.

Fig. 9.7 Pesticide use on California cotton per bearing acre, 1991–1999



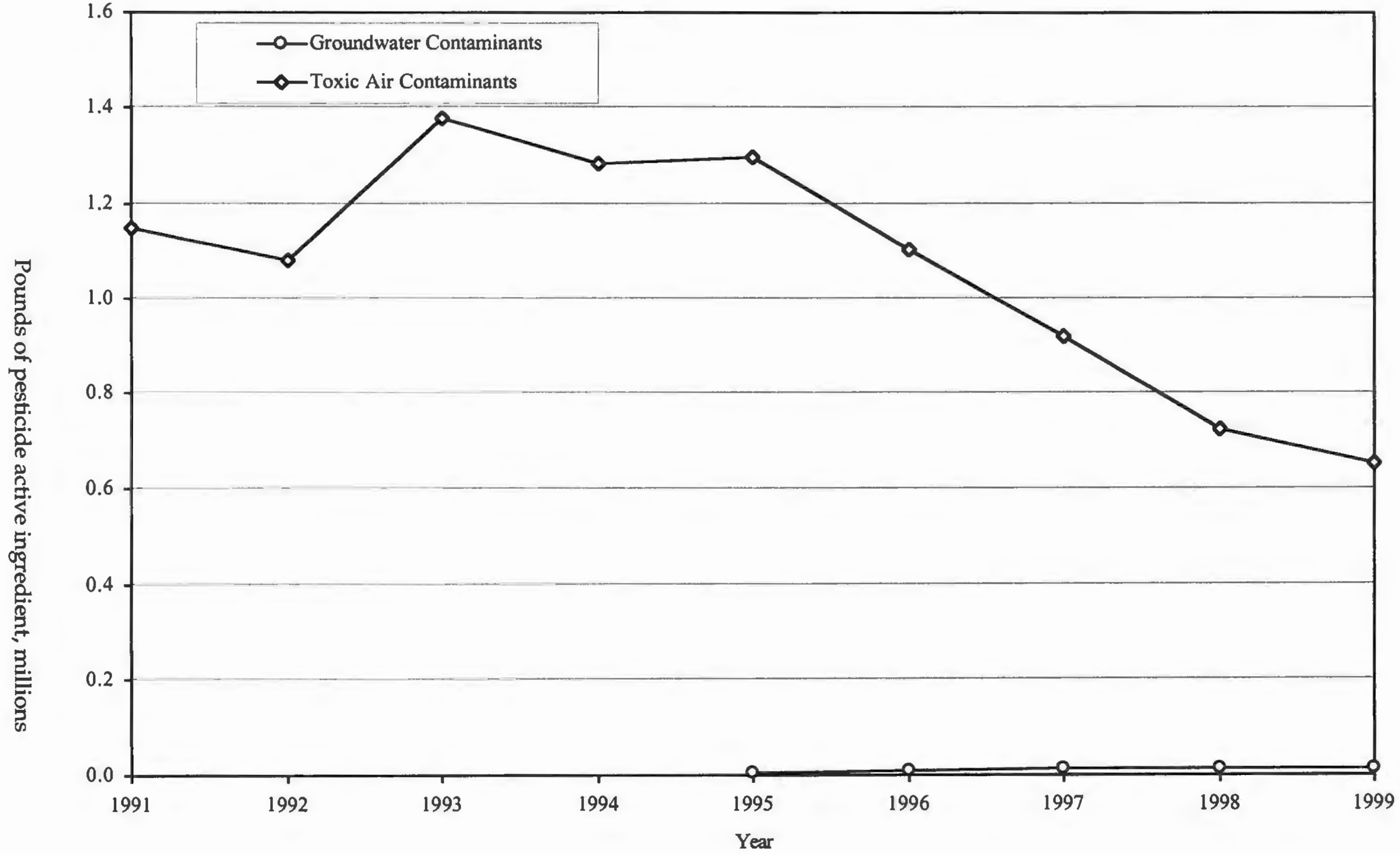
Source: Compiled by the authors from California Department of Pesticide Regulation, PUR database, 2001.

Fig. 9.8 Pesticide use on California cotton, 1991–1999



Source: Compiled by the authors from California Department of Pesticide Regulation, PUR database, 2001.

Fig. 9.9 Pesticide use on California cotton: human health, 1991–1999



Source: Compiled by the authors from California Department of Pesticide Regulation, PUR database, 2001.

Fig. 9.10 Pesticide use on California cotton: the environment, 1991–1999

The cotton industry uses a range of herbicides. Trifluralin has been widely used for a long time. Since 1991 metam sodium has been increasingly used to control nightshade, which had previously been controlled by hand hoeing. As growers use more Roundup-Ready cotton, the use of glyphosate is expected to increase.

Sodium chlorate and paraquat (both also herbicides) and mepiquat chloride are widely used as defoliants and desiccants in the cotton industry. Cotton accounts for 97 percent of all sodium chlorate used for agricultural purposes in California (Wilhoit et al. 1999).

In terms of total pounds, the cotton industry uses less pesticide than the grape, almond and processing tomato industries and about the same amount as the orange, strawberry and carrot industries. Nevertheless, the pesticides it uses are expensive, and hence total expenditure on pesticides in the cotton industry is higher than in the other commodities we examined (Table 4.7). On a per acre basis, however, cotton at $115 per acre in 1999 is a moderate user behind the strawberry, grape, almond, carrot and head lettuce industries.

9.5 Changes in Pesticide Use: Environmental and Human Health Risk Perspectives

Changes in pesticide use in the cotton industry appear to give mixed results for human health and environmental risk outcomes. Roughly one-quarter of pesticides used in cotton are cholinesterase inhibitors—mainly organophosphates and carbamates—and the cotton industry accounts for roughly one-fifth of all use of cholinesterase inhibitors on crops. The use of these chemicals on cotton followed total pesticide use fairly closely (Table 9.2a), with a peak in use in 1995 and then a decline to a rate of use similar to 1990. Hence the use of these chemicals on cotton appears to have been largely driven by the size of the industry. The use of organophosphates declined over the period, but the use of carbamates, particularly aldicarb, increased.

Carcinogens generally accounted for about 10 percent of the chemicals used in cotton and their use also followed the inverted U-shaped curve of total pesticide use. The use of chemicals causing reproductive toxicity followed that of carcinogens closely and was of a similar order of magnitude (Figure 9.9). Both finished in 1999 at almost twice the use at which they started in 1991.

The industry was much smaller in 1999 than in 1991, hence it would seem that growers are using cholinesterase inhibitors, carcinogens and reproductive toxins more intensively in recent years.

The use of chemicals that are air contaminants, about 8 percent by weight in 1999, decreased significantly (almost 50 percent) from 1993 to 1999 (Figure 9.10). While the use of potential groundwater contaminants increased because of the increased use of aldicarb, they remained at low use levels, as did reduced-risk and biopesticides.

9.6 Changes in the On-Farm Costs of Pest Management

As noted above there seems to be a broad consensus that IPM in the cotton industry resulted in a significant reduction in pesticides used to control insects. The next step is to develop scenarios for the cotton industry "with" and "without" this pest management technology that are specific enough to allow benefits to be quantified. This requires information about the farm-level impact of the technology and the extent of its adoption (for both the "with" and "without" scenarios).

To recap, Hurd (1992) found that his survey respondents made on average 3.2 applications of insecticides during the 1990 season, much lower than the 10 to 12 applications that he suggested growers made in the 1970s. Hall (1977), using survey data over the 1970–74 seasons, early days for IPM programs, found that growers who used IPM methods were able to halve their pesticide costs without yield loss, a savings of about $20 per acre in real terms, but that farm income was unchanged. Leigh and Goodell (1996) suggested that IPM had allowed growers to reduce pesticide applications from a range of three to six per season to a little more than one per season.

Some indication of pesticide use practices can be gained from the cotton enterprise budgets that have been prepared over many years by UC Cooperative Extension.[4] Since the early 1990s, budgets have been prepared for the San Joaquin Valley as a whole rather than for individual counties. We assembled a collection of 57 budgets from the main cotton growing counties in the Central Valley from 1952 to 1999. We estimated the share of variable production costs attributable to pest management, where pest management costs included materials, hired labor and machinery costs associated with the control of weeds and insects, and growth regulation in cotton. The budgets perhaps underestimate the cost of insect control in that they are based on a spray program easily overturned in the event of an unanticipated pest outbreak. Weed control programs are more certain, but the budgets suffer from inconsistencies in the treatment of machinery costs through time. In general weed control costs were often more than twice as large as insect control costs, although in the most recent budgets, insect control costs are larger than weed control costs. Total pest control costs have generally been 20 to 25 percent of the variable costs of growing cotton. Pest control costs have been lower in Tulare and Kern counties. In the 1990s for the San Joaquin Valley as a whole, the share of variable costs accounted for by pests had risen to 30 to 40 percent of variable costs.

Table 9.3 presents these estimates for the insecticide share of pest management costs as well as information on expected yields. Despite the limited number of observations and several observations that seem inconsis-

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[4] The qualifications to be borne in mind in using this crop budget information have already been noted.

tent with their neighbors, there does seem to be a pattern that is consistent with the view that IPM has reduced the use of insecticides in cotton. The general story appears to be that by 1970, insect and spider mite management costs had risen to about 10 percent of variable production costs. Data on the number of applications were less complete but suggest that the number of applications had risen from two to three. By 1980 insect and mite management costs had fallen to about 5 percent of variable costs and the number of applications had dropped back to two. Noticeably lower yields were being used in the budgets at this time, reflecting the historical pattern of yields discussed earlier. Our interpretation is that the fall in yields was related to verticillium wilt rather than to the reduction in pesticide use. From the mid-1980s, pest management costs rose again, for reasons explained above, to be above 10 percent of variable costs. The costs of weed control had no obvious similar trend.

In constant (year-2000) dollar terms, from the enterprise budgets, the average cost per acre for insect and mite control over all counties for each decade since the 1950s was: 1950s, $56; 1960s, $94; 1970s, $67; 1980s, $52; and 1990s, $68. If the observation period is divided in two, the average real cost per acre during 1951-73 was $74 and for 1974-99, it was $54. The average real cost of insecticide applications over the period, estimated as the ratio of total real costs to number of applications, was in the range of $25 to $30 per application per acre.

Hence, while the budgets support the general concept of reduced pesticide use as a result of IPM, the reduction in the number of applications is far less dramatic than sometimes suggested in the literature, although the budgets may reflect more the "targets" of those who prepared them rather than actual practice.

With respect to adoption, Fernandez-Cornejo and Jans (1999) and Hurd (1994) estimated that some degree of IPM was practiced by about 60 to 70 percent of growers in California.

9.7 Expenditure by UC on Cotton Pest Management Research and Extension

CRIS data on research expenditure on pest management in cotton by California institutions (expected to closely approximate UC expenditure) are available from 1970 to 1997. As can be seen from Table 3.6, the expenditure fell dramatically in real terms from $3.6 million in 1970 to $0.7 million in 1994, before rising again to $1.4 million in 1997. Discussions with industry specialists suggested that expenditure in the 1970s was high because of a large flow of federal grants to support IPM research. Expenditure on extension, by our estimate (Table 3.7), has risen from about $0.6 million in 1970 to $1 million in recent years.

The total value of this stream of research and extension investments from 1970 to 1997 compounded forward to 2000 was $162 million.

Table 9.3 Yields and pest management share from county cotton budgets, 1952–1999

			County			
Year	San Joaquin	Madera & Merced	Kern	Tulare	Kings	Fresno
			yield, pounds/acre (percentage of insect and mite management share of costs is in parentheses)			
1952						
1953				750 (5)		750 (4)
1955			750 (4)		750 (6)	
1956						750 (8)
1957		750 (7)				
1959			1,200 (8)		1,000 (9)	1,000 (13)
1961		750 (9)		1,000 (11)		
1965		1,000 (7)			1,000 (10)	
1966			1,200 (9)			1,000 (12)
1967				900 (10)		
1969						1,000 (11)
1970					1,000 (10)	
1971		900 (9)	1,000 (10)	800 (7)		
1974				800 (5)	900 (3)	
1975			1,000 (8)	800 (5)		
1976						1,000 (8)
1977		900 (7)		800 (7)		
1978						800 (11)
1979		900 (8)		900 (5)		
1980			1,100 (5)			1,000 (7)
1981		900 (9)	1,100 (3)	900 (4)		
1982			1,100 (2)		1,000 (4)	1,000 (8)
1983	1,000 (5)	900 (7)		1,000 (5)		1,000 (7)
1984				1,000 (5)		
1985		1,000 (6)		1,000 (5)		
1986	1,100 (5)					
1990		1,000 (5)				
1991	1,076 (7)					
1995	1,250 (13)					
1999	1,250 (15)					

Source: Compiled by the authors from UC Cooperative Extension Service, cost of production budgets for cotton.

Note: Pest management share is the share of insecticide in total operating costs. Years for which there were no observations have been deleted.

9.8 The UC Contribution to Pest Management in Cotton

This section identifies where the UC system made its major contributions since 1950 and attempts to put a value on the associated gains to the industry.

A major contribution of the UC system was in reducing the costs of managing such insect pests as lygus, mites and aphids through the development and promotion of an IPM program. No doubt breeding for resistance to verticillium wilt and other diseases has made an important contribution to yields and to expanding the area where cotton can be profitably grown, but much of this work was undertaken initially by the USDA and more recently by private breeding activities. No doubt the UC system contributed to the more rapid adoption of varieties in regions to which they are most suited. We have not attempted to value these benefits.

More recently breeding has been used to introduce into cotton varieties either resistance to insects or tolerance of herbicides, both of which have the potential to lower pest management costs. Again we have attributed none of the benefits of either the development or the more rapid adoption of these technologies to the UC system.

There have also been large changes in the management of weeds related to the development of herbicides during this period. Many of the benefits of these changes in weed management can be attributed to the chemical companies that developed the herbicides. Some of the benefits of better weed management arose from UC research and extension, which has been important in adapting control strategies to particular areas throughout the San Joaquin Valley, but at this stage we have been unable to specifically identify and value these changes, and hence our estimates of the contribution of the UC system are understated to this extent.

The Pink Bollworm Suppression and Eradication Program has also had a major impact on the management of insects in the cotton industry. This program has been administered by the CDFA and has a strong regulatory component. While the UC system no doubt contributed through its research and extension activities to the success of this program, we have not attempted to estimate this contribution.

We have not been able to empirically compare the benefits from the UC activities in these broad areas of pest management. However, in common with the general theme of this report, it is clear that the development and adoption of arthropod management systems has had a large impact on pest management in the cotton industry. In particular, information on the life cycles of arthropods and their interactions with predators, control strategies, and climate allowed the development of an IPM program that is widely used within the industry and led to cost savings from reduced pesticide use.

In a static world in which pests did not adapt to control strategies, it is likely that growers would eventually learn efficient pest management strategies or adapt them from other growing areas. Hence in this situation, the

UC contribution may be limited to the number of years by which it was able to speed up adoption. However, we have assumed that the contribution of the UC system has been ongoing because it has been necessary to continually adapt the IPM program as pests adapted to the program and in response to new control technologies, new pests and changing regulatory and economic environments.

As already noted, there has been no single dominant pest in the San Joaquin Valley, but different pests have assumed prominence in different years in response to climatic factors and changes in control strategies, particularly switches between pesticide chemical groups. This dynamic pest environment has meant that research and extension resources have to be used to prevent the IPM program form becoming obsolete and to maintain cost savings to growers. As the experience of the 1985 to 1995 period demonstrates, it may take a few years to develop the new information about the changed pest environment that will allow growers who adopt the technology to maintain pesticide savings.

In terms of the original paper on IPM by Stern et al. (1959), a continuing UC investment is required to achieve a series of temporary reductions in the general equilibrium pest population through more efficient timing and choice of pesticides. At the very least, UC activities make this information available to growers earlier than if they relied on their own experimentation or had to adapt the information from other cotton growing regions.

In one of our scenarios, we assumed that this ongoing stream of new information allowed growers to save on average one pesticide application per year. In a second scenario we have tried to use the Mississippi State University crop-loss database to model more closely the number of pesticide applications saved as the pest environment changed from the 1975 to 1985 period to the 1985 to 1995 period. From 1975 to 1985, estimates of the number of applications were not available, and we used the estimate of 1.5 applications per season from Goodell et al. (1997). The estimated number of pesticide applications applies to the whole industry, not just IPM users. We assumed that in the absence of IPM, growers would have made three applications per season, and hence the benefit of the IPM program is the difference between actual applications and three. In 1988 and 1995 estimated applications exceeded three, and for these years we assumed that there were no savings in pesticides.

9. 9 Key Assumptions in the Benefit-Cost Analysis of the Cotton IPM Program

The following benefit-cost analysis is based on these key assumptions:

One-Application Savings Scenario

- The IPM program resulted in a reduction of one insecticide application per season.

- The real value of one less application is $27.50 per acre.
- The IPM program was adopted by 70 percent of growers in the Central Valley (but not in other areas of California such as the Imperial Valley).
- The benefits from the IPM program in any one year are estimated by applying these last two assumptions to the area of cotton in the Central Valley in each year.
- The benefits from the IPM program began in 1975 and continue to the present day.
- Expenditure on research and extension to develop and maintain the technology was incurred from 1950 to 1999.

Variable Savings Scenario

- Three pesticide applications are required under the calendar spraying approach.
- Saving in applications is the estimated number of applications subtracted from 3 (zero in years when actual applications exceed three).
- Savings are made by all the industry in the San Joaquin Valley.
- Other assumptions are the same as for the one-application savings scenario.

Implicit assumptions of our approach are that changes in the size of the cotton industry in the Central Valley have been unrelated to the widespread adoption of an IPM program and that the IPM program had no impact on the yield and quality of cotton. Hence the "without" IPM scenario is that the industry size, yield, and quality of cotton would be unchanged but that growers would have to apply one or more insecticides (depending on the scenario) for these parameters to hold. An implication is that the production of cotton in California did not increase significantly in response to the pest management cost savings, and hence the benefits of the IPM Program have been captured by growers rather than passed on to consumers in the form of increased production and lower prices.[5]

Also implicit is an assumption that growers choose pest management programs to maintain yield. IPM programs often point out to growers that they should compare the damage from pests with the costs of control at the margin, but we have assumed that the savings in pesticides were achieved without a yield sacrifice. Similarly, we assumed no change in the quality of the cotton produced.

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[5] With annual cost savings of less than, say, 10 percent of total costs of production, the total benefits will be closely approximated, regardless. If there were any induced price changes, however, some of the benefits would have shifted away from California growers to consumers and processors, most likely non-Californians. Given relatively elastic demand for California cotton, even with substantial quantity increases, the price effects would have been small.

Investments in research and extension over many years were required to develop this knowledge about insect and spider mite pests of cotton that became the basis of the IPM program. However, the estimates of this stream of investments based on CRIS only go back to 1970. Since the development of the program, a stream of investments has been required to maintain the pesticide savings. No doubt some of the benefits of these research and extension investments will continue into the future, but we assumed that they would be quickly eroded as insects adapt to control strategies, unless the stream of maintenance research is continued.

9.10 Findings from the Benefit-Cost Analysis

The One-Application Saving Scenario

The sum of the stream of benefits in 2000 estimated under these assumptions and compounded forward at a real interest rate of 2 percent is almost $710 million (in year-2000 dollars), giving a benefit-cost ratio of 4.4:1. This is the scenario we think is most reasonable.

Variable Savings Scenario

The real value in 2000 of the stream of pesticides, estimated under the variable savings scenario, was $1,372 million, giving a benefit-cost ratio of 8.5:1.

CHAPTER 10

An Evaluation of Pest Management R&D in Oranges

10.1 The Orange Industry in California

Among California's agricultural commodities, oranges ranked ninth in cash receipts in 1999, with a value of $430 million. Both navel and Valencia oranges are grown, and both varieties are largely sold on the fresh market. The largest production areas are the Central Valley counties of Fresno, Kern and Tulare, but San Bernardino, Riverside and Ventura counties are still important production areas. Data on important industry statistics are presented in Table 10.1 and Figures 10.1 to 10.5.

Harvested Area

From 1950 to 1964 the area harvested dropped significantly, from a high of 212,000 acres to a low of 122,000 acres (Figure 10.1). During the next 11 years, orange acreage increased dramatically, to almost 200,000 acres in 1975, as water became available in the San Joaquin Valley. The next 11 years, from 1976 to 1987, saw a minor decreasing trend in acreage to around 170,000 acres in 1987. Since then harvested acreage has again increased steadily. In 1999, harvested acreage again approached 200,000 acres, with about 170,000 acres in the San Joaquin Valley and almost 40,000 acres in Southern California.

Yield, Production, Price and Value

Orange yields have increased about 75 percent over the last 50 years. Year-to-year variation in yield is high. From 1950 to 1978, orange yields averaged about 220 boxes per acre (Figure 10.2). Since 1978, when yield was 200 boxes per acre, it has increased to around 310 boxes per acre. Although yields generally increased from 1978 to 1999, there was considerable annual variation. The years 1990 and 1998, in particular, were poor crop years because of freezes.

Orange production fell from 1950 to 1967, reaching a low of 20 million boxes in 1967. Since that time, orange production has increased significantly, reaching an average of around 55 million boxes per year. Record production of 76.1 million boxes was achieved in 1982 (Figure 10.3).

Orange prices, in nominal terms, averaged around $3 per box from 1950 to 1975. Since the mid-1970s, average orange prices have increased almost threefold to around $8 per box. In 1990, the year of a freeze, the price reached $14.50 per box. In real terms (year-2000 dollars), the price of oranges rose from a low of $10 per box in 1952 to $21 per box in 1961 before declining to about $10 in 1968. The price has remained around $10 per box since 1968, although it has been subject to wide fluctuations (Figure 10.4). Price fell as low as $6.53 per box in 1999.

The annual value of orange production, in nominal terms, stayed around $110 million from 1950 to 1970. Since 1970 the value of production has quadrupled. There has been little trend in the real value of production, with an average of about $525 million (year-2000 dollars) and fluctuations from $360 million in 1967 to $760 million in 1984 (Figure 10.5). The value of production (year-2000 dollars) was around $440 million in 1999.

10.2 Significant Pests in the Orange Industry

The two most important pests of citrus have traditionally been citrus thrips, *Scirtothrips citri*, and California red scale, *Aonidiella aurantii* (Musk). The impact of these pests is discussed in Grafton-Cardwell (2000). Citrus thrips cause a ring-like scar on the surface of newly developing fruit, which adversely affects quality, particularly of fruit destined for the fresh market. Thrip populations can develop quickly to economic threshold levels. Hence, growers tend to spray as soon as the insects appear rather than risk being unable to schedule a spray while they wait for stronger evidence that the pest will reach an economic threshold. Morse (1995, p. 376) reviewed research on the economic significance of the foliar damage caused by thrips and concluded that it was unlikely to be economical to use pesticides for this purpose.

Scale pests cause cosmetic damage and can severely reduce yield. In addition to California red scale, citricola scale has emerged as difficult to control with the reduced use of broad-spectrum pesticides (Grafton-Cardwell 2000, p. 7). Cottony cushion scale has been controlled to a large degree by the vedalia beetle, but there were outbreaks in the San Joaquin Valley in the late 1990s in orchards adjacent to those using the new insect growth regulators (IGRs) against California red scales because the IGRs had an adverse impact on vedalia beetles (Grafton-Cardwell 2000, p. 8). Other pests that cause cosmetic damage include forktailed katydid and citrus cutworm.

10.3 Eras of Pest Management in Oranges

An historical perspective on insect management in citrus can be found in Luck et al. (1996) and Morse and Luck (2000), and the following discussion draws heavily on these papers. The latter paper used a three-era pest management classification system similar to the one that we have applied to other crops. Some of the earliest applications of biological control can be found in the citrus industry.

The Presynthetic Era to the late 1940s

The chemicals used to control scale in this period included hydrogen cyanic acid (from 1886), Paris green (copper arsenate), lead and calcium arsenate, oil, sulfur, lime sulfur, nicotine, rotenone and pyrethrum. The first case of successful biological control was the introduction to orchards in Southern California in 1888 of vedalia beetle and the *Cryptochaetum iceryae* fly to

Table 10.1 California orange production, 1950–1999

Year	Harvested acres	Yield	Production	Price	Value of production	Real price	Value of production
				(nominal dollars)		(year-2000 dollars)	
	(thousands)	(boxes/acre)	(boxes, millions)	(dollars/box)	(millions)	(dollars/box)	(millions)
1950	211.6	214	45.2	2.03	91.9	12.45	563.0
1951	207.7	185	38.4	2.09	80.3	11.96	459.2
1952	200.8	229	46.0	1.77	81.7	9.99	459.7
1953	192.2	169	32.4	2.74	88.6	15.20	492.4
1954	183.2	215	39.4	2.36	92.8	12.95	510.6
1955	170.1	226	38.4	2.79	107.0	15.08	578.8
1956	151.9	236	35.9	2.84	102.1	14.86	533.6
1957	148.6	156	23.2	4.66	108.0	23.55	546.5
1958	145.0	277	40.2	3.05	122.6	15.07	605.8
1959	138.7	222	30.8	3.74	115.1	18.26	562.4
1960	136.5	183	25.0	4.27	106.8	20.59	514.7
1961	129.8	158	20.5	4.44	91.1	21.18	434.2
1962	125.8	227	28.6	4.15	118.6	19.49	557.5
1963	125.0	254	31.7	4.08	129.3	18.96	601.1
1964	122.4	251	30.7	3.58	109.9	16.40	503.5
1965	125.7	285	35.9	3.08	110.4	13.83	496.7
1966	130.4	282	36.8	2.86	105.1	12.49	459.5
1967	139.9	137	19.2	4.40	84.2	18.65	357.1
1968	150.5	294	44.3	2.37	104.8	9.62	426.2
1969	160.2	244	39.0	2.75	107.1	10.64	415.0
1970	167.9	220	37.0	3.26	120.7	12.01	444.2
1971	180.4	241	43.4	2.84	123.2	9.94	431.4
1972	188.8	223	42.1	3.14	132.0	10.54	443.7
1973	196.0	203	40.4	3.88	156.9	12.36	499.3
1974	197.2	279	55.0	3.23	177.9	9.44	519.4
1975	197.8	267	52.8	2.97	156.9	7.94	419.0
1976	192.5	242	46.6	3.44	160.4	8.70	405.5
1977	187.4	227	42.6	5.87	250.0	13.94	593.6
1978	186.4	200	37.3	6.88	256.8	15.26	569.3
1979	185.1	321	59.4	3.85	228.8	7.88	468.2
1980	183.3	356	65.3	4.47	291.8	8.38	547.0
1981	180.3	232	41.9	8.80	368.7	15.09	632.2
1982	177.4	429	76.1	4.16	316.7	6.72	511.1
1983	177.1	273	48.5	8.21	398.2	12.74	618.1

(continued)

Table 10.1 Continued

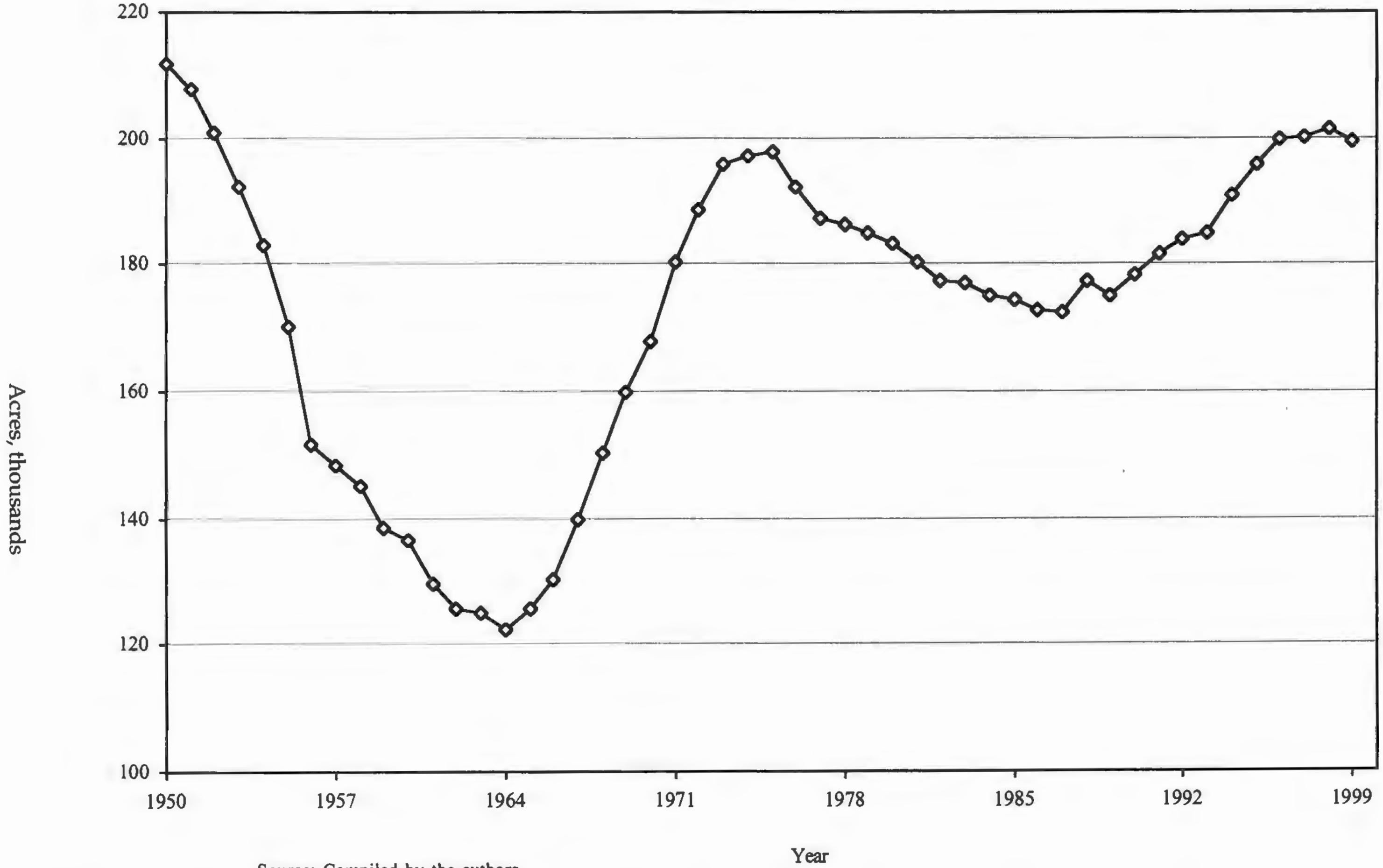
Year	Harvested acres	Yield	Production	Price	Value of production	Real price	Value of production
				(nominal dollars)		(year-2000 dollars)	
	(thousands)	(boxes/acre)	(boxes, millions)	(dollars/box)	(millions)	(dollars/box)	(millions)
1984	175.3	299	52.4	9.66	506.0	14.45	757.3
1985	174.6	309	53.9	6.77	365.0	9.82	529.5
1986	172.9	335	57.9	7.50	434.1	10.64	616.3
1987	172.6	342	58.8	7.80	458.4	10.75	631.9
1988	177.6	332	58.9	7.85	462.3	10.46	616.2
1989	175.1	408	71.4	7.77	555.1	9.98	712.7
1990	178.4	144	25.6	14.46	370.2	17.87	457.6
1991	181.7	371	67.3	6.89	463.9	8.22	553.2
1992	184.0	363	66.8	7.07	472.0	8.23	549.5
1993	185.0	344	63.6	7.27	462.6	8.27	525.9
1994	191.0	293	56.0	8.44	472.8	9.40	526.6
1995	196.0	296	58.0	8.44	489.5	9.20	533.5
1996	200.0	320	64.0	9.13	584.3	9.76	624.7
1997	200.2	345	69.0	8.91	614.6	9.34	644.6
1998	201.5	179	36.0	11.55	415.9	11.97	430.8
1999*	199.5	336	67.0	6.40	428.8	6.53	437.6

Source: Compiled by the authors from the California Agricultural Statistics Service, Fruit and Nut Report, 1950-1992, and USDA, National Agricultural Statistics Service, Citrus Fruits, 1993-1999.

*Preliminary

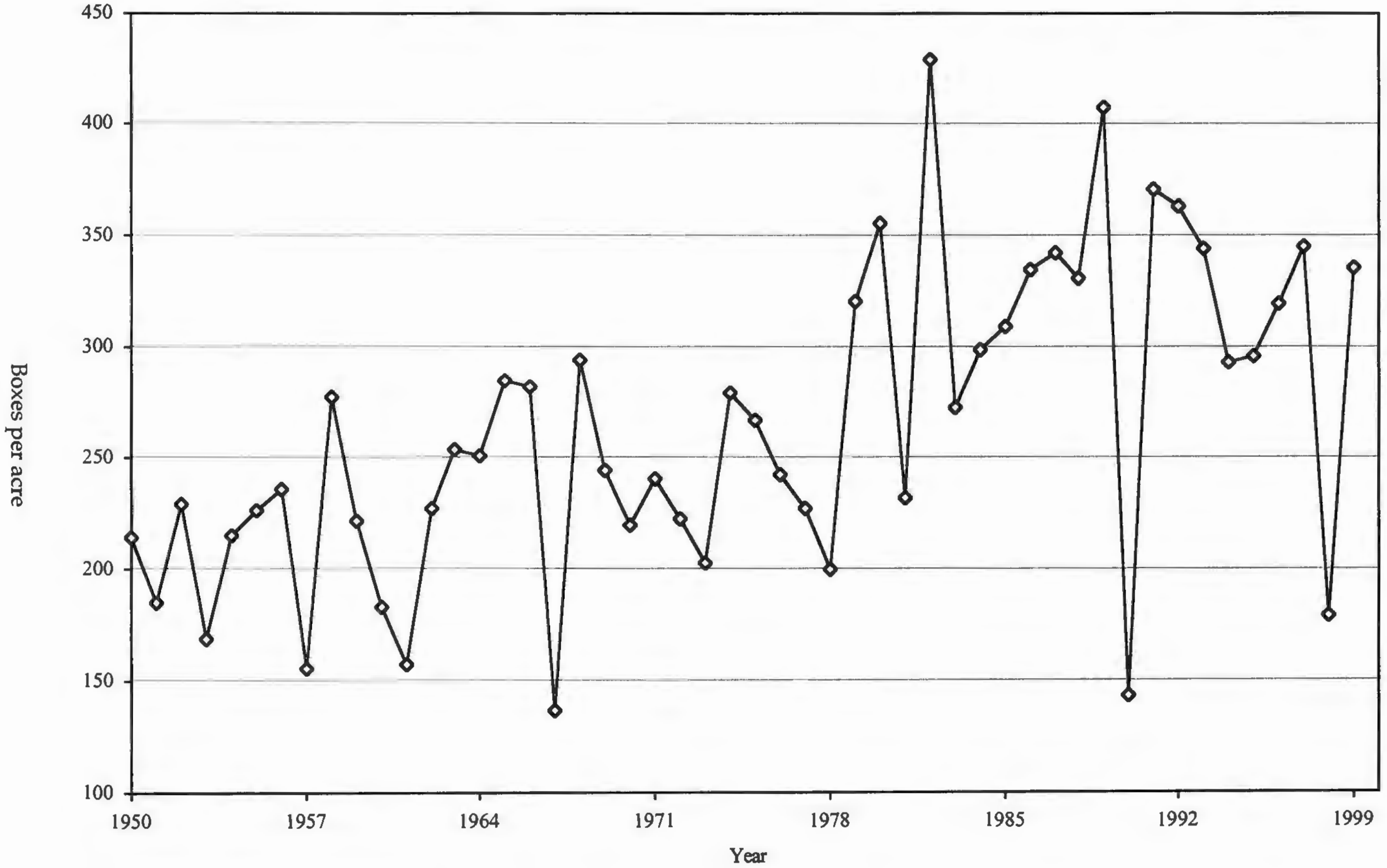
control cottony cushion scale. Morse and Luck (2000) attributed this early success to the establishment of UC biological control units at Berkeley and Riverside. Some of these practices were later to be components of IPM packages, but important components were undeveloped at this time. Morse and Luck (2000, p. 5) noted that in Southern California 13 exotic pests of oranges had been controlled biologically.

Another important development in this era was the establishment of the Fillmore Citrus Protective District in 1922 to manage California red scale (described in Klonsky et al. 1998, and Graebner et al. 1984) and later the citrophilus mealybug. The mealybug was controlled by the annual release of *Cryptolaemus montrouzieri* (Mulsant). The significance of the "cooperative" protective district was in the recognition and response by growers to the potential common property nature of pest management. At first, management options had a significant chemical control component, but by 1961 biological control through the purchase and production of natural enemies of pests became the main weapon.



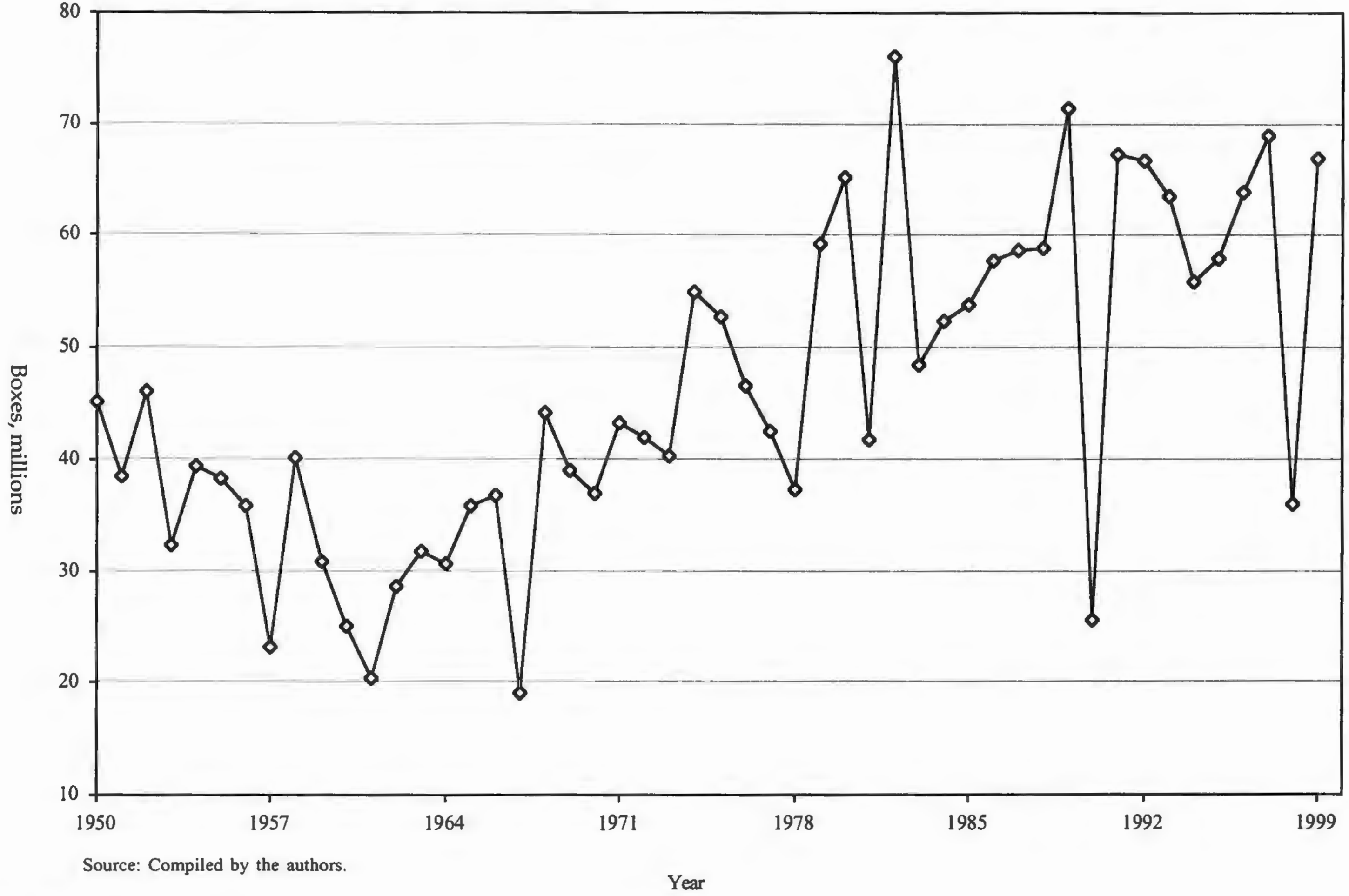
Source: Compiled by the authors.

Fig. 10.1 California orange harvested acreage, 1950–1999



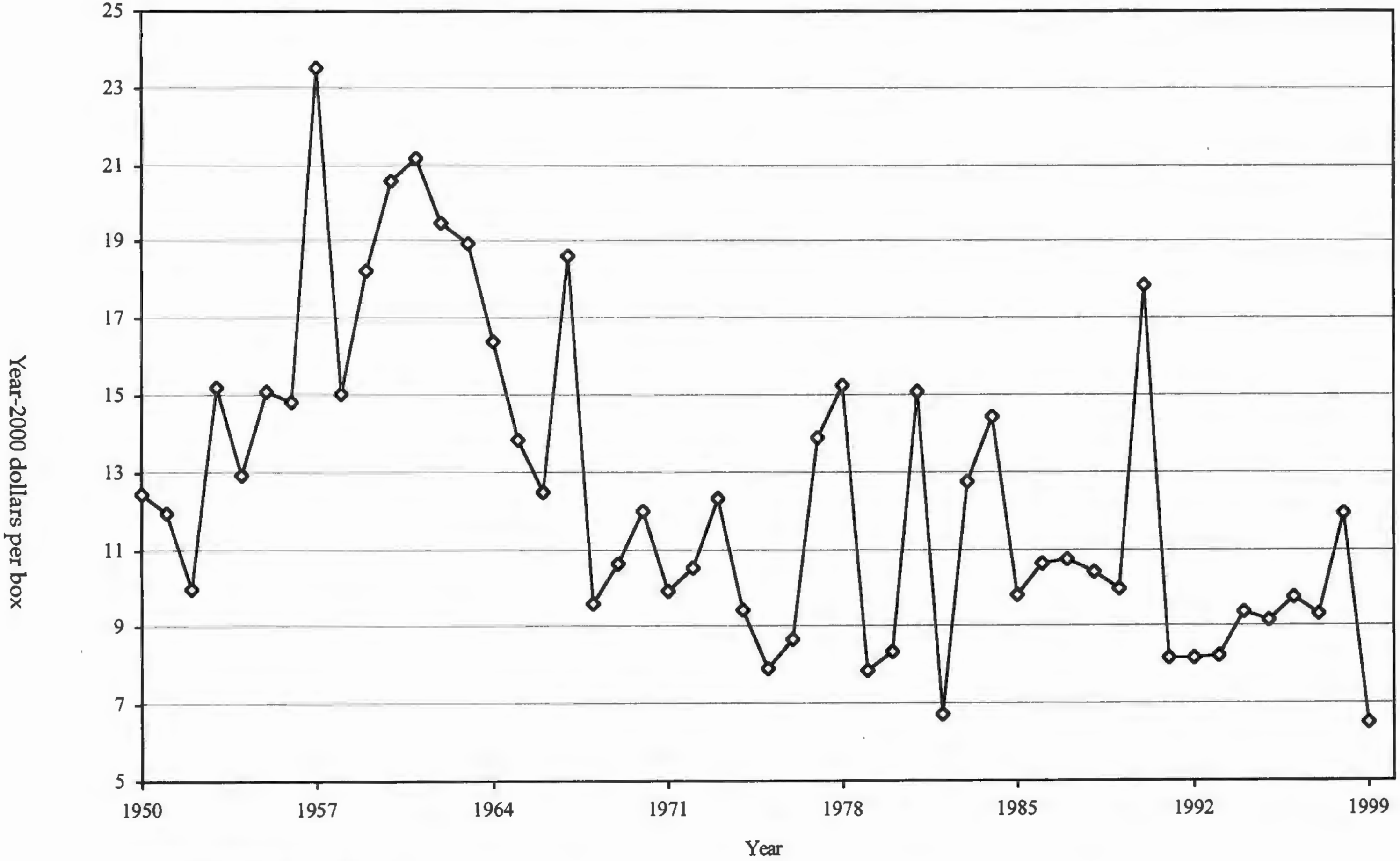
Source: Compiled by the authors.

Fig. 10.2 California orange yield, 1950–1999



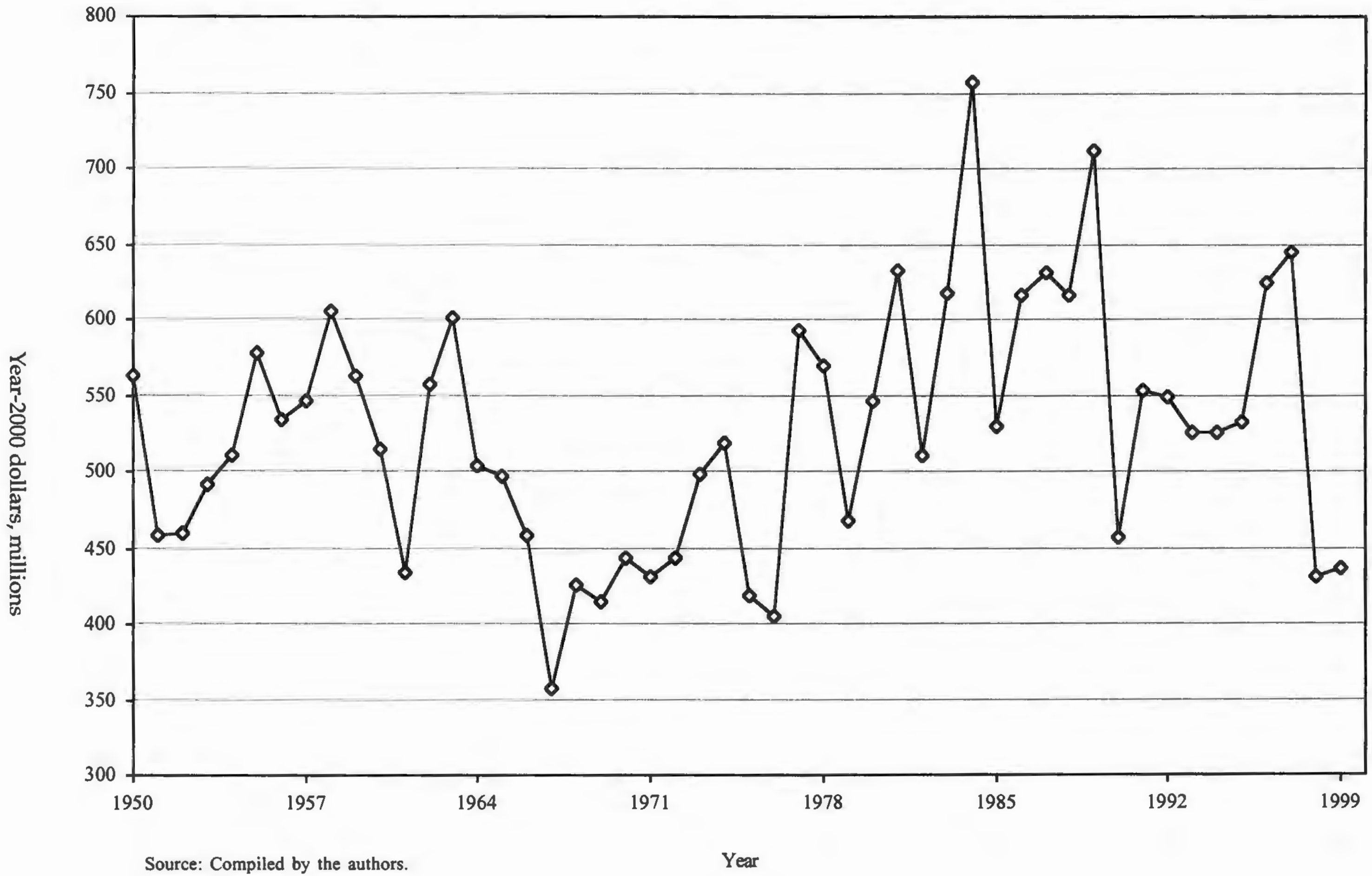
Source: Compiled by the authors.

Fig. 10.3 California orange production, 1950–1999



Source: Compiled by the authors.

Fig. 10.4 California orange price, 1950–1999



Source: Compiled by the authors.

Fig. 10.5 California orange value of production, 1950–1999

The Synthetic Pesticide Era from the 1950s to the late 1970s

Once synthetic organic insecticides became available, they dominated pest control strategies for the next couple of decades. DDT was first used against California red scale and citrus thrips in 1946, followed by parathion in 1949, dieldrin in 1953, and malathion in 1954. However resistance in citrus thrips to DDT emerged in 1949, and the rapid emergence of resistance to new chemicals has been observed ever since.

Starting in the 1950s, nematodes were controlled with annual applications of DDD (1,1-dichloro-2,2-bis(p-chlorophenyl) ethane) and EDB (1,2-dibromoethane), and later with DBCP (1,2-dibromo-3-chloropropane) as a result of UC research discovering their nematocidal properties. Use of DBCP was phased out in the 1970s, and the chemical was withdrawn altogether in 1980 after it was found to be a reproductive toxin and showed up in groundwater wells. DDD and EDB had been withdrawn earlier.

The IPM Era in the 1980s and 1990s

According to Grafton-Cardwell (2000), organophosphates and carbamates, when first registered, provided good control of scale when applied once every two years, but by the 1990s some growers (at least in the San Joaquin Valley) were applying these pesticides three times per year at a cost of $160 per acre per treatment. This trend to increased use of pesticide in citrus, similar to the experience of pest management in other commodities, led to renewed interest in cultural and biological control mechanisms.

Morse and Luck (2000, p. 7) noted that some elements of an IPM package were available from the mid-1960s, and by the mid-1970s an identifiable IPM program had been developed for Southern California. The components of IPM in citrus, including monitoring and the use of thresholds, are similar to those in other crops, although it would seem that the augmentative release of biological control agents such as *Aphytis melinus* DeBach against scale has been a more regular feature of IPM in citrus. Natural enemies are produced privately, and Luck et al. (1996, p. 500) quoted research suggesting that the cost of these releases is less than the cost of an insecticide. The use of natural enemies has sometimes been supplemented by one or two applications of oils and selective pesticides.

IPM based on biological control has been far more widely adopted in Southern and Coastal California than in the San Joaquin Valley, despite expectations that it would also prove profitable to growers in the valley. Hall (1977) reported an econometric analysis of grower survey data for the years 1970 to 1974 which suggested that IPM growers saved half the pesticide costs of their non-IPM counterparts with no discernible difference in yield.

A more detailed review of the prospects for IPM in the Central Valley can be found in Luck, Forster and Morse. (1996). They outlined an IPM strategy that they estimated would reduce the costs of managing arthropod pests by 40 percent. Their pest-management strategy, developed from experience in

Southern California, required the reduction or elimination of broad-spectrum chemicals early in the season and the release of 19,000 *Aphytis melinus* per hectare every two weeks for 13 weeks as soon as temperatures exceeded 18° C in late winter to control scale. Morse and Luck (2000, p. 7) identified other elements of this package as being intensive monitoring of specific insects, intervention thresholds, and selective insecticides such as sabadilla, a botanically derived insecticide, to control thrips. Early in the season, California red scale was to be controlled by oil sprays and low rates of chlorpyrifos. Morse and Luck (2000, p. 8) listed some of the research findings that made this IPM package possible for the Central Valley. Morse (1995) identified the chemical control of thrips as an impediment to the development of an IPM program for the San Joaquin Valley. Few insecticides are available to control thrips that do not also upset the biological control agents being used to control scales.

Nevertheless, the predominant management regime in the San Joaquin Valley remained the widespread use of broad-spectrum pesticides, certainly until the late 1990s. Grafton-Cardwell (2000) attributed this to greater climatic variability in the valley, which has meant that pest stages are synchronized with those of their natural enemies, and hence natural enemies do not have a continuous food source throughout the year. The valley also grows navel oranges, which are more susceptible to pest damage than Valencia oranges. Morse and Luck (2000 p.10) observed that growers were likely to favor broad-spectrum insecticides in an environment where new pests, such as the glassy-winged sharpshooter, the citrus peelminer, the imported fire ant, and the citrus leafminer, were emerging, but IPM strategies lagged.

In the 1990s new chemicals became available to control thrips and red scale. These new pesticides were generally less expensive to use than either the traditional broad-spectrum chemicals or the release of natural enemies. Grafton-Cardwell (2000) noted that the shift away from organophosphates and carbamates in the 1990s toward more selective pesticides, while consistent with an IPM philosophy, seems to have created other problems, still difficult to manage, in the form of secondary pest outbreaks, caused in some instances by the destruction of natural enemies of pests. Similar problems were experienced in the cotton industry on the introduction of pyrethroids. These problems in the cotton and orange industries reinforce the view that IPM programs have to be adapted continually as new pests invade, target pests develop resistance, and new pesticides, even if more selective, are introduced.

In the case of oranges, the new chemicals included pyriproxyfen, an insect growth regulator, to treat the increasingly resistant red scale population, and spinosad for thrip control. However pyriproxyfen is extremely toxic to predatory beetles, and there were secondary pest outbreaks of cottony cushion scale in neighboring orchards which were still following biological control practices. Grafton-Cardwell (2000, p. 9) found that the use of methidathion and malathion to control cottony cushion scale increased markedly in 1998 and 1999. There were also outbreaks of citricola scale, which are unaffected by spinosad introduced to replace organophosphates and carbamates. She suggested that similar problems may surface when the neonicotinoid insecticides are registered to control red scale and glassy-winged sharpshooter in California.

Some information on the extent of adoption of IPM practices can be found in Vandeman et al. (1994) and Fernandez-Cornejo et al. (1999). The drawback of these reports is that the adoption data are for the U.S. citrus industry rather than the industry in California, making it impossible to assess the specific extent of adoption in California and the different growing regions of California. Fernandez-Cornejo et al. (1999) drew on the 1993 USDA "Agricultural Chemical Usage" fruits survey for citrus data. Vandeman et al. (1994) drew on the 1991 survey. Some of the data from these studies are summarized in Table 10.2.

Table 10.2 Adoption of IPM practices in the U.S. citrus industry

IPM Practice	1991 Survey Data	1993 Survey Data
	(percentage of acres)	(percentage of acres)
Use of scouting	75	90
Economic thresholds	84	68
Predetermined schedule	11	16
Use of beneficials	22	8
Use of pheremones	28	16

Source: Compiled by authors from Fernandez-Cornejo et al. (1999) and Vandeman et al. (1994).

A number of apparent inconsistencies in these results, which may be due to sampling error or to changes in the survey instrument, make us wary about making inferences about trends in IPM use. However, the surveys do suggest that the extent of adoption of at least some IPM practices was quite high in the citrus industry. Vandeman et al. (1994) found that both scouting and economic thresholds were used on 64 percent of orange acreage and that 26 percent of the acreage was subject to these two practices and another three IPM practices— "high IPM practice" in their terminology. In contrast, Morse (1995, p. 373) talked of only a small number of growers using IPM in the early 1980s.

10.4 Pesticide Use in Oranges

Trends in pesticide use in citrus are discussed in Grafton-Cardwell (2000), Wilhoit et al. (1999), Morse (1995), and Morse and Klonsky (1994). The last two studies were based on an analysis of DPR data in 1990. As observed elsewhere in this report, this first year of DPR data is now generally regarded as being unreliable, and hence these two studies are not reviewed here. Morse and Klonsky (1994) did observe that 1991 was also an atypical year because of a freeze in December 1990. Data on pesticide use are presented in Tables 10.3a and 10.3b and Figures 10.7 to 10.10.

Based on our price data and DPR quantity data for 62 chemicals, expenditure on pesticides in the orange industry rose from $14.9 million in 1991 to $18.6 million in 1999, with a peak of $29.9 million in 1997 (Table 10.3b). The rise in expenditure up to 1997 can be partly explained by the growth of the industry. However, on a per acre basis, expenditure was also rising, from $82 in 1991 to $93 in 1999 after peaking at $149 in 1997 (Figure 10.6). Perhaps this can be explained by the scale-resistance problems in the San Joaquin Valley. In terms of total expenditure on the 62 pesticides, the orange industry was smaller than most of the other industries we tracked, but on a per acre basis, pesticide expenditure in the industry was above the average for California, particularly in the mid-1990s, although it was still less than several of the other commodities (Table 4.7).

In terms of total pounds applied of active ingredient, pesticide use, mainly in the form of insecticides, more than doubled during the 1990s, although use in 1999 was less than peak use of 11.5 million pounds in 1997 (Figure 10.8). Some of this increase can be explained by a 20,000-acre increase in the size of the industry, but the trend on a per acre basis is similar to that for total pesticide use (Figure 10.7). In 1999 the orange industry accounted for about 5 percent by weight of total pesticide use in California, similar to the cotton, carrot and strawberry industries (Table 4.6 and Table 4.7).

In 1996, insecticides accounted for 81 percent, herbicides for 10 percent and fungicides for 8 percent of the pounds of active ingredient applied to oranges, but in terms of number of both applications and acres treated, the percentages were about 35 percent for insecticides, 45 percent for herbicides and 10 percent for fungicides (Wilhoit et al., 1999), indicating there were fewer applications and fewer cumulative acres treated with insecticides than herbicides. The expenditure shares for insecticides, herbicides and fungicides were roughly the same as their shares of total pounds applied (Table 10.3b).

From Table 10.3a it is clear that there has been a switch from the use of organophosphates and carbamates to oils, and this largely explains the increase in total pounds of pesticides applied (because by weight, oils are applied at high rates). Wilhoit et al. (1999) explained these shifts in terms of growing resistance of scale to organophosphates and carbamates and a trend to IPM management strategies. Grafton-Cardwell (2000, p. 6) suggested that the decrease in use of organophosphates and carbamates in 1998 and 1999 could also be attributed to the use of pyriproxifen and buprofezin (both insect growth regulators) to control scales, spinosad and cyfluthrin (a pyrethroid) to control thrips, and to

Table 10.3a All pesticide use on California oranges, 1991–1999

					Year				
Pesticide	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
					(thousand pounds active ingredient)				
Oils	731	2,263	3,581	3,468	4,608	4,931	6,000	5,220	4,371
Cholinesterase inhibitors	602	1,036	1,075	1,057	961	1,009	1,114	507	356
Organophosphates	452	652	655	638	598	637	790	394	293
Potential groundwater contaminants	347	459	501	463	472	515	495	513	481
Carbamates	150	384	420	418	363	372	325	112	63
Toxic air contaminants	94	247	293	318	337	349	337	140	81
Reproductive toxins	57	42	3	2	19	69	33	29	14
Carcinogens	13	10	8	7	11	71	15	14	25
Biopesticides		2	2	2	3	2	3	4	4
Reduced risk pesticides							1	10	12
Total pesticide use in oranges	*3,569*	*6,050*	*7,571*	*7,455*	*8,962*	*9,555*	*11,461*	*10,160*	*8,734*
					(lbs)				
Active ingredient per acre	20	33	41	39	46	48	57	50	44
					(percentage)				
Share of California total	2.7	3.9	4.4	4.3	4.8	5.2	6.0	5.1	4.7

Source: Compiled by the authors from California Department of Pesticide Regulation, Pesticide Use Database, 2001.

*Total pesticide use=all pesticides used in production agriculture

Table 10.3b Use of 62 major pesticides on California oranges, 1991–1999[a]

	Year								
Class	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
	(thousand pounds active ingredient)								
Insecticides	1,200	3,099	4,413	4,464	5,543	5,921	7,061	5,743	4,741
Fungicides	638	582	601	596	623	572	828	786	618
Herbicides	465	609	675	646	683	710	693	733	728
Fumigants	57	40	0	2	16	79	61	41	33
Plant growth regulators	2	3	3	3	4	4	5	5	5
	(percentage of total orange pesticide use, by weight)								
Insecticides	50.8	71.5	77.5	78.1	80.7	81.3	81.7	78.6	77.4
Fungicides	27.0	13.4	10.6	10.4	9.1	7.9	9.6	10.8	10.1
Herbicides	19.7	14.1	11.9	11.3	9.9	9.7	8.0	10.0	11.9
Fumigants	2.4	0.9	0.0	0.0	0.2	1.1	0.7	0.6	0.5
Plant growth regulators	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	(year-2000 dollars, millions)								
Estimated expenditures[b]	14.9	23.5	24.6	25.9	26.5	27.0	29.9	24.2	18.6
	(year-2000 dollars/acre)								
Estimated expenditures[b]	82	128	133	136	135	135	149	120	93

Source: Compiled by the authors from California Department of Pesticide Regulation, Pesticide Use Database, 2001.

[a] The 62 pesticides are listed in Table 4.5

[b] Estimated expenditures are for the 62 major pesticides

weather conditions unfavorable to thrip populations.

The main herbicides used have been glyphosate, simazine and diuron. Use of herbicides increased in the early 1990s, but this seems to have been largely driven by an increase in the size of the orange industry. Herbicide use increased again in 1998 and 1999. Fungicide use seems to have been largely driven by weather patterns in the 1990s. It peaked in 1997 after reaching its low point in 1996.

Health Risk and Environmental Outcomes

In general it would seem that by weight, pesticide use in orange production in recent years has changed for the better with respect to human health risk and environmental outcomes. In particular the use of organophosphates and carbamates declined considerably in 1998 and 1999 (Table 10.3a), and this is consistent with meeting the concerns of the EPA. The use of cholinesterase inhibitors increased from 1991 to 1997 to account for about 10 percent of all pesticides, perhaps reflecting increased use of organophosphates and carbamates as resistance in scale emerged (Figure 10.9). Use of these chemicals fell in the late 1990s as growers switched to pyriproxifen. There appears to have been little change in the use of chemicals classed as carcinogens and those associated with reproductive toxicity,[1] which have always been low relative to the use of cholinesterase inhibitors.

The use of potential groundwater contaminants increased until 1993, after which it leveled off (Figure 10.10). The increase was probably driven by the greater use of herbicides such as diuron and simazine as the industry expanded. The use of toxic air contaminants has fallen with the decline in use of carbaryl. The use of biopesticides and reduced-risk pesticides has risen, even if from low bases.

10.5 Changes in the On-Farm Costs of Pest Management

The next step is to develop scenarios for the orange industry "with" and "without" new pest management technology that are specific enough to allow benefits to be quantified. This requires information about the farm-level impact of the technology and the extent of its adoption for both the "with" and "without" scenarios.

As noted above, IPM in the orange industry has resulted in a significant reduction in pesticides used to control insects in Southern California. However, in the San Joaquin Valley, adoption of IPM technologies was much lower, and pest management costs appear to be higher.

Some indication of pesticide use practices can be gained from the orange enterprise budgets that have been prepared over many years primarily by UC Cooperative Extension.[2] We assembled a collection of 41 budgets from

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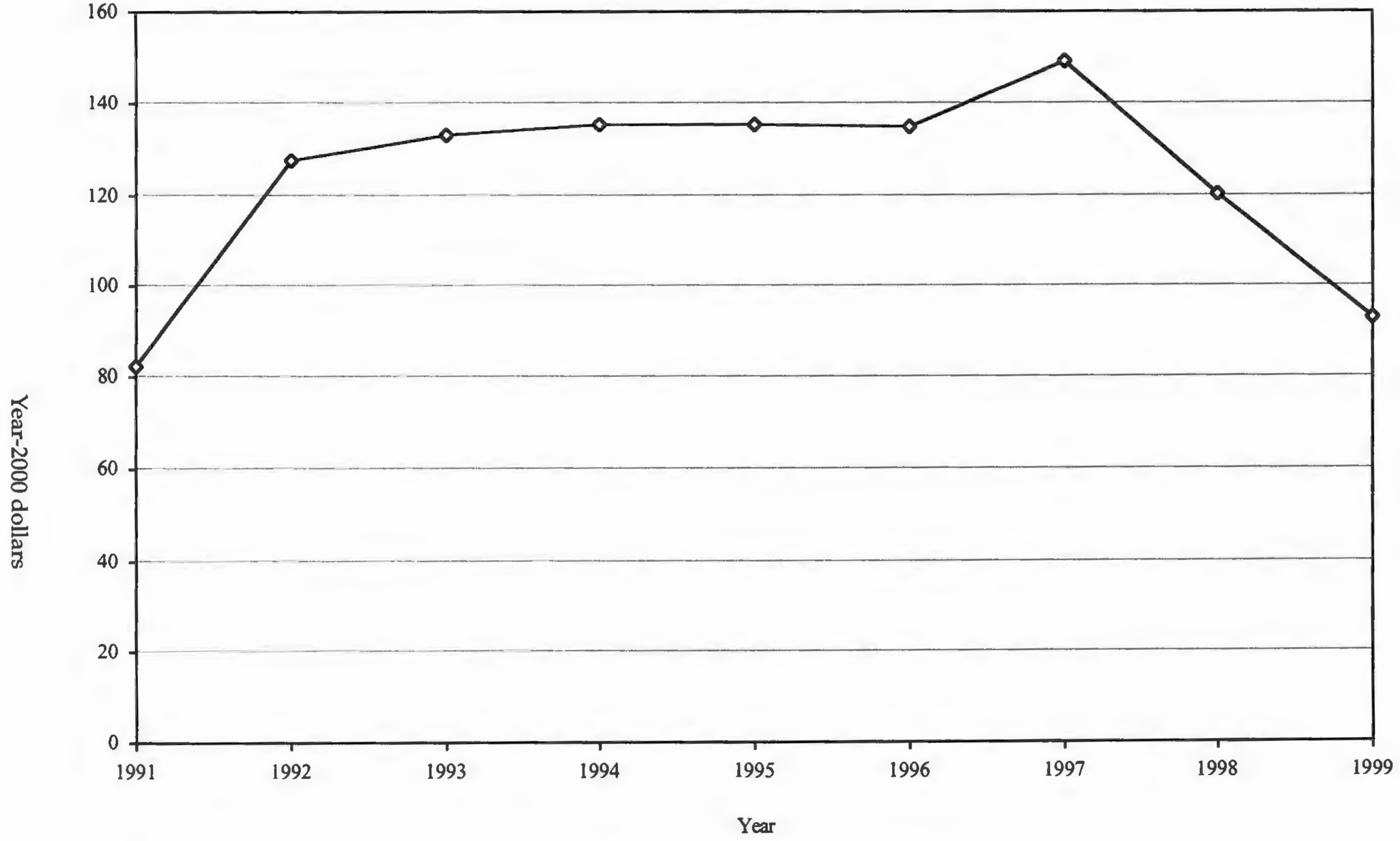
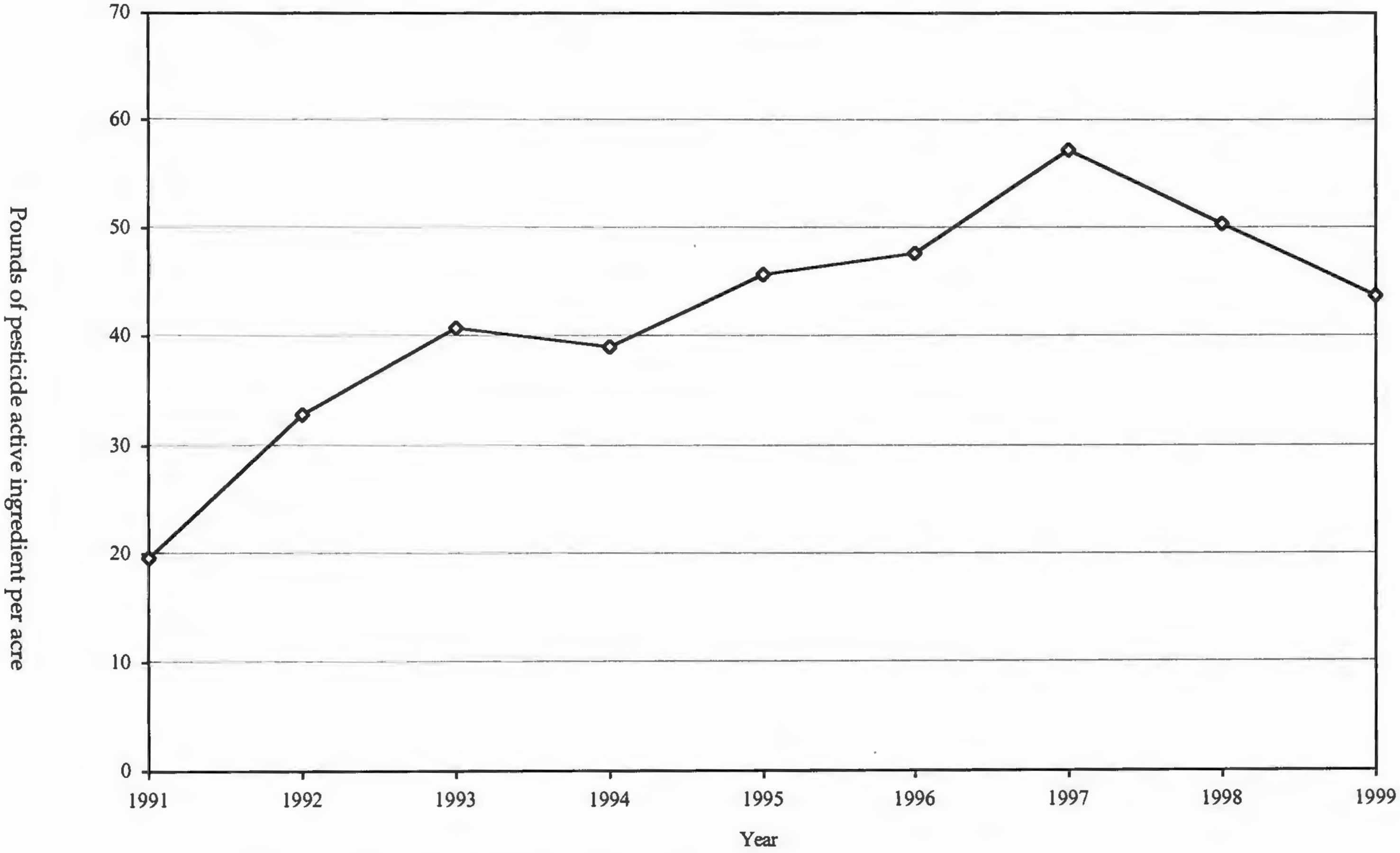
[1] Chapter 3 and the Glossary discuss these categories as defined in California statutes.

[2] See Chapter 7 for qualifications associated with using this crop budget information.



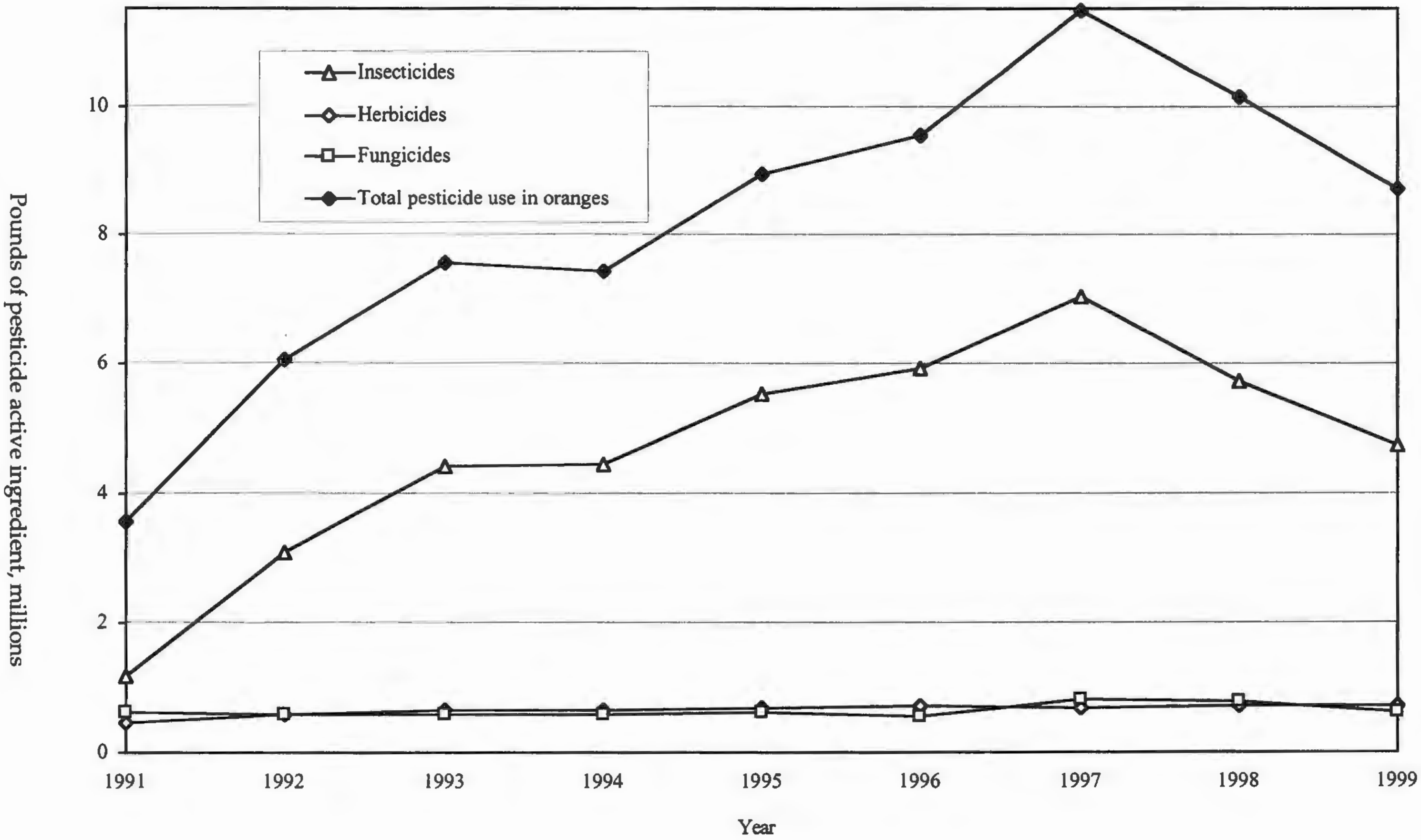
Source: Compiled by the authors from California Department of Pesticide Regulation, PUR database, 2001.

Fig. 10.6 Pesticide expenditure per acre on California oranges, 1991–1999



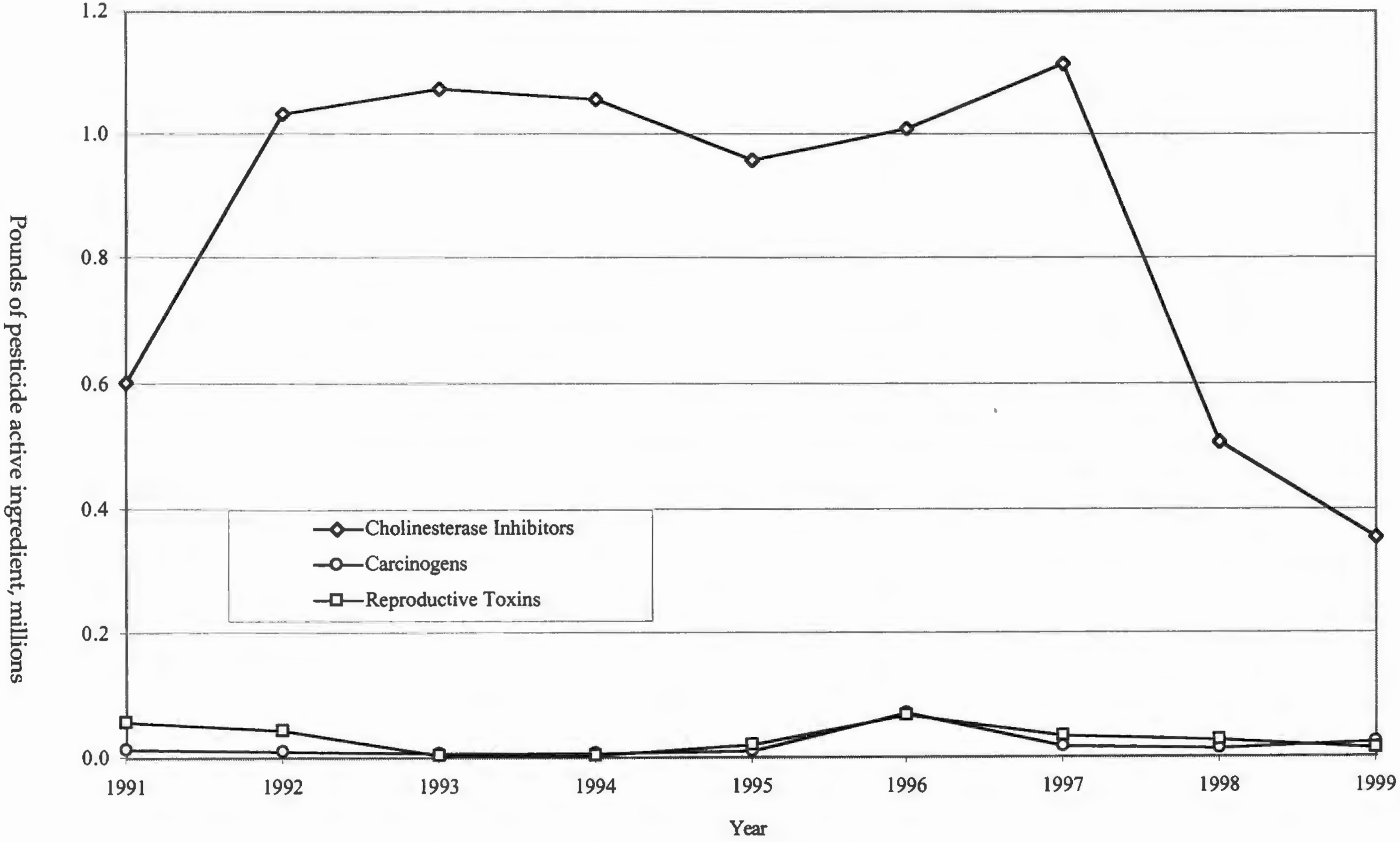
Source: California Department of Pesticide Regulation, PUR database, 2001.

Fig 10.7 Pesticide use on California oranges per bearing acre, 1991–1999



Source: Compiled by the authors from California Department of Pesticide Regulation, PUR database, 2001.

Fig. 10.8 Pesticide use on California oranges, 1991–1999



Source: Compiled by the authors from California Department of Pesticide Regulation, PUR database, 2001.

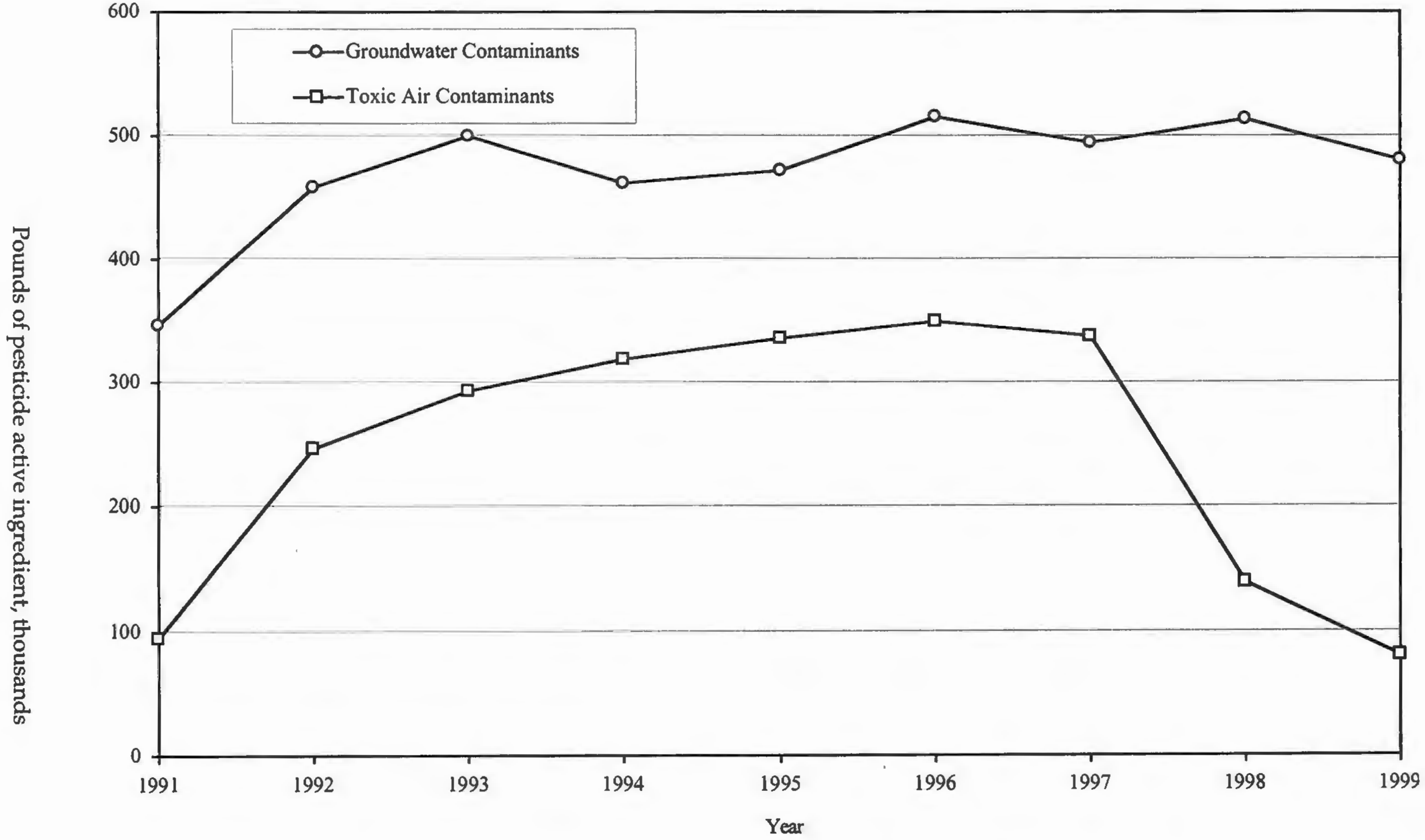
Fig. 10.9 Pesticide use on California oranges: human health, 1991–1999

the main orange-growing counties in California from the early 1950s to 1999. We estimated the share of preharvest production costs attributable to arthropod management, where management costs included materials, hired labor and machinery costs. These budget shares and real arthropod management costs are presented in Table 10.4. Although UC Cooperative Extension prepared most of the budgets, all the 1973 budgets for California and for a range of counties were prepared as part of a joint project with the University of Arizona. The budgets for Ventura County were prepared as part of a series known as "Citrimation for Ventura County." The budgets perhaps underestimate the cost of insect control in that they are based on a spray program easily overturned in the event of an unanticipated pest outbreak. As the costs of pest management for navel oranges were neither consistently larger nor smaller than pest management cost for Valencia oranges, we have not differentiated them.

Budgets were available from 1997 and 1998 for the San Joaquin Valley, the Coachella Valley in Riverside County, western Riverside County, San Diego County, and Ventura County. Per acre arthropod management costs (in real-year 2000 dollar terms) were $409 for the San Joaquin Valley, $127 for the Coachella Valley, $132 for western Riverside County, $103 for San Diego County, and $317 for Ventura County. The differences largely reflect the extent of biological control in each area. In the San Joaquin Valley, the usual practice is still to apply insecticides for worms in March, thrips in May and June and scale in July. In Ventura County, one or two insecticides are applied, but the budgets noted that many growers used fewer applications. The other counties rely more on biological control through the release of natural enemies. Coachella Valley growers are required to participate in a scale eradication program.

The limited number of records, particularly in the 1960s and early 1970s before the introduction of IPM, make it impossible to confidently draw inferences about trends in pest management practices. It does seem, however, that pest management costs were higher in Central Valley counties than for counties in Southern California or along the coast. In the San Joaquin Valley, arthropod management costs in real terms were in the $300 to $400 per acre range, amounting to 25 to 30 percent of preharvest costs. Two budgets for Tulare County suggest that in the late1970s, arthropod management costs were around $110 per acre and 12 percent of preharvest costs. This is in line with Hall's (1977) results.

In Riverside, San Bernardino and Orange counties, arthropod management costs were generally less than $300 per acre (year-2000 dollars), with the exception of 1984 when budget estimates for San Bernardino County rose to almost $500. In the late 1970s, budget shares for arthropod management in Southern California were around 20 percent. Unfortunately, we were not able to find budgets for the intervening years to confirm this trend. Arthropod control costs in Ventura County were generally in the order of



Source: Compiled by the authors from California Department of Pesticide Regulation, PUR database, 2001.

Fig. 10.10 Pesticide use on California oranges: the environment, 1991–1999

Table 10.4 Estimates of pest management costs from orange budgets, 1951–1999

Year	County	Variety	Real pest management costs per acre	Pest management share of pre-harvest costs
			(year-2000 dollars)	(percentage)
1951	Orange	V	251	16
1954	Orange	V	204	22
1956	Orange	V	243	25
1973	Orange	V	254	23
1973	San Bernardino	V	398	34
1973	San Bernardino	N	398	33
1973	Riverside	V	382	25
1973	Riverside	N	398	25
1973	San Diego	V	239	14
1973	Ventura	V	382	29
1973	Ventura	N	366	28
1973	Tulare	V	366	31
1973	Tulare	N	413	34
1976	Kern	N	329	27
1977	San Bernardino	N	284	18
1977	Tulare	V	119	12
1977	Tulare	N	119	14
1977	Ventura	V	427	26
1977	Ventura	N	438	27
1978	San Bernardino	N	246	18
1979	Ventura	V	461	29
1980[a]	Riverside		243	20
1980[b]		V	390	35
1980[b]		N	324	27
1980	Fresno	N	300	20
1980	Tulare	V	85	10
1980	Tulare	N	103	12
1981	Ventura	V	470	30
1982	San Joaquin	N	283	23
1984[a]	San Bernardino		488	29
1984	Ventura	V	237	18
1985	San Joaquin	N	302	22
1986[b]		V	339	29
1986[b]		N	380	34
1987[a]	San Joaquin		353	24
1995[a]	San Joaquin		388	28
1997	Ventura	V	317	25
1998	Riverside	V	127	13
1998	Riverside	N	132	9
1998	Coachella	V	127	13
1998	San Diego	V	103	4
1999[a]	San Joaquin		409	39

[a] Variety not specified Note: V = Valencia; N = navel

[b] Statewide

Source: Compiled by the authors.

25 percent of preharvest costs and greater than $300 (year-2000 dollars), showing little trend. However, we have at most only six entries for any of the counties.

It is difficult to discern from the budgets when IPM practices became widespread in Southern California and hence when arthropod management costs declined there. It would seem from the limited evidence in Table 10.4 that this did not occur as a general practice until after 1980, although some growers may have adopted IPM earlier.

10.6 Expenditure by UC on Research and Extension in the Orange Industry

In 1997, the UC system spent an estimated $4.1 million on research (Table 3.6) and $0.6 million on extension (Table 3.7) related to pest management in oranges (year-2000 dollars). The present value in 2000 of the stream of research and extension investments from 1970 to 1997 was $168 million. We suspect that this estimate of expenditure may be high.

The CRIS data (Chapter 3) does not provide an estimate of expenditure in the orange industry. However, it does provide aggregate data for citrus and tropical and subtropical fruit. Real expenditure on this category was $5.4 million in 1970, rising to $7.2 million in 1982 and falling to $4.5 million in 1991 before rising again to $6.5 million in 1997 (Table 3.5a). If California spent little on tropical and subtropical fruit, it may be reasonable to compare total expenditure for this category to the benefits on IPM research in oranges. No doubt there have been some IPM benefits to the lemon and grapefruit industries, but benefits are few relative to the control of scales, which was a major area of UC activity. Scales are not a severe problem in lemons, and the grapefruit industry is subject to a statutory eradication campaign.

From the CRIS data (Table 3.5), total expenditure on pest management by the UC system in 1997 was $61 million. The share of total farm receipts accounted for by oranges is about 2 percent. If 2 percent of these research funds are also devoted to the orange industry, then annual expenditure on pest research in oranges is about $1.2 million.

Alternatively, the UC system spends about $200 million on all agricultural research. If the orange industry also gets 2 percent of research funds, then expenditure on research in oranges is about $4 million. If pest management in oranges accounts for 25 percent of this total, then expenditure on pest management research for oranges is about $1 million per year.

Lacking better information on expenditure on pest management research and extension in oranges, we followed two scenarios. The first was to use the estimate of expenditure based on the CRIS dataset. The second was to assume that real expenditure on research in oranges was $1 million per year, based on the congruence approach outlined above. To this stream of research expenditure, we added our estimate of expenditure on extension. For this second scenario, the present-value stream of real expenditure on research and extension in pest management in oranges from 1970 to 1997 compounded forward to 2000 was $62.6 million.

10.7 Financial Analysis of Benefits and Costs

The key issues in the management of pests in oranges were identified above. The objective of this section is to identify where the UC system has made major contributions since 1950 and attempt to put a value on the associated gains to the industry.

A significant contribution of the UC system has been in reducing the costs of managing arthropod pests through the development and promotion of an IPM program that, in the case of the orange industry, is based on the use of biocontrol agents. In particular, information on the life cycle of scales and their interaction with *Aphytis melinus,* other control strategies and the climate has allowed the development of an IPM program that is widely used within the industry in Southern California and has led to cost savings there from a reduction in pesticide use.

It has been difficult to value the benefits from UC research and extension activities in the San Joaquin Valley. As discussed, most resources seem to have been used to develop for the San Joaquin Valley an IPM program adapted from the program successfully developed for Southern California. However this IPM program has yet to be widely adopted in the San Joaquin Valley. Some of the explanations offered by Grafton-Cardwell (2000) have already been noted. Part of the reason for slower adoption of IPM in the San Joaquin Valley is that the technology is more expensive to apply in the valley. Natural enemies have to be released at a far greater rate, and in some years oils have to be applied so scale populations do not outstrip the released aphytis populations. Despite the lower economic attraction, the adoption of the IPM program has increased in the valley, particularly among growers with resistant scale populations, who were spraying three times a season, and by growers hoping to avoid scale resistance problems. The extent of adoption in the San Joaquin Valley has never been documented. Our assumptions below reflect the judgment of industry specialists at the UC Kearney Agricultural Center.

The program became less attractive to many growers with the advent of new pesticides in the mid-1990s, particularly the insect growth regulators (IGRs) in 1998 and 1999. As indicated by the rapid adoption of these chemicals, many growers have benefited from their introduction, but others have experienced disruption of their biologically based control strategies. Although chemical companies developed these new pesticides, UC research and extension programs have no doubt contributed to their adoption and use in appropriate situations. UC researchers have also been anxious to warn of their dangers, particularly in terms of their toxicity to natural enemies, and some argued against the emergency registration of the IGRs in 1998. It is too early to be definitive about the impact of these new insecticides with respect to the ability of both target and nontarget insects, particularly beneficials, to develop resistance. Hence it is not clear how the IPM program for the San Joaquin Valley will have to be adapted in coming years.

In the analysis below, we have focused on the benefits from the use of biological agents to control scales. As in other industries, research and extension resources have also been devoted to a range of other issues since 1950 in response to changing, often short-term, pest problems. Examples include research that led to increasing the pesticide tolerance of female citrus red mites and research into selective insecticides for thrip control. We concentrated on what we see as the major achievement in pest management in oranges and have not attempted to value the benefits that flowed from these other projects. With respect to the San Joaquin Valley, we have taken a conservative approach in focusing on the adoption of and benefits from the existing IPM program, ignoring changes occurring in the industry in 1998 and 1999 (except for the lower use of the IPM program) because of uncertainty about their longer term impacts.

Key Assumptions in Valuing the Orange IPM Program

We attempted to estimate the benefits from research and extension on the control of scales in Southern California and the San Joaquin Valley. The benefit-cost analysis is based on the following key assumptions:

- In Southern and Coastal California, scale can be controlled by biological agents at a cost of about $40 per acre, whereas the cost of controlling scale in the San Joaquin Valley using insecticides is about $120 per acre, a net gain of $80 per acre. (These cost estimates are taken from the UC Cooperative Extension cost of production budgets from 1997 to 1999. The advent of IGRs since 1997 may have lowered the benefits from biological control of scale at least temporarily, but we have not valued this.)
- The IPM program was adopted by 70 percent of growers in Southern and Coastal California.
- The benefit of the IPM program in any one year is estimated by applying these last two assumptions to the area of oranges in California other than the San Joaquin Valley.
- The benefits of the IPM program began in 1980 and continue to the present day.
- In the San Joaquin Valley, the technology was adopted gradually from 1980 and peaked at around 25 percent of the area in 1997. In our analysis we assumed that adoption increased by 5 percent in 1980 and by 1 percent every two years until 1992 then, because of the appointment of an extension specialist at Kearney to serve citrus industry needs in the San Joaquin Valley, increasing by 4 percent per year until 1997. It has since declined to about 15 percent of area because of the attractiveness of the IGRs.

- The cost of *Aphytis* release in the San Joaquin Valley is $60 per acre (because a higher rate of release is required), and we have assumed that oils have to be applied at a cost of $180 per acre every four years. The gain is only $15 per acre. However, this is a conservative estimate for those growers with significant resistance problems.

The benefits we have recognized here arise from the introduction of biological control agents for scale insects. It is difficult to see how such a program could have been developed without the UC contribution.[3] The opportunities for growers to "learn by doing" seem limited, and to the extent that some of these scale problems are peculiar to California, it is unlikely that the technology could have been imported from other states. Hence it seems reasonable to accredit these benefits to the UC system and to assume that they continue to this day. In the case of San Joaquin Valley growers, we have assumed that the IPM program is presently less attractive, but if resistance to IGRs develops, technology based on biological control may regain its value.

Our approach of only valuing the net savings from controlling scales by releasing their natural enemies understates the benefits of the IPM program if predator communities also reduce the need to use insecticides to control other arthropods. This explains to some extent why the benefits recognized here of $80 per acre are much less than the difference in arthropod management costs between the San Joaquin Valley and other growing regions, which may be due to region-specific factors rather than to a UC contribution.

Implicit assumptions of our approach are that changes in the size of the orange industry have been unrelated to the widespread adoption of an IPM program and that the IPM program has had no impact on the yield and quality of oranges. Hence the "without" IPM scenario is that areas, yield and quality in the industry are unchanged but that growers have to apply one more insecticide for these parameters to hold.

An implication of this assumption is that the supply of oranges in California is inelastic—supply has not increased in response to cost savings. Hence price has not been changed by the technology, and most of the benefits of the IPM program have been captured by growers rather than passed on to consumers in the form of increased production and lower prices.

Also implicit is an assumption that growers choose pest management programs to maintain yield. IPM programs often point out to growers that they should compare the damage from pests with the costs of control at the margin, but we have assumed that the savings in pesticides are achieved without a yield sacrifice. Similarly, we have assumed no change in the quality of the oranges produced.

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[3] The USDA Boyden Laboratory may have contributed to the management of pests in Southern California in earlier years, but this did not extend to biological control in the San Joaquin Valley.

Benefit-Cost Analysis

The real benefits from the biological control of scales, compounded forward to 1999, were $66.8 million in Southern California and $5.6 million in the San Joaquin Valley, giving a total benefit stream worth $72.4 million. The value of the stream of research and extension expenditures from 1970 to 1997 was $168 million, hence the benefit-cost ratio under these assumptions is 0.43:1. Such a low benefit-cost ratio was unexpected, given the pioneering work done in IPM in the orange industry. One reason for the low return may be related to the contraction in the size of the industry in Southern California as urban demand for land has increased. For the scenario in which research expenditure was at the rate of $1 million per year since 1970, the benefit-cost ratio is 1.2:1.

It would seem that the key to enhancing the flow of benefits from this investment in pest management in citrus over many years is to be able to extend or adapt the principles of managing insect and mite pests of citrus from the industry in Southern California to the now larger industry in the San Joaquin Valley. The difficulties presented by the insecticidal control of thrips have already been discussed. We also noted that an IPM program developed for the San Joaquin Valley was being adopted more widely, particularly among growers experiencing resistance problems. However, the uncertainties surrounding the advent of new pesticides and the threat of exotic pests mean that the San Joaquin Valley program, relying heavily on the release of Aphytis wasps to control scale, is less relevant to growers at the present time. There may be large payoffs to research and extension activities that further adapt the extensive knowledge about the control of insects and mites in oranges in California to the San Joaquin Valley.

CHAPTER 11

An Evaluation of Pest Management R&D in Processing Tomatoes

11.1 The Processing Tomato Industry in California

The California tomato industry is made up of two different segments: processing tomatoes and fresh market tomatoes. California accounts for roughly 88 percent of harvested acres of processing tomatoes in the nation. In 2000, the value of processing tomatoes was roughly $617 million, placing the industry seventh in terms of cash receipts in California in 1999. The majority of the processing tomato crop is grown in the Sacramento Valley and the San Joaquin Valley. Data on such key variables as harvested acres, yield, production, price, and value of production are presented in Table 11.1 and Figures 11.1 to 11.5.

Harvested Area

The area of processing tomatoes harvested increased from 75,500 acres in 1950 to 271,000 acres in 2000. The industry grew most in the early 1970s and the late 1980s. The largest area harvested was 329,000 acres in 1999. The area harvested has been more variable in the 1990s. Area harvested is not always a good guide to area planted because in years of heavy crops and low prices, some plantings are not harvested.

Yield, Production, Value, and Price

Processing tomato yields almost tripled over the past 50 years, increasing steadily from about 12.7 tons per acre in the early 1950s to 38 tons per acre in 2000. Processing tomato production from the 1950s to the late 1960s saw few dramatic changes, growing from 960,000 tons in 1950 to 3.9 million tons in 1971 and then rapidly increasing during the early to mid-1970s. After a plateau in tomato production during the 1980s, another uptrend appeared in the late 1980s, and production grew to 10.3 million tons in 2000 (after peaking at 12.2 million tons in 1999).

The value of processing tomato production (in real year-2000 dollar terms) grew slowly in the 1950s and 1960s. During the 1970s to 1985, the value of tomato production varied widely from a low of roughly $390 million in 1970 to a high of $1.2 billion in 1975. Since 1980 the value of production has fluctuated around $600 million (with a peak at $881 million in 1999).

The price of processing tomatoes (in real year-2000 dollar terms) fluctuated around $140 per ton from 1950 to the late 1970s. It exceeded $180 per ton on several occasions during this time but never fell as low as $100 per ton. Since 1980 the price fell steadily to $60 per ton in 2000. Hence, it would

Table 11.1 California processing tomato production, 1950–2000

Year	Harvested acres	Yield	Production[a]	Price[b]	Value of production	Real price	Value of production
				(nominal dollars)		(year-2000 dollars)	
	(thousands)	(tons/acre)	(tons, thousands)	(dollars/ton)	(millions)	(dollars/ton)	(millions)
1950	75.5	12.7	959	23.50	22.5	144.00	138.1
1951	148.3	14.9	2,210	30.20	66.7	172.64	381.5
1952	112.9	16.1	1,818	25.50	46.4	143.50	260.8
1953	83.0	17.0	1,411	22.90	32.3	127.22	179.5
1954	79.5	16.9	1,344	20.40	27.4	112.21	150.8
1955	116.3	17.1	1,989	22.80	45.3	123.27	245.2
1956	151.5	18.3	2,772	22.70	62.9	118.65	328.9
1957	128.7	15.7	2,021	21.90	44.3	110.81	223.9
1958	152.9	17.2	2,630	22.70	59.7	112.19	295.1
1959	129.7	15.4	1,997	21.80	43.5	106.53	212.8
1960	130.0	17.3	2,249	23.40	52.6	112.75	253.6
1961	146.8	15.8	2,319	30.10	69.8	143.43	332.6
1962	177.2	18.2	3,218	27.60	88.8	129.76	417.6
1963	129.0	19.1	2,464	25.40	62.6	118.10	291.0
1964	143.0	21.0	3,003	31.30	94.0	143.38	430.6
1965	122.8	20.1	2,468	41.60	102.7	187.07	461.7
1966	162.5	19.3	3,136	36.10	113.2	157.84	495.0
1967	186.7	17.1	3,193	44.90	143.3	190.42	607.9
1968	231.3	21.2	4,904	41.40	203.0	168.33	825.4
1969	154.0	21.9	3,373	33.50	113.0	129.83	437.9
1970	141.3	23.8	3,363	31.60	106.3	116.28	391.0
1971	163.7	23.7	3,880	34.00	131.9	119.11	462.1
1972	178.9	25.3	4,526	34.00	153.9	114.26	517.1
1973	218.0	22.3	4,861	41.10	199.8	130.79	635.8
1974	249.9	23.4	5,848	63.80	373.1	186.29	1,089.4
1975	299.2	24.3	7,271	62.50	454.4	166.92	1,213.6
1976	233.8	21.7	5,066	56.20	284.7	142.06	719.7
1977	276.4	24.1	6,670	63.90	426.2	151.75	1,012.1
1978	231.9	22.8	5,290	63.70	337.0	141.23	747.0
1979	250.0	25.4	6,350	67.50	428.6	138.14	877.2
1980	208.3	26.6	5,541	59.70	330.8	111.90	620.0
1981	204.3	24.0	4,903	64.70	317.2	110.93	543.9
1982	232.0	26.5	6,148	68.50	421.1	110.55	679.7

(continued)

Table 11.1 Continued

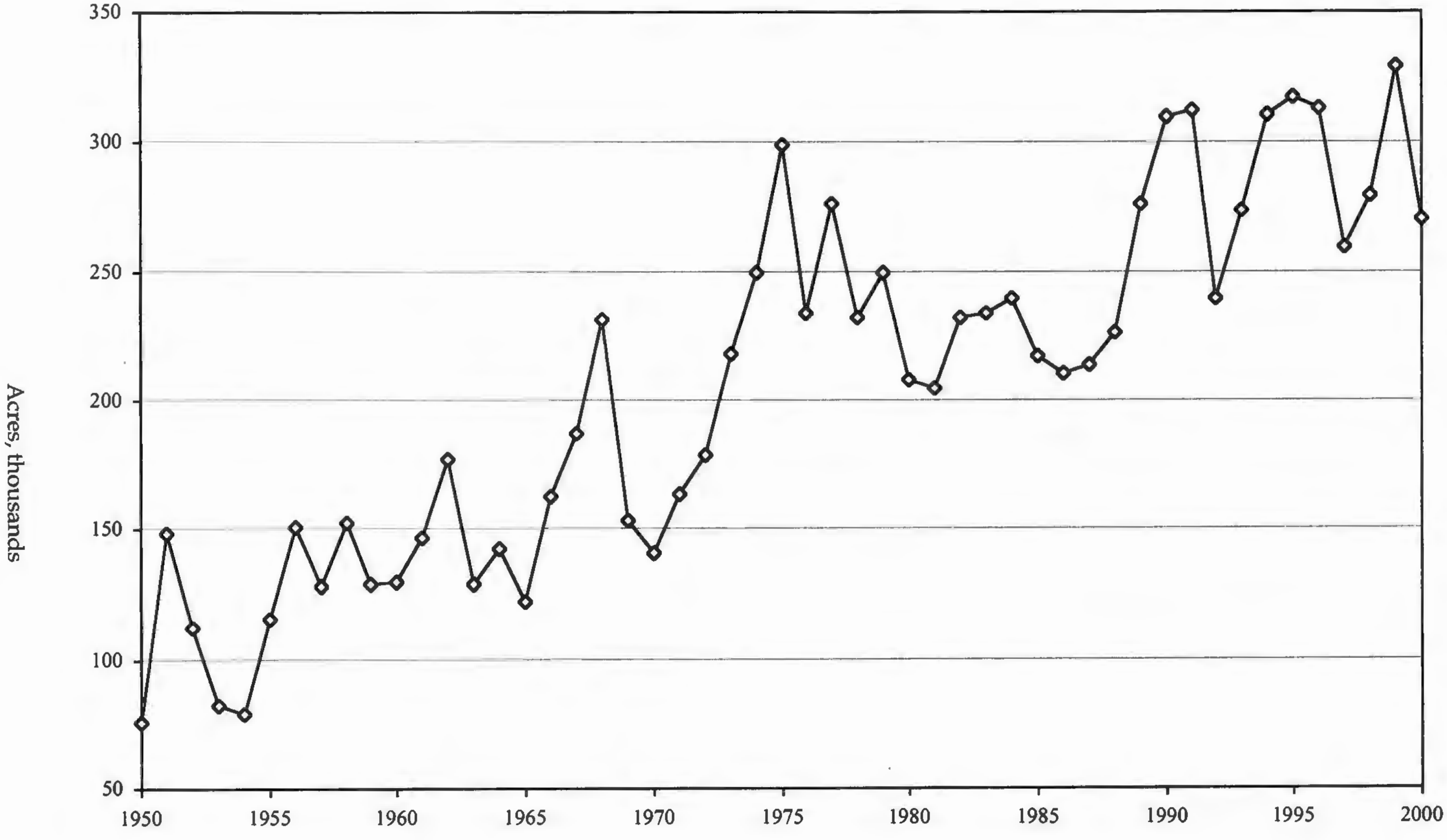
Year	Harvested acres	Yield	Production[a]	Price[b]	Value of production	Real price	Value of production
				(nominal dollars)		(year-2000 dollars)	
	(thousands)	(tons/acre)	(tons, thousands)	(dollars/ton)	(millions)	(dollars/ton)	(millions)
1983	233.5	25.6	5,973	65.70	392.4	101.99	609.2
1984	239.7	27.5	6,592	64.80	427.1	96.99	639.3
1985	217.0	28.1	6,102	64.10	391.1	93.01	567.5
1986	210.4	30.8	6,480	62.20	403.1	88.30	572.2
1987	214.0	31.3	6,702	57.20	383.4	78.84	528.4
1988	226.1	29.0	6,548	58.90	385.7	78.51	514.1
1989	276.5	31.1	8,585	68.30	586.4	87.70	752.9
1990	310.0	30.0	9,306	66.30	617.0	81.94	762.6
1991	312.0	31.7	9,894	64.70	640.1	77.16	763.3
1992	240.0	33.1	7,932	56.40	447.4	65.66	520.8
1993	274.0	32.7	8,952	59.10	529.0	67.19	601.5
1994	311.0	34.6	10,748	61.00	655.6	67.94	730.2
1995	317.0	33.5	10,607	62.30	660.8	67.90	720.2
1996	313.0	34.1	10,661	61.10	651.4	65.33	696.5
1997	260.0	36.0	9,350	59.50	556.3	62.40	583.5
1998	280.0	31.8	8,893	64.20	570.9	66.50	591.4
1999	329.0	37.2	12,239	70.50	862.9	71.95	880.6
2000[c]	271.0	38.0	10,287	60.00	617.2	60.00	617.2

Source: Compiled by the authors from the California Agricultural Statistics Service, *California Vegetable Crops*, 1950-1992; and the USDA, National Agricultural Statistics Service, *Vegetables Annual Summary*, 1993-2000.

[a] Production on basis of paid for tonnage purchased from growers as reported by processors, dockage not included

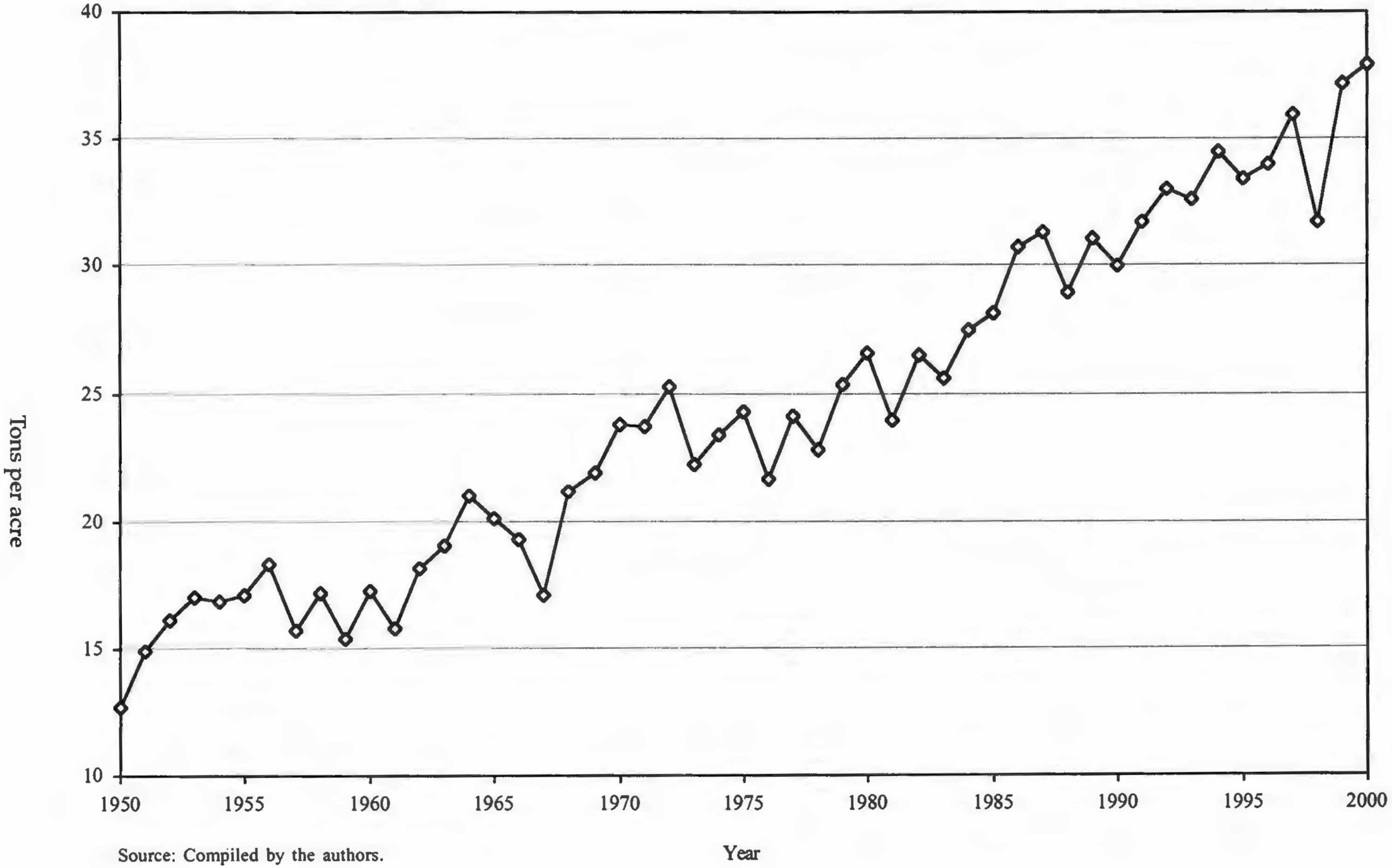
[b] Price on basis of equivalent return at processing plant door

[c] Preliminary



Source: Compiled by the authors.

Fig. 11.1 California processing tomato harvested acreage, 1950–2000



Source: Compiled by the authors.

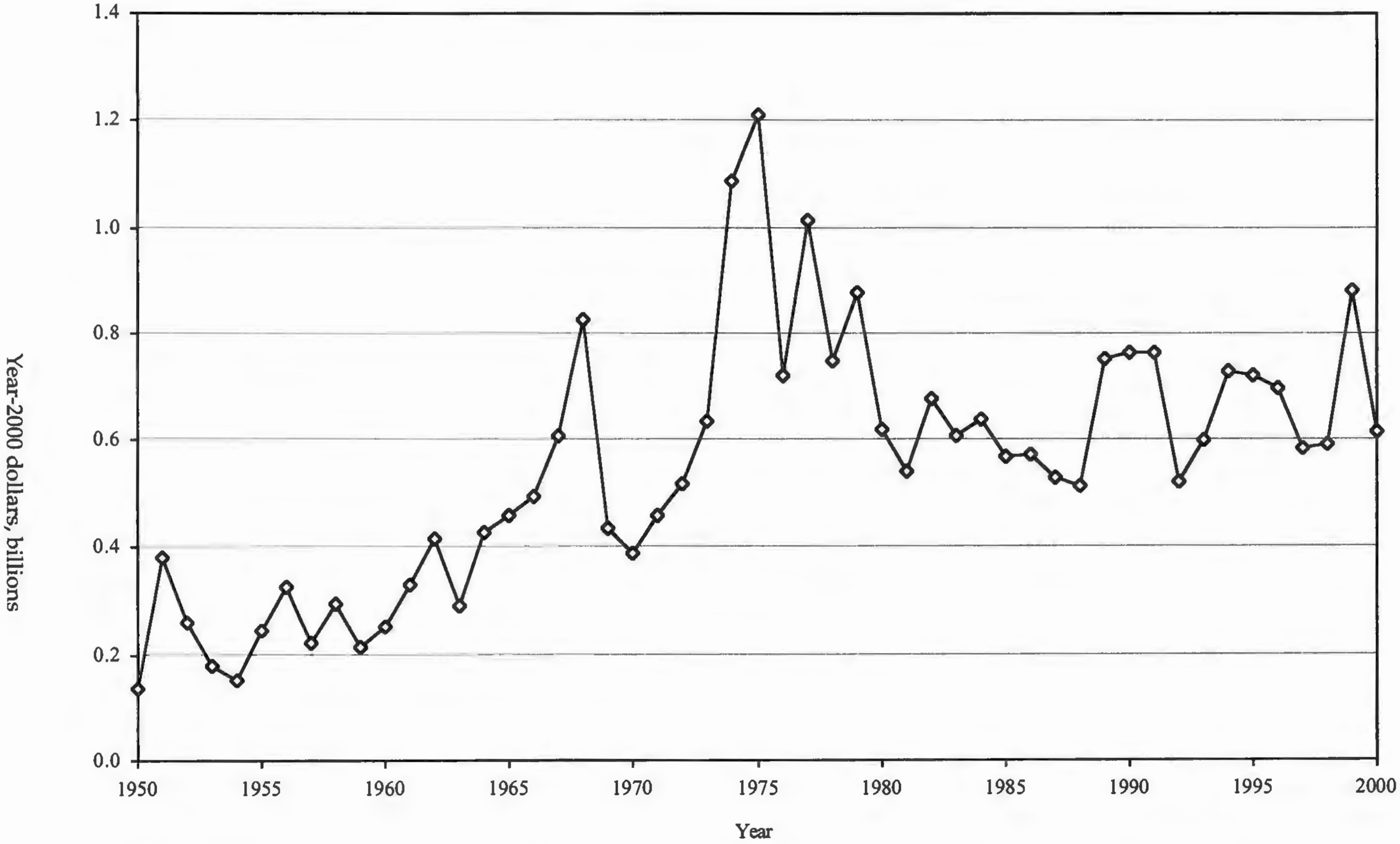
Fig. 11.2 California processing tomato yield, 1950–2000

Source: Compiled by the authors.

Fig. 11.3 California processing tomato production, 1950–2000

Source: Compiled by the authors.

Fig. 11.4 California processing tomato price, 1950–2000



Source: Compiled by the authors.

Fig. 11.5 California processing tomato value of production, 1950–2000

seem that yields rose quickly enough that production was maintained despite this downward trend in prices.[1]

11.2 Significant Pests in the Processing Tomato Industry

The pests and diseases of processing tomatoes are described by a number of sources, including the UC IPM Project (1998), the UC Agricultural Issues Center (1988), Lange and Bronson (1981) and the USDA's website crop profile for processing tomatoes in California (ipmwww.ncsu.edu/opmppiap). These sources are drawn on extensively in the following discussion.

Worms causing damage to tomatoes include, most commonly, the tomato fruitworm and beet armyworm and, less commonly, the yellowstriped armyworm, tobacco budworm, and the tomato pinworm. The first two in this list can be found throughout California, but the others are pests in specific regions. Stinkbugs and hornworms damage fruit in some years in all regions. In general, cosmetic damage is less important in the processing tomato industry than in the fresh tomato industry, and yield loss from cosmetic damage is generally not high. However, a high level of contamination can mean a discounted price or the rejection of a load, particularly for tomatoes going to end uses that require peeling.

It is important to control these insects early before they enter the fruit and when they are most susceptible to insecticides. The UC IPM Project (1998) describes protocols for monitoring armyworms, fruitworms and other insects and for making pest management decisions based on threshold numbers of insects. Pheromone trapping and augmentative release of natural enemies are used less widely. According to Wilhoit et al. (1999), the main insecticides used include esfenvalerate, methomyl, carbaryl, diazinon and *Bacillus thuringiensis*, Bt.

At the seedling stage some pests, such as cutworms, garden symphylans and flea beetles can reduce stands to the extent that some replanting is required. The UC IPM Project (1998) notes that many insects, including tomato russet mite, leafminers, cabbage loopers and hornworms cause foliage damage but seldom affect yield and are easily controlled.

Some insects such as aphids, thrips and beet leafhoppers are vectors for diseases such as alfalfa mosaic virus, spotted wilt and curly top virus. The UC IPM Project (1998) suggests that controlling the vectors is usually ineffective in controlling these diseases because by the time the infestation is observed, the damage has already occurred. Hence, insecticides are no longer recommended for this purpose. There are natural enemies of some aphid and caterpillar species. Sulfur is widely used to treat mites and powdery mildew.

Lange and Bronson (1981) noted that the introduction of mechanical harvesting had an impact on pest management. Vinegar flies, for example, are

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[1] At the time of writing this report in 2001 prices and area planted had both fallen.

no longer a major pest because of the rapid harvesting and removal of fruit from the field. However, protection against such insects as *Heliothis* and *Spodoptera* is still required at a particular growth stage.

Nematodes (*Meloidogyne spp.*) damage tomatoes, especially in sandy soils. Roberts, May and Matthews (1986) observed yield losses of about 50 percent in field trials of crops grown in nematode infested sites. As a result of UC research, the Mi gene for resistance to three common strains of root-knot nematode was introduced to commercial processing-tomato varieties in the early 1980s. Until then crop rotation and the use of fumigants or nematicides were the only means of control. No single chemical provided protection against all nematode species. While the Mi gene provides good resistance against the most common nematode, *Meloidogyne incognita*, protection against other species, particularly *Meloidogyne hapla*, is not nearly as effective.

Tomatoes are susceptible to a range of diseases that varies by locality. According to the UC IPM Project (1998), losses from disease, particularly verticillium and fusarium wilt, Alternaria stem canker, and tobacco mosaic, are now lower because of resistant varieties. Further control is achieved by field selection and careful irrigation practices. Fungicides and bactericides are usually used in a preventative mode, although there is growing interest in models allowing tactical response.

The most problematic weeds in tomatoes include perennials, dodder, and the nightshade family. Crop rotation is a valuable control tool because it allows the use of different cultural practices and a wider range of herbicides. Herbicides that cannot be used on tomatoes, for example, can be used on corn to control nightshades. In addition to herbicide treatments, cultivation and hand hoeing are generally required. One herbicide strategy is to use selective herbicides that pose no threat to tomatoes. The "cost" of this strategy is the buildup of populations of weeds closely related to tomatoes. The use of a broad-spectrum herbicide requires some strategy to protect the tomatoes. Almost 20 percent of all trifluralin in California is used in the tomato industry (fresh and processed). Metam sodium is used widely to control the nightshades, which were a particular problem in 1996.

11.3 Eras of Pest Management in Processing Tomatoes

The Synthetic Pesticide Era from the 1950s to the late 1970s

Lange and Bronson (1981) noted that in California pesticides commonly used to control insects and mites included carabaryl, methomyl, azinphosmethyl, parathion and sulfur. Bt was also being used to control lepidopterous larvae. They observed the problems with heavy reliance on chemicals common among the range of crops we have examined, including increased use, resistance, resurgence in pest populations, and secondary outbreaks associated with the loss of natural enemies.

Nematicides were widely used to control nematodes, but many were subsequently withdrawn because of their threat to human health and the environment. Tomato varieties resistant to nematodes were developed within the UC system but were not widely adopted until the 1990s when problems with fruit softness had been overcome, and growers had to use alternatives to banned nematicides.

The IPM Era in the 1980s and 1990s

The IPM program for processing tomatoes was released in 1985 and is described by the UC IPM Project (1998 and previous editions) and the UC Agricultural Issues Center (1988). The program relies heavily on monitoring pest populations, treatments based on pest population thresholds, and the use of crop rotation to break weed and disease cycles. As new pests have become prominent, monitoring protocols and thresholds have been developed. The UC Agricultural Issues Center (1988) noted a strong potential for the use of biological control techniques to control lepidopteran pests, including the use of Bt and augmentative release of parasites such as *Trichogramma pretiosum*, which is effective against a number of insects.

Grieshop, Zalom and Miyao (1988) found a high level of awareness of IPM worm sampling techniques and estimated that almost 60 percent of growers of California processing tomatoes had at least partially adopted IPM techniques. In contrast to the study by Antle and Park (1986) reviewed below, Grieshop, Zalom and Miyao (1988) concluded that tomato growers lowered their costs by reducing pesticide use.

UC research (Grattan, Schwankl and Lanini 1988) has suggested that weeds and diseases can be better controlled using subsurface drip irrigation systems, but the extent to which such systems have been adopted is low, probably because of the high cost. According to the USDA crop profile (ipmwww.ncsu.edu/opmppiap), insecticides are applied to about 90 percent of California's tomatoes, with processing tomatoes receiving an average of a little less than two insecticide applications per year. Nearly all of the crop (99 percent) receives some form of herbicide treatment. About 60 percent of the crop receives one to 1.5 fungicide treatments.

11.4 The Use of Pesticides in the California Processing Tomato Industry

Pesticide Use from 1991 to 1999

Pesticide use report data (DPR 2000) on pesticide use in processing tomatoes in California are unreliable until 1995 because until that time it was not always possible to make a clear distinction between pesticide use in the fresh and processing sectors. Hence the data in Table 11.2 and Figures 11.6 to 11.10 are based on 1995–2000 data.

Based on our group of 62 major pesticides,[2] real expenditure on pesti-

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[2] See Table 4.5 for the list of 62 chemicals.

Table 11.2a All pesticide use on California processing tomatoes, 1995–1999

			Year		
Pesticide	**1995**	**1996**	**1997**	**1998**	**1999**
			(thousand pounds active ingredient)		
Carcinogens	3,140	4,003	2,962	3,304	4,491
Reproductive toxins	2,873	3,695	2,703	2,660	3,936
Cholinesterase inhibitors	444	467	387	394	487
Carbamates	306	320	275	285	322
Toxic air contaminants	182	206	182	426	460
Organophosphates	109	114	101	93	122
Oils	16	11	8	9	15
Biopesticides	3	2	4	6	6
Potential groundwater contaminants	0	0	0	0	0
Reduced risk pesticides			6	15	17
Total pesticide use in tomatoes	*11,551*	*14,670*	*11,072*	*11,623*	*12,741*
			(lbs)		
Active ingredient per acre	35	46	41	41	38
			(percentage)		
Share of California total*	6.2	8.0	5.8	5.9	6.9

Source: Compiled by the authors from the California Department of Pesticide Regulation, Pesticide Use Database, 2001.

*Total pesticide use=all pesticides in production agriculture

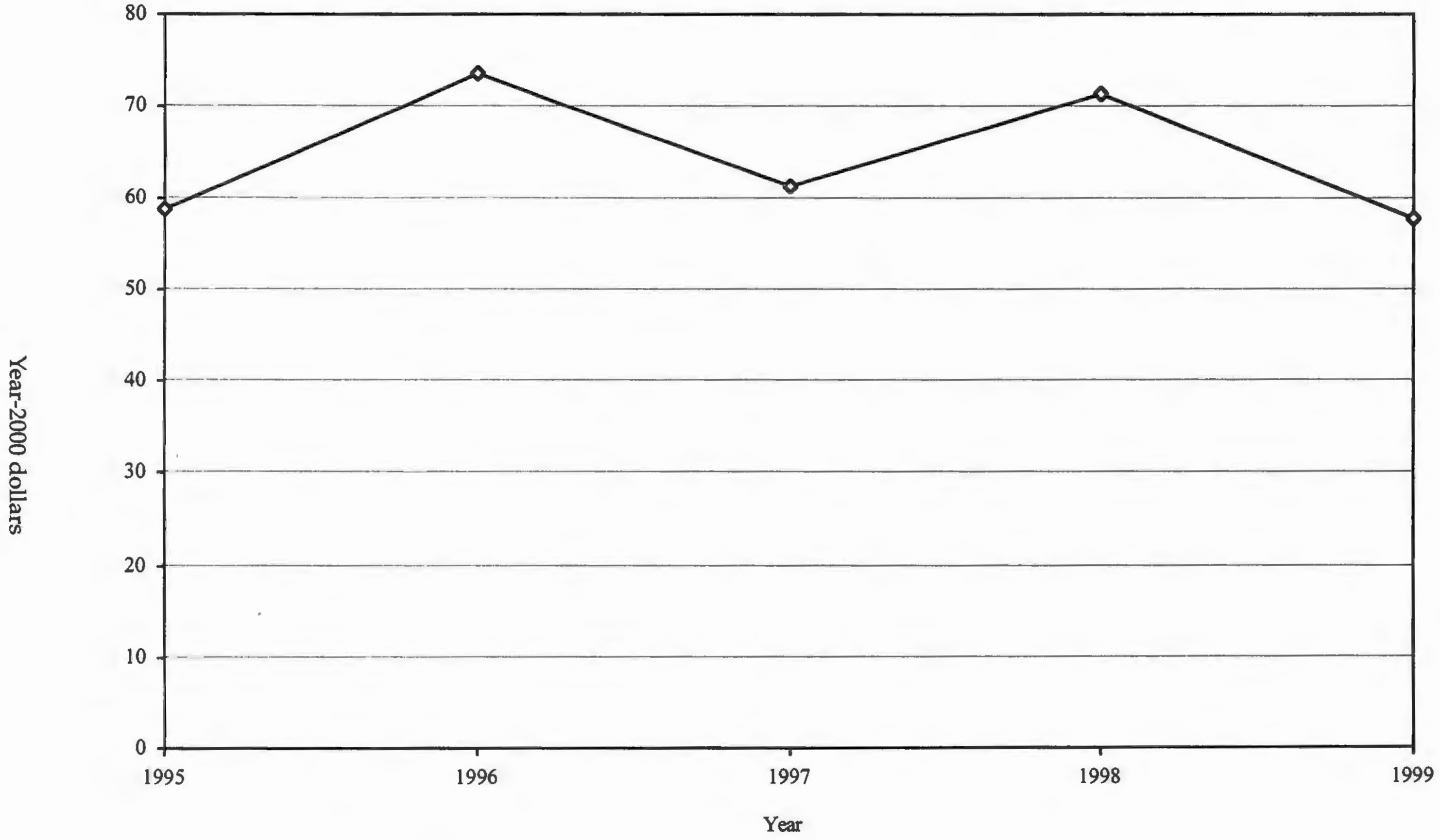
Table 11.2b Use of 62 major pesticides on California processing tomatoes, 1995–1999[a]

			Year		
Class	**1995**	**1996**	**1997**	**1998**	**1999**
			(thousand pound active ingredient)		
Fungicides	7,763	10,023	7,597	7,972	7,643
Fumigants	2,839	3,670	2,715	2,729	4,161
Herbicides	245	289	204	276	250
Insecticides	161	171	164	145	205
Plant growth regulators	29	33	11	17	43
			(percentage of total tomato pesticide use, by weight)		
Fungicides	70.3	70.7	71.1	71.6	62.1
Fumigants	25.7	25.9	25.4	24.5	33.8
Herbicides	2.2	2.0	1.9	2.5	2.0
Insecticides	1.5	1.2	1.5	1.3	1.7
Plant growth regulators	0.3	0.2	0.1	0.2	0.4
			(year-2000 dollars, millions)		
Estimated expenditures[b]	19.5	23.4	16.5	20.1	19.5
			(year-2000 dollars/acre)		
Estimated expenditures[b]	59	74	61	71	58

Source: Compiled by the authors from the California Department of Pesticide Regulation, Pesticide Use Database, 2001.

[a] The 62 pesticides are listed in Table 4.5

[b] Estimated expenditures are for the 62 major chemicals

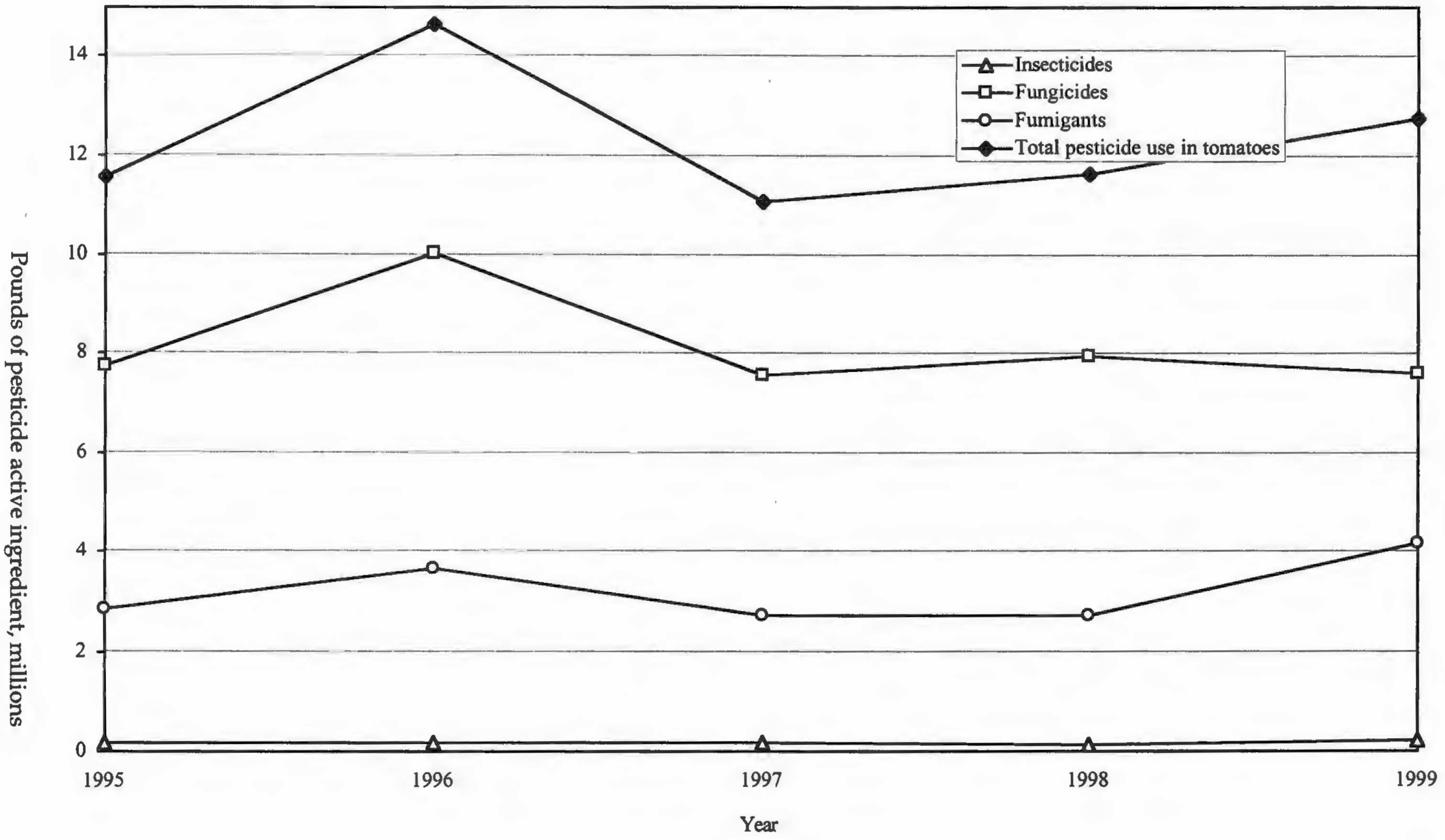


Source: Compiled by the authors from California Department of Pesticide Regulation, PUR database, 2001.

Fig. 11.6 Pesticide expenditure per acre on California processing tomatoes, 1995–1999

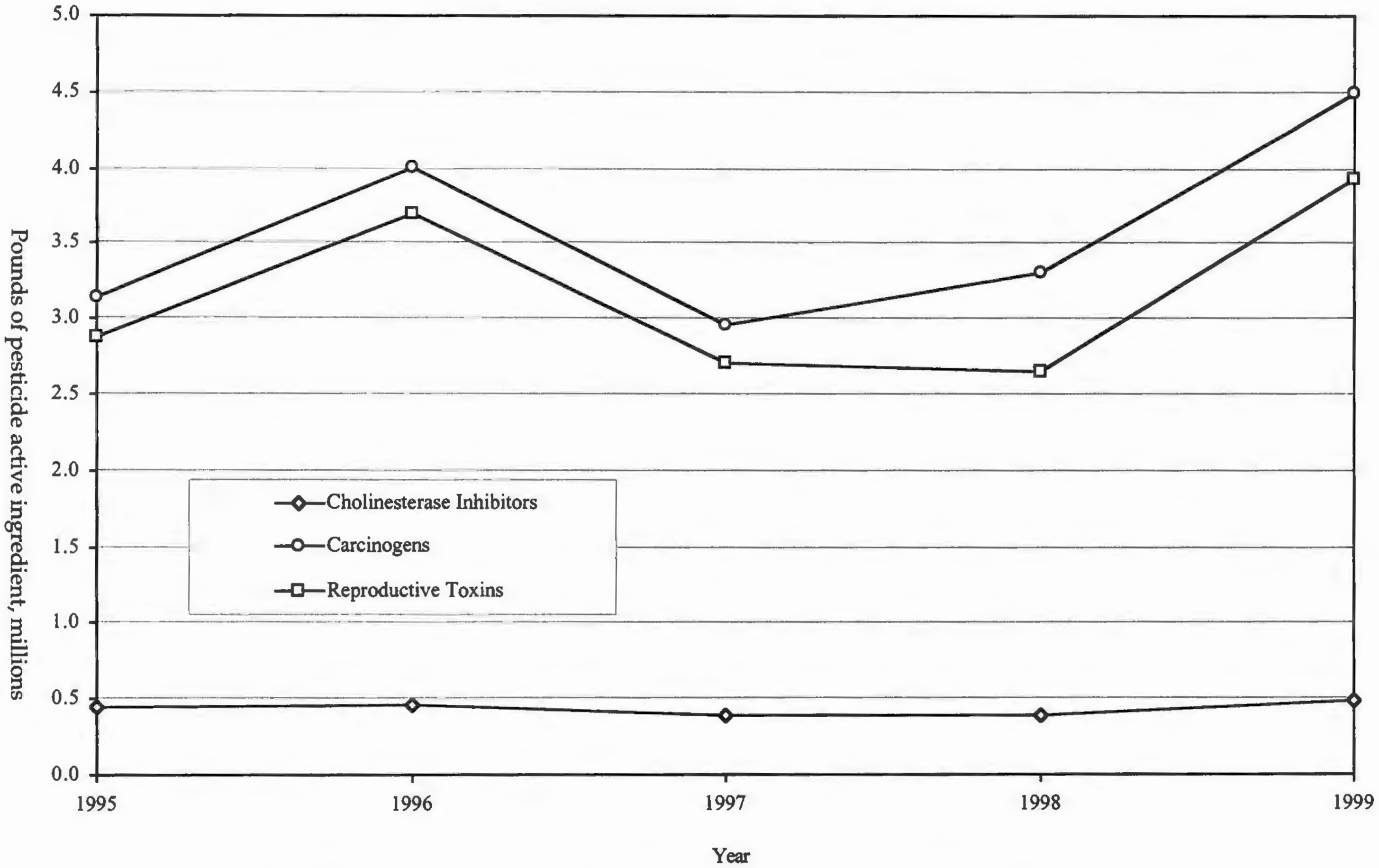
Source: Compiled by the authors from California Department of Pesticide Regulation, PUR database, 2001.

Fig. 11.7 Pesticide use on California processing tomatoes per harvested acre, 1995–1999



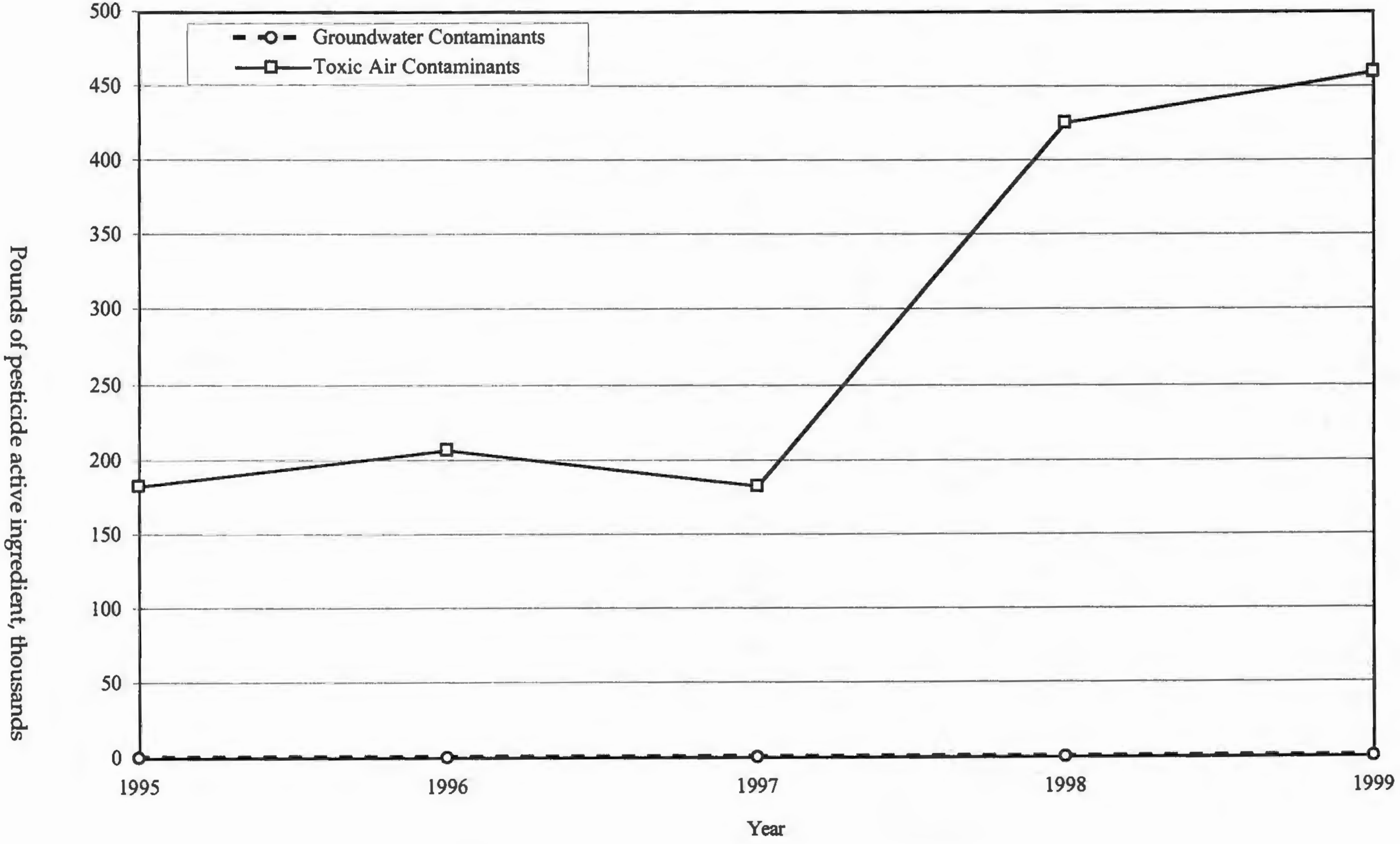
Source: Compiled by the authors from California Department of Pesticide Regulation, PUR database, 2001.

Fig. 11.8 Pesticide use on California processing tomatoes, 1995–1999



Source: Compiled by the authors from California Department of Pesticide Regulation, PUR database, 2001.

Fig. 11.9 Pesticide use on California processing tomatoes: human health, 1995–1999



Source: Compiled by the authors from California Department of Pesticide Regulation, PUR database, 2001.

Fig. 11.10 Pesticide use on California processing tomatoes: the environment, 1995–1999 cides was $19.4 million in 1995 and 1999, rising to $23.4 million in 1996 and falling to $16.5 million in 1997. Expenditure on pesticides is typically less in processing tomatoes than in the other case study crops but similar to pesticide expenditure in the orange industry. Real expenditure per acre was about $60 per acre except for the high pesticide use years of 1996 when it was $71 and 1998 when it rose to $74. This rate of expenditure per acre during these high years was similar to the average for California as a whole (Table 4.7).

The pesticide quantity data (DPR 2000) is for all pesticide use rather than the 62 pesticide subset. Pesticide use grew from 11.6 million pounds of active ingredient in 1995 to 14.7 million pounds in 1996 before falling to 12.7 million pounds in 1999. There was little change in use per harvested acre in this time. There was a spike in the use of sulfur and metam sodium in 1996, which presumably was a wet year. The use of glyphosate was also higher in 1996. There was frequent substitution between sulfur, chlorothalonil and copper hydroxide, all fungicides.

In some years up to 75 percent of the total weight of pesticides applied was accounted for by the use of sulfur. Metam sodium was the next most heavily used pesticide. The commonly used herbicides were pebulate, trifluralin and glyphosate. The main insecticides, by weight of active ingredient, were dimethoate and methomyl.

Data on the shares of total pesticides accounted for by fungicides, herbicides, insecticides, and fumigants are unavailable for processing tomatoes, but Wilhoit et al. (1998) estimated that for all tomatoes (processing and fresh), fungicides and fumigants accounted for over 90 percent by weight of active ingredients applied. The California Department of Pesticide Regulation (DPR) also collects data on the total number of pesticide applications and the total (cumulative) number of acres to which pesticides have been applied. In terms of the number of applications and acres treated, fungicides and insecticides each accounted for about one-third of use in each of these two categories, with fungicides slightly larger. Herbicides accounted for about one-quarter of the total number of applications and acres treated. From our subset of 62 pesticides, fungicides generally accounted for 70 percent and fumigants for 25 percent of total pesticide use by weight, leaving little for insecticides and herbicides (Table 11.2b).

Health Risk and Environmental Outcomes

While the processing tomato industry, in terms of pesticides tracked by DPR, has been an insignificant user of potential groundwater contaminants and has held steady in its use of cholinesterase-inhibiting chemicals that could pose human health and environmental risks (Table 11.2a and Figures 11.9 and 11.10), the industry's scorecard has deteriorated since 1995. As previously noted, a discussion of the statutory definition of these categories is provided in Chapter 3 and the glossary. Heavy and increasing use of metam sodium has meant that chemicals linked to cancer and reproductive toxicity have both increased significantly since 1995. Trifluralin has been the main source of toxic air contaminants and has been supplemented to a limited extent by the use of 1,3-D (telone II), a fumigant reintroduced in 1996. The use of pesticides classed as toxic air contaminants has also more than doubled since 1995.

11.5 Changes in the On-Farm Costs of Pest Management

Surveying past budgets for processing tomatoes prepared by UC Cooperative Extension was a less useful exercise than for other commodities, partly because there were long gaps in the availability of budgets for most counties. A series of budgets for processing tomatoes was available for Yolo County for many (but not all) years back to 1957. Pest control costs were about 10 percent of total operating costs from the 1970s to mid-1980s. During the late 1980s and throughout the 1990s, pest control as a share of total operating costs was about seven percent. This is broadly consistent with the key advances we identified in the form of the adoption of nematode resistant varieties (replacing nematicides) and reduced worm damage through better management of arthropods. However, there was too little detail in these budgets about management practices and their costs to form the basis of some of the key parameters used in the analysis below.

11.6 UC Expenditure on Research and Extension for Processing Tomatoes

From Chapter 3 (Table 3.8), we estimate that expenditure on research and extension in pest management in the processing tomato industry grew from \$1.0 million in 1970 to \$1.8 million in 1997 (in year-2000 dollars) as the industry grew. The compound value of this stream of investments from 1970 to 1997 at a discount rate of 2 per cent was \$65.3 million in 2000.

11.7 The UC Contribution to Pest Management in Processing Tomatoes

The key issues in the management of pests in processing tomatoes were identified above. The objective of this section is to identify where the UC system has made its major contributions since 1950 and attempt to value the associated gains to the industry.

In our view the UC system made two key contributions to managing pests in processing tomatoes. The first was in the use of IPM practices to reduce worm damage, and the second was the development of the Mi varieties, which have significant resistance to nematodes and allowed savings in the use of nematicides. Our approach to estimating the benefits from these two key contributions is described below.

The Management of Insects and Mites

In common with the general theme of this report, we identified the development and adoption of arthropod management systems as a significant contribution of the UC system to pest management in the processing tomato industry. In particular, information on the life cycle of arthropods and their interaction with predators and parasites, control strategies, and the climate has allowed the development of an IPM program that is widely used within the industry.

As for other crops, a range of pests have been of economic significance in the industry at different places and times in response to climatic factors and changes in control strategies. This dynamic pest environment has meant that research and extension resources have had to be used to prevent the IPM program from becoming obsolete and to maintain benefits to growers.

In terms of the original paper on IPM by Stern et al. (1959), a continuing UC investment is required to achieve a series of temporary reductions in the general equilibrium pest population through more efficient timing and choice of pesticides. At the very least, UC activities make this information available to growers earlier than if they relied on their own experimentation. California's dominance of the industry means that it is likely that little research is done elsewhere in the United States that could be adapted by growers in California.

Review of Previous Studies of IPM in Processing Tomatoes

Antle and Park (1986) reviewed California's IPM program for processing tomatoes soon after its introduction. The program was introduced in 1984 and tested on 2000 acres in the Sacramento Valley in that year. Antle and Park (1986) conducted an econometric analysis of yields and pesticide use in 56 fields, 21 of which were part of the IPM program.

They estimated an increase in revenue from IPM of $7.10 per acre arising from a 39.5 percent reduction in worm damage (assuming a yield of 25 tons per acre, a price of $52 per ton, and a preharvest damage level of 1.5 percent). Participation in the program resulted in a more-concentrated distribution of worm damage such that program fields had a 75 percent chance of experiencing damage of one percent or less compared with 20 percent for nonprogram fields. They valued this reduction in risk at $0.60 per acre. The amount of pesticides applied to program fields was 22 percent less but of a higher "quality." Hence there was little change in expenditure on pesticides. Antle and Park (1986) suggested that there might have been environmental benefits from the use of higher-quality pesticides. They found no significant change in labor costs from more systematic monitoring, but their wage rate does not seem to include any skill premium. In a later unpublished survey of 73 growers, Wiebers and Alston (1991) found a high level of IPM use in the processing tomato industry but concluded that the benefits of IPM lie in cost savings rather than yield gains.

Nematode Resistance

As already noted, another UC contribution has been in developing varieties with resistance to nematodes. This resistance to nematodes also provided some protection against potato aphid, although this has broken down in recent years and appears not to have resulted in any savings in pesticides.

Nematodes had long been a problem in the tomato processing industry. They were managed using crop rotation and a range of nematicides, the most expensive of which was telone. None of these practices was wholly effective. Moreover, there was concern about the health and environmental risks associated with nematicides. In April 1990 telone was banned as a nematicide because of its contribution to air pollution. Other nematicides may have been banned before 1990. There is no reliable data on the use of nematicides in processing tomatoes prior to 1990.

The alternatives to telone—methyl bromide and metam sodium—were not an economic proposition in the processing tomato industry. Hence growers turned to the resistant varieties. When first developed in the early 1970s, the Mi (nematode resistant) varieties were not popular with growers because their fruit was softer, which led to a higher percentage of quality downgrades. However, by 1990 Mi varieties had overcome the fruit softness problem. Resistant varieties are now used on about 40 percent of the area planted. The most popular peeling variety, 3155, which is not resistant, accounts for about 25 percent of area harvested, and the remaining 35 percent is still planted with older nonresistant varieties. Nonresistant varieties are planted in areas where nematodes are not expected to be a problem, sometimes in a rotation with the resistant varieties

This Mi technology could quickly become obsolete if nematodes overcome the single-gene resistance trait. Breeding is presently focused on introducing multiple sources of resistance. There is also some evidence that the use of resistant tomato varieties provides yield benefits to crops such as cotton and carrots that may follow in a rotation because the nematode population in the soil is much lower than is the case after a nonresistant variety. In fact, resistant tomatoes are sometimes used in a rotation as a means of reducing nematode populations. We have not attempted to estimate these benefits.

Other UC Contributions to Pest Management in the Processing Tomato Industry

Another area of pest management research has been in developing models that provide growers with weather-related disease forecasts, allowing better decisions to be made about the use of fungicides to control diseases. The industry has installed a number of weather stations in the Central Valley with matching funds from a U.S. EPA grant obtained by UC IPM and the DPR to assist with forecasting for powdery mildew, for example. Attempts to commercialize this service in California have met with limited success. At least one farm supplier, Western Farm Service, has established this service for specific crops in certain regions. In Chapter 3 we argued that information-based approaches to disease management might become more valuable to growers as technology is developed that provides growers with information on disease spread in time to allow them to respond with control strategies.

We have focused on the processing tomato industry, where IPM technologies have been more widely accepted because there is greater tolerance in this industry for some fruit damage than in the fresh sector. Nevertheless, research and extension in each industry has had spillover effects on the other. An alternative approach would have been to evaluate the industries together.

The introduction of the mechanical tomato harvester, where UC staff also made major contributions, had an impact on pest management issues in processing tomatoes. We did not attempt to estimate costs and benefits of pest management changes associated with this technology. It is debatable whether these benefits and costs should be attributed to investments in research in agricultural engineering (or other disciplines involved in developing the technology package for mechanically harvesting processing tomatoes), although it is highly likely that mechanical harvesting had an impact on pest management research and extension activities.

There have also been large changes in the management of weeds related to the development of herbicides during this period. Many of the benefits from these changes in weed management can be attributed to the chemical companies that developed the herbicides. Some of the benefits of better weed management arise from UC research and extension, which has been important in adapting control strategies to particular growing areas throughout California, but at this stage we have been unable to identify and value these changes. Hence our estimates of the contribution of the UC system are understated to this extent.

11.8 Key Assumptions in the Benefit-Cost Analysis

The following are key assumptions in the benefit-cost analysis in relation to the benefits from nematode resistance:

- There were no benefits from the Mi resistant varieties prior to 1990 because of the fruit softness problem, although it is likely that some growers with severe nematode problems were using the resistant varieties before this time.
- From 1990 the benefits were the savings of $100 per acre (year-2000 dollars) in the cost of telone treatments for 40 percent of the area planted. This estimate overstates the benefits to the extent that less expensive nematicides were used, but some of these pesticides may have been banned by 1990. It understates the benefits to the extent that the use of a resistant variety allows nonresistant varieties to be planted in the following year.

In valuing the benefits from insect and spider mite management technologies, we used the same assumptions as Antle and Park (1986) (although, in keeping with our other case studies, we did not follow them in including an additional benefit for a reduction in risk):

- Without the insect and mite management strategies in the IPM program for processing tomatoes, the preharvest level of worm damage is 1.5 percent, although the range of possible damage to an individual grower could vary considerably.

- The IPM strategies reduce this rate of preharvest yield loss by 40 percent.
- The technology has been adopted by 70 percent of growers. The rates of adoption in the years from 1981 to 1987 were 2, 5, 15, 25, 35, 45, and 70 percent of growers, respectively.

In any year the benefits from the technology were estimated by applying these assumptions about yield loss and adoption to the production of tomatoes and the real price.

11.9 Financial Analysis of Benefits and Costs

At a discount rate of 2 percent per year, the value in 2000 of the stream of benefits from 1990 to 1999 from the development of nematode resistant varieties was $134 million. The benefits from better management of insects and mites between 1981 and 1999 were $48 million. Total benefits amounted to $182 million. Recall that the value in 2000 of the investment in research and extension in pest management in processing tomatoes from 1970 to 1997 was $65.3 million. If we relate the benefits from the two key advances we have identified to these total investments in research and extension in pest management in processing tomatoes, the benefit-cost ratio is 2.8:1.

CHAPTER 12

An Evaluation of Pest Management R&D in Lettuce

12.1 The Lettuce Industry in California

The lettuce industry in California has three main sectors. Here we focus on the traditional iceberg or head lettuce sector, but the leaf and romaine lettuce sectors are also significant and have grown rapidly in the past 20 years. Pest management problems are similar across the three sectors.

The three main locations for the industry are the coastal valleys around Salinas and Santa Monica, the desert areas in southern California in winter, and the San Joaquin Valley in the spring and fall. Some growers operate in several of these locations, using expensive growing and packing equipment over a longer growing season. Lettuce is a short-season crop of between 70 and 130 days, depending on sowing time and temperature.

California accounts for roughly 70 percent of harvested acres of head lettuce in the nation. In 1999, the value of head lettuce was $744 million (year-2000 dollars). The value of farm receipts from all types of lettuce was over $1 billion in 1999, placing the industry fifth in terms of cash receipts in California. Data on key parameters such as harvested acres, yield, production, price, and value of production are presented in Table 12.1 and Figures 12.1 to 12.5.

Harvested Area

The area of head lettuce harvested increased from 129,500 acres in 1950 to 143,500 acres in 2000 (the other two sectors of the industry grew more rapidly). The industry grew most rapidly in the 1970s and 1980s, reaching 168,000 harvested acres in 1989 (Figure 12.1). Area harvested is not always a good guide to area planted because in years of heavy crops, and hence low prices, or when disease and insect damage is high, some plantings are not harvested.

Yield, Production, Value, and Price

Head lettuce yields almost tripled over the past 50 years, increasing steadily from about 140 hundredweight per acre in the early 1950s to 380 hundredweight per acre in 1999 (Figure 12.2). Yields have increased for a number of reasons. The release of the Salinas variety in 1975 increased yields from around 600 cartons per acre to 750 cartons per acre. Its advantages were resistance to tip burn, a physiological problem in relation to the movement of calcium in the plant, and "softer" leaves, which led to less damage during packing and transport. Yields also increased when planting densities increased from 26,000 to 30,000 plants per acre in the mid-1980s. Much of the increase in yield comes from varieties that are more uniform in head size and harvest date, attractive qualities for one-pass harvesting. Resistance to downy mildew and mosaic virus also contributed to higher yields.

Production of head lettuce has followed the trends in yield, growing from around 18 million hundredweight per acre in the early 1950s to over 53 million hundredweight per acre in 1999. In the 1990s production was more variable than in earlier decades. It was as high as 57 million hundredweight per acre in 1989, but in some years it fell to about 42 million hundredweight (Figure 12.3). Head lettuce is one of the few commodities for which real price showed no discernible trend over the 1950 to 1999 period (Figure 12.4), fluctuating around $18 per hundredweight (year-2000 dollars). Price was as high as $27 per hundredweight in 1995 but was as low as $14 per hundredweight in 1991 and 1999. Rarely has the price of lettuce risen or fallen for more than two consecutive years. The annual value of head lettuce production (in real year-2000 dollar terms) was about $400 million in the 1950s. Since the 1960s it has grown, topping $1 billion in 1987 and again in 1995, although it was often as low as $700 million in the 1990s (Figure 12.5).

12.2 Significant Pests in the Lettuce Industry

Information about pests of lettuce in California and their management can be obtained from a number of sources, including Davis et al. (1997), the USDA crop profile for lettuce (ipmwww.ncsu.edu/opmppiap), and Wilhoit et al. (1999). A feature of the lettuce industry is the low tolerance by consumers of insect or disease damage. Hence growers are likely to use pesticides in a preventative manner rather than to monitor and wait for pest and disease populations to develop to a threshold level. However, UC research (Toscano et al. 1982) demonstrated that some lettuce varieties were adversely affected early in their growth by some insecticides.

Insect pests that attack lettuce include aphids (including green peach, lettuce, lettuce root and potato aphid), leafminers, worms (lepidopterous larvae, including alfalfa looper, beet armyworm, cabbage looper and corn earworm), lygus, and whitefly. The significance of these insects varies by region. Aphids not only directly damage the crop, but are often vectors for viruses.

Insects are controlled by a range of pesticides chosen with reference to the combination of pests in the field and resistance management principles. The main insecticides used in terms of pounds of active ingredient have been methomyl, acephate, and diazinon. Wilhoit et al. (1999) identified cypermethrin as the most widely used insecticide in 1996, followed by permethrin. These chemicals are synthetic pyrethroids. The authors noted that the use of imidacloroprid and avermectin had increased significantly in the late 1990s.

It would seem that for seasonal crops such as lettuce, which are only in the ground for 70 to 130 days, biological control based on predator popula-

Table 12.1 California head lettuce production, 1950–2000

Year	Harvested acres	Yield	Production	Price[a]	Value of production	Real price[a]	Value of production
				(nominal dollars)		(year-2000 dollars)	
	(thousands)	(cwt/acre)	(million cwt)	(dollars/cwt)	(millions)	(dollars/cwt)	(millions)
1950	129.5	140	18.2	3.29	59.7	20.14	366.0
1951	119.8	144	17.2	4.13	71.1	23.60	406.2
1952	128.6	153	19.7	4.01	78.8	22.56	443.4
1953	123.6	162	20.0	3.98	79.7	22.12	443.0
1954	124.7	159	19.9	3.89	77.3	21.39	425.3
1955	125.3	171	21.4	4.01	85.7	21.65	463.5
1956	128.5	174	22.4	3.22	72.0	16.82	376.5
1957	87.9	246	21.7	3.76	81.3	19.00	411.6
1958	116.5	164	19.1	3.26	62.2	16.12	307.5
1959	115.2	175	20.2	3.62	73.0	17.68	356.5
1960[b]	124.9	181	22.6	3.92	74.7	18.89	360.0
1961[c]	120.5	183	22.0	3.29	67.0	15.68	319.3
1962[d]	107.3	206	22.1	4.03	87.8	18.95	412.9
1963	120.2	193	23.2	3.70	85.7	17.20	398.6
1964	115.1	200	23.0	4.04	92.9	18.51	425.5
1965	115.6	206	23.9	4.04	96.4	18.17	433.7
1966	120.7	219	26.4	5.23	138.2	22.87	604.1
1967	129.4	204	26.3	4.43	116.6	18.79	494.3
1968	132.8	218	29.0	4.09	118.5	16.63	481.8
1969	137.7	210	28.9	4.70	135.9	18.22	526.6
1970[e]	144.9	220	31.8	4.60	146.3	16.93	538.2
1971[f]	134.3	241	32.3	5.85	188.9	20.49	661.6
1972[g]	140.7	248	34.9	5.26	183.3	17.68	615.9
1973[h]	143.4	246	35.3	7.38	260.7	23.48	829.7
1974	150.7	242	36.4	6.80	248.0	19.86	724.1
1975	156.5	250	39.1	6.40	250.3	17.09	668.6
1976	155.1	256	39.6	8.27	327.7	20.90	828.3
1977	159.7	263	42.0	7.22	303.5	17.15	720.8
1978	159.4	278	44.3	9.09	402.9	20.15	893.4
1979[i]	160.5	278	44.7	8.25	368.5	16.88	754.2
1980	163.6	287	46.9	8.23	386.1	15.43	723.7
1981	156.3	294	46.0	10.10	465.2	17.32	797.6
1982	144.9	306	44.3	10.80	479.0	17.43	773.0

(continued)

Table 12.1 Continued

Year	Harvested acres	Yield	Production	Price[a]	Value of production	Real price[a]	Value of production
				(nominal dollars)		(year-2000 dollars)	
	(thousands)	(cwt/acre)	(million cwt)	(dollars/cwt)	(millions)	(dollars/cwt)	(millions)
1983	142.2	293	41.7	12.30	512.8	19.09	796.0
1984	150.9	313	47.3	10.70	505.8	16.02	757.1
1985	145.5	295	42.9	10.70	459.3	15.53	666.4
1986	145.5	290	42.2	11.50	485.2	16.33	688.9
1987	157.1	315	49.5	15.10	747.3	20.81	1,029.9
1988	166.7	310	51.7	12.20	630.5	16.26	840.4
1989	168.4	340	57.3	11.70	669.9	15.02	860.2
1990	162.2	345	56.0	12.20	682.7	15.08	843.8
1991	152.0	335	50.9	11.80	600.9	14.07	716.5
1992	147.0	360	52.9	13.00	688.0	15.13	800.9
1993	141.0	360	50.8	16.50	837.5	18.76	952.2
1994	145.0	330	47.9	14.60	698.6	16.26	778.0
1995	144.0	295	42.5	25.00	1,062.0	27.25	1,157.5
1996	135.5	350	47.4	15.40	730.3	16.47	780.9
1997	141.0	350	49.4	19.20	947.5	20.14	993.8
1998	135.0	315	42.5	16.30	693.2	16.88	718.0
1999	140.0	380	53.2	13.70	728.8	13.98	743.8
2000[j]	143.5	370	53.1	18.90	1,003.5	18.90	1,003.5

Source: Compiled by the authors from the California Agricultural Statistics Service, *California Vegetable Crops*, 1950-1992; and the USDA, National Agricultural Statistics Service, *Vegetables Annual Summary*, 1993-2000.

[a] Season average price and value for fresh market based on packed and loaded basis, F.O.B. shipping point

[b] Excludes 3,540,000 cwt not harvested or marketed due to economic conditions

[c] Excludes 1,690,000 cwt not harvested or marketed due to economic conditions

[d] Excludes 282,000 cwt not harvested or marketed due to economic conditions

[e] Excludes 915,000 cwt not harvested or marketed due to economic conditions

[f] Excludes 300,000 cwt not harvested or marketed due to economic conditions

[g] Excludes 42,000 cwt not harvested or marketed due to economic conditions

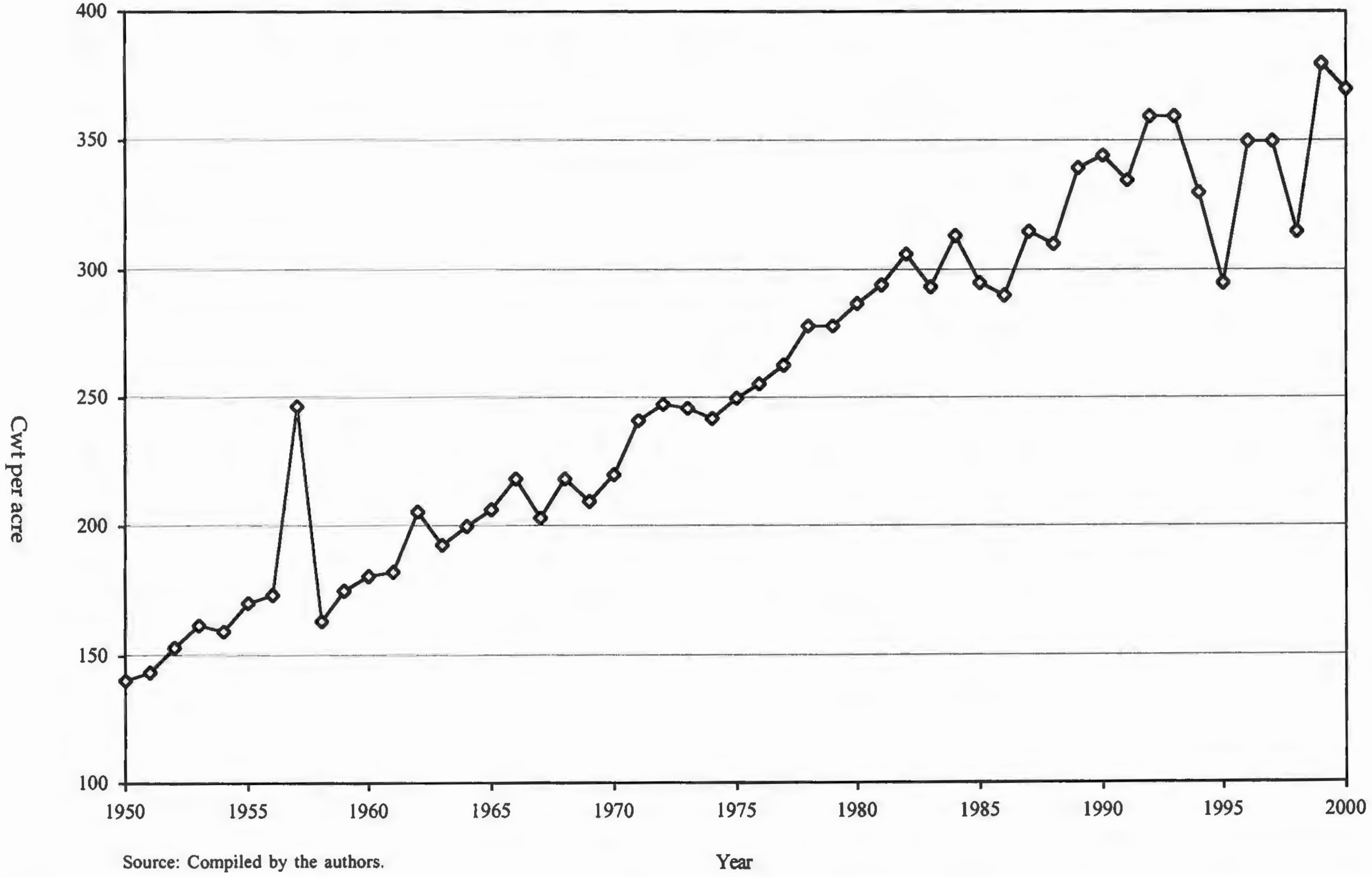
[h] Excludes 1,229,000 cwt not harvested or marketed due to economic conditions

[i] Excludes 1,583,000 cwt not harvested or marketed due to economic conditions

[j] Preliminary

Source: Compiled by the authors.

Fig. 12.1 California head lettuce harvested acreage, 1950–2000

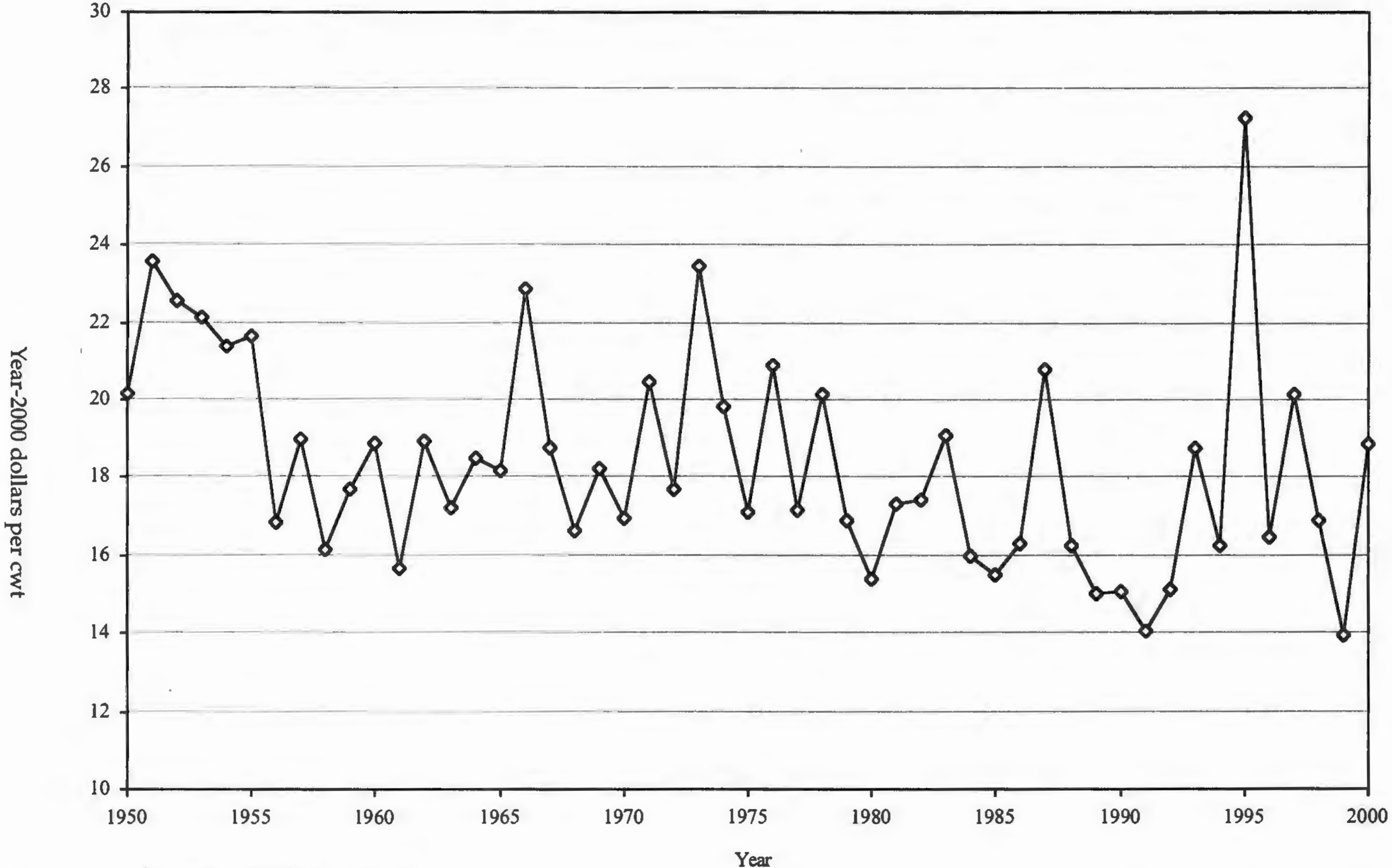


Source: Compiled by the authors.

Fig. 12.2 California head lettuce yield, 1950–2000

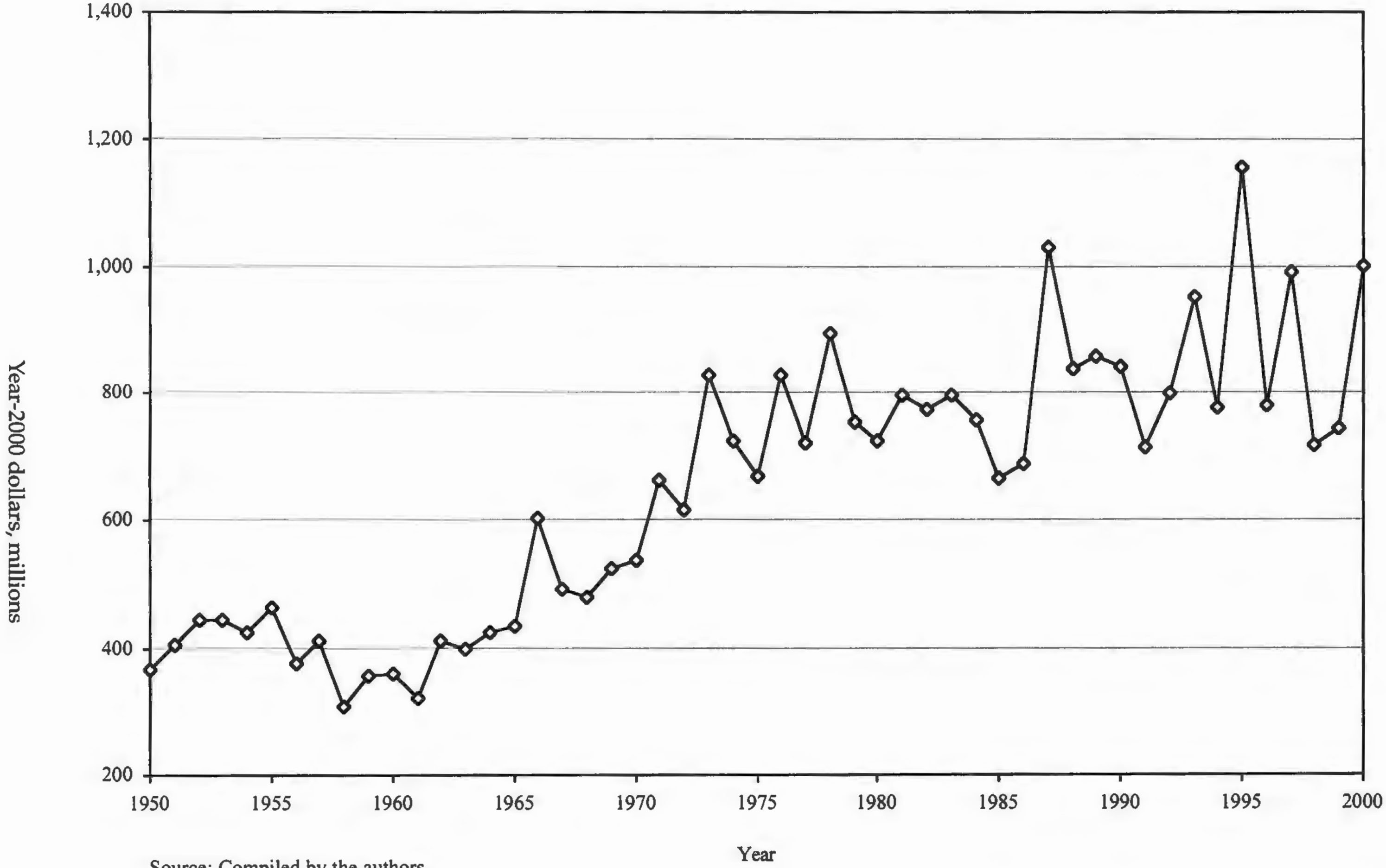
Source: Compiled by the authors.

Fig. 12.3 California head lettuce production, 1950–2000



Source: Compiled by the authors.

Fig. 12.4 California head lettuce price, 1950–2000



Source: Compiled by the authors.

Fig. 12.5 California head lettuce value of production, 1950–2000

tions is not practical because there is not a continual source of food for the predators. Against this, the growing season for lettuce in some areas such as Monterey is now 10 months, so it is unclear why biological control and other IPM practices have been less successful in lettuce than in other annual crops. Other insect control strategies include crop rotation and the removal of Lombardy poplars (an alternate host of lettuce root aphid), which is mandatory in Monterey County. An objective of lettuce breeding is to increase resistance to aphids.

Diseases of lettuce include fungal diseases such as anthracnose, bottom rot, lettuce drop, downy mildew, verticillium wilt and powdery mildew; bacterial diseases such as bacterial leaf spot and corky root; and viral diseases such as beet western yellows virus, lettuce big vein and lettuce mosaic virus. Disease outbreaks are associated with cool, wet weather. The main emphasis in long-term pest management has been on breeding for resistance. In some counties, such as Monterey, a lettuce-free period over winter is mandatory for the control of lettuce mosaic virus.

Diseases are treated by a range of fungicides, including maneb, fosetyl-al, iprodione, and vinclozolin, which are often applied preventatively. The tenor of the USDA crop profile (ipmwww.ncsu.edu/opmppiap) is that disease losses can be high, particularly from downy mildew and lettuce drop. Up to three-quarters of the crop is treated for lettuce drop, and losses still remain in the 5 to 20 percent range. Downy mildew is more of a problem in the wetter coastal areas. The fungus adapts quickly so that, in spite of some success in breeding resistant varieties, strains often exist that are not controlled by either fungicides or resistant varieties.

Weed control is also an important aspect of lettuce production. Only a limited number of herbicides do not damage lettuce, and these are usually applied pre-emergence. Hence mechanical control and hand hoeing remain important components of weed control in lettuce. According to the USDA crop profile, there are no successful biological control strategies for weeds in lettuce. Wilhoit et al. (1999) identified Propyzamide, bensulide, benefin, glyphosate and metam sodium as the main herbicides used in lettuce.

12.3 Eras of Pest Management in Lettuce

Unlike other commodities we have studied, little has been written about the history of pest management in lettuce, but discussions with scientists suggest that the "three-era" scenario of pest management is applicable. Apparently, in lettuce, as in other crops, pesticides were initially highly successful, but emerging resistance and secondary pest problems eventually required solutions with an IPM component.

A distinctive feature of the lettuce industry has been the emphasis on breeding for resistance as a means of reducing damage from disease and insects rather than the more traditional IPM approach of biological control and more efficient chemical control based on knowledge of the life cycle of pests and their interaction with predators and climate. A particular focus of the breeding program has been resistance to downy mildew. Maintaining resistance requires ongoing breeding activities because the fungus is continually adapting to new defense mechanisms. Downy mildew has reemerged as a major problem in recent years, particularly with the emergence of resistance by the fungus to Ridomil in the mid-1990s. Several chemicals are being used to replace Ridomil, but their effectiveness is lower.

A noteworthy approach to the control of lettuce mosaic virus, based on principles that later emerged in IPM programs, was initiated in 1958 through an ordinance promulgated in Monterey County, which prescribed management practices designed to interrupt the life cycle of the disease. UC Davis research identified that a primary source of the virus was seed that carried the virus. The green peach aphid also spread the virus. Lettuce growers in Monterey County were required to use seed certified to have no more than one seed in 1,000 carrying the virus. Growers were also required to carry out sanitary practices such as discing old crops immediately after harvest and keeping surrounding areas free from weeds. The regulations were strengthened in 1962 to a criterion of no virus-carrying seeds per 30,000 seeds tested. This program has been largely successful in controlling what was a major disease of lettuce, although occasionally, as in the late 1980s, the disease reemerged as a serious problem either because resistance broke down or sanitary practices had been less rigorously enforced. The program has been copied on either mandatory or voluntary bases in other lettuce-growing areas. Varieties resistant to lettuce mosaic virus have been released since 1975.

The Lettuce Research Board has funded research into downy mildew prediction systems based on weather conditions that allow better scheduling of fungicide applications. This research has demonstrated the feasibility of the technology, but adoption by growers has not been high.

12.4 The Use of Pesticides in the California Lettuce Industry

Pesticide Use from 1991 to 1999

The data used in this section are drawn almost exclusively from the pesticide use database (PUR) maintained by the Department of Pesticide Regulation in California Environmental Protection Agency and are reported in Table 12.2 and Figures 12.6 to 12.10. Based on our group of 62 major pesticides,[1] real expenditure on pesticides was $23.9 million in 1991, rising to $35 million in 1995 and falling to $28 million in 1999 (Table 12.2b). Expenditure on pesticides in head lettuce is higher than for many other California commodities. Of the case-study commodities, annual expenditure on pesticides in lettuce is less than in cotton and almonds but more than in oranges

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[1] See Table 4.5 for the list of 62 chemicals.

Table 12.2a All pesticide use on California lettuce, 1991–1999

					Year				
Pesticide	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
					(thousand pounds active ingredient)				
Carcinogens	577	575	521	601	706	1124	541	712	555
Cholinesterase inhibitors	406	381	356	396	428	414	407	390	444
Reproductive toxins	358	466	442	413	1046	851	418	394	288
Toxic air contaminants	288	533	615	598	1182	710	637	655	586
Organophosphates	267	277	258	300	281	272	253	265	334
Carbamates	140	104	98	97	147	142	154	125	110
Oils	6	4	4	1	2	3	2	2	2
Biopesticides	4	3	3	3	7	8	13	10	7
Reduced risk pesticides							3	10	12
Potential groundwater contaminants									
Total pesticide use in lettuce	*1654*	*1845*	*1807*	*1814*	*2670*	*2335*	*1732*	*1883*	*1579*
					(lbs)				
Active ingredient per acre	11	13	13	13	19	16	12	14	11
					(percentage)				
Share of California total*	1.2	1.2	1.0	1.0	1.4	1.3	0.9	0.9	0.9

Source: Compiled by the authors from the California Department of Pesticide Regulation, Pesticide Use Database, 2001.

*Total pesticide use=all pesticides in production agriculture

Table 12.2b Use of 62 major pesticides on California lettuce, 1991–1999[a]

Class	Year 1991	1992	1993	1994	1995	1996	1997	1998	1999
	(thousand pounds active ingredient)								
Fungicides	659	732	668	743	833	1159	596	818	500
Insecticides	401	386	362	398	445	420	410	385	443
Herbicides	92	84	89	81	85	78	81	81	71
Fumigants	84	314	395	297	1043	394	399	343	322
Plant growth regulators					0	0	0	0	0
	(percentage of total lettuce pesticide use, by weight)								
Fungicides	53.3	48.3	44.1	48.9	34.6	56.5	40.1	50.2	37.4
Insecticides	32.4	25.4	23.9	26.2	18.5	20.5	27.6	23.7	33.1
Herbicides	7.4	5.6	5.9	5.3	3.5	3.8	5.5	5.0	5.3
Fumigants	6.8	20.7	26.1	19.6	43.3	19.2	26.8	21.1	24.1
Plant growth regulators	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	(year-2000 dollars, millions)								
Estimated expenditures[b]	23.9	28.3	28.9	27.8	35.0	34.1	28.6	29.7	28.0
	(year-2000 dollars/acre)								
Estimated expenditures[b]	157	192	205	192	243	227	203	220	200

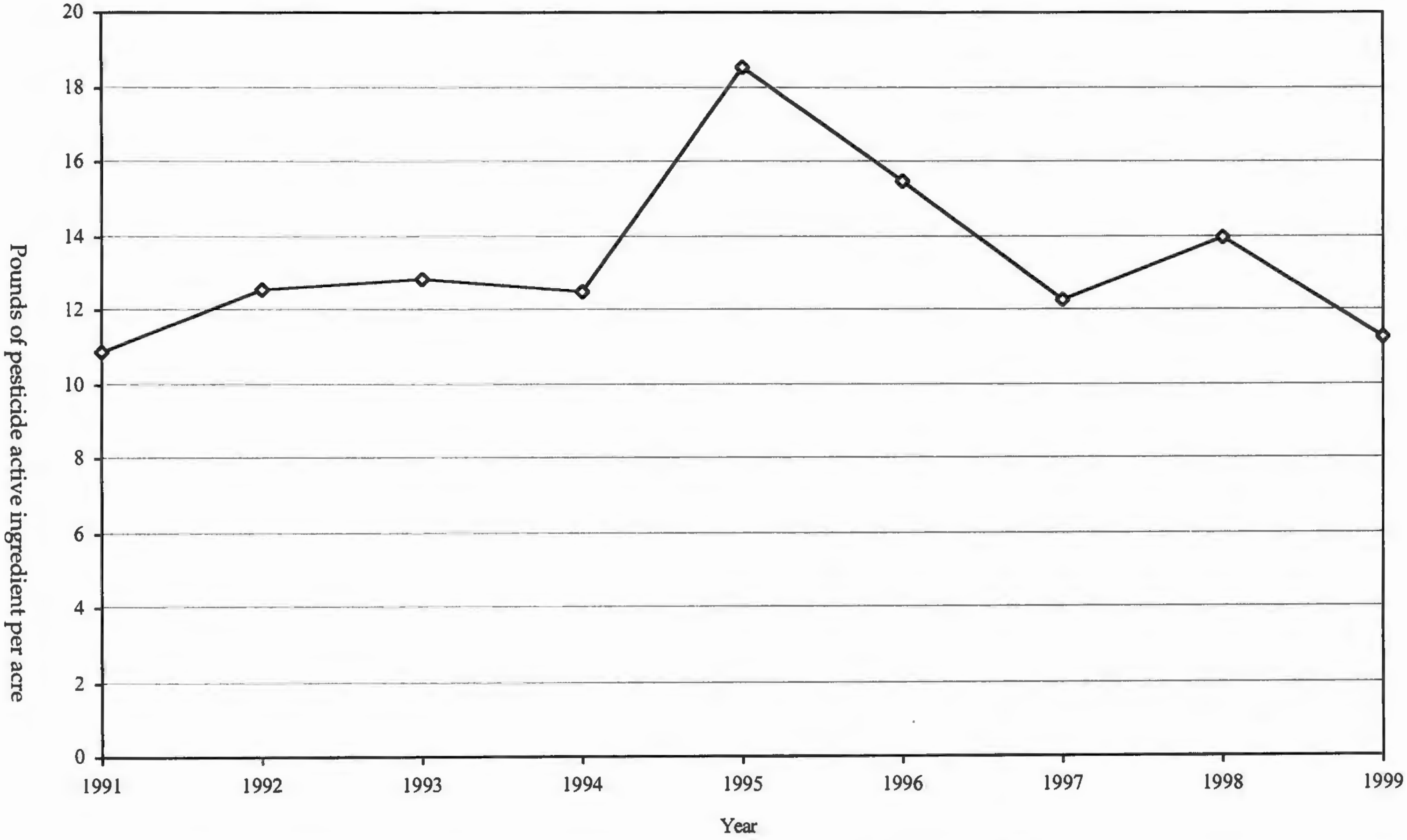
Source: Compiled by the authors from the California Department of Pesticide Regulation, Pesticide Use Database, 2001.

[a] The 62 pesticides are listed in Table 4.5

[b] Estimated expenditures are for the 62 major chemicals

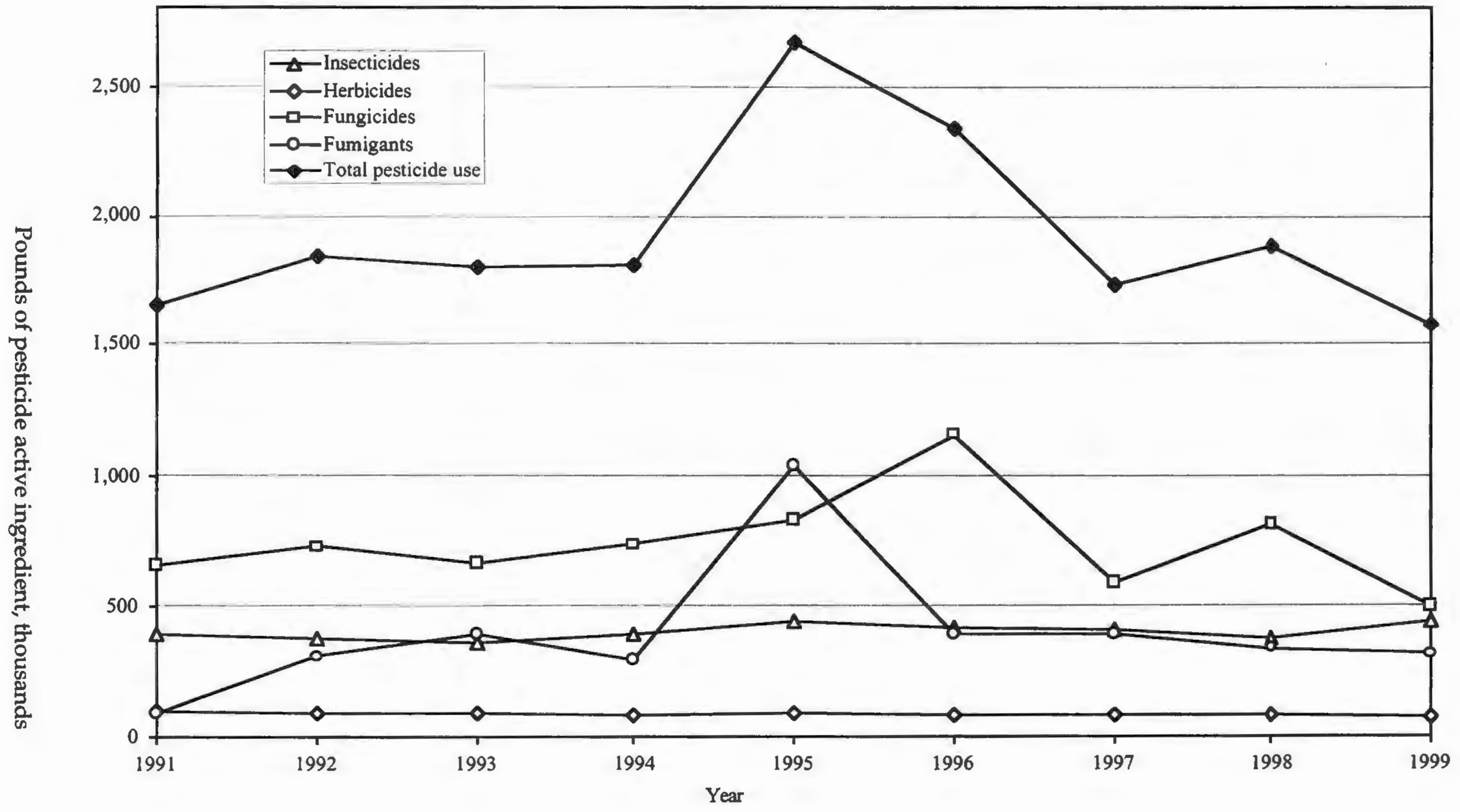
Source: Compiled by the authors from California Department of Pesticide Regulation, PUR database, 2001.

Fig. 12.6 Pesticide expenditure per acre on California head lettuce, 1991–1999



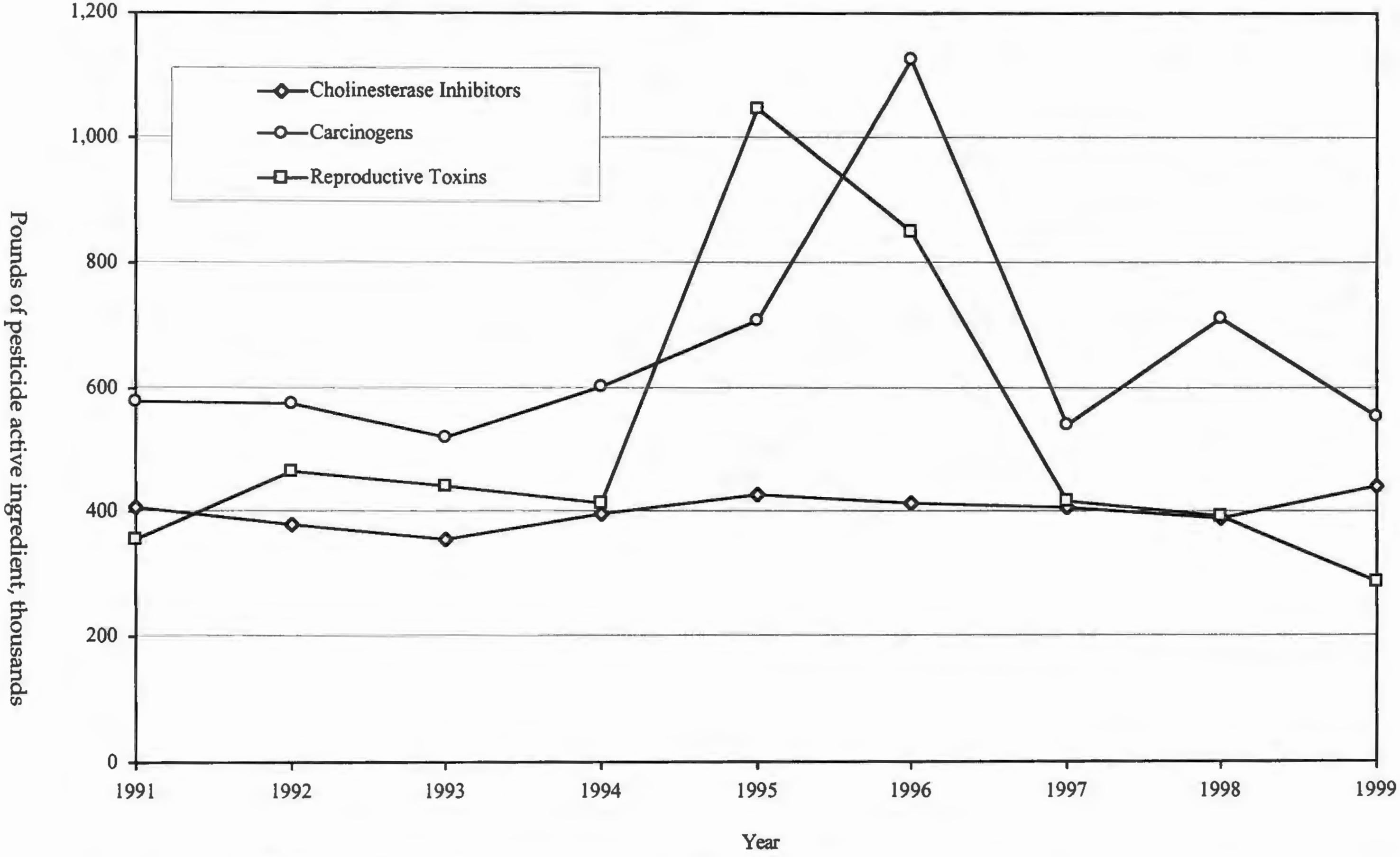
Source: Compiled by the authors from California Department of Pesticide Regulation, PUR database, 2001.

Fig. 12.7 Pesticide use on California head lettuce per bearing acre, 1991–1999



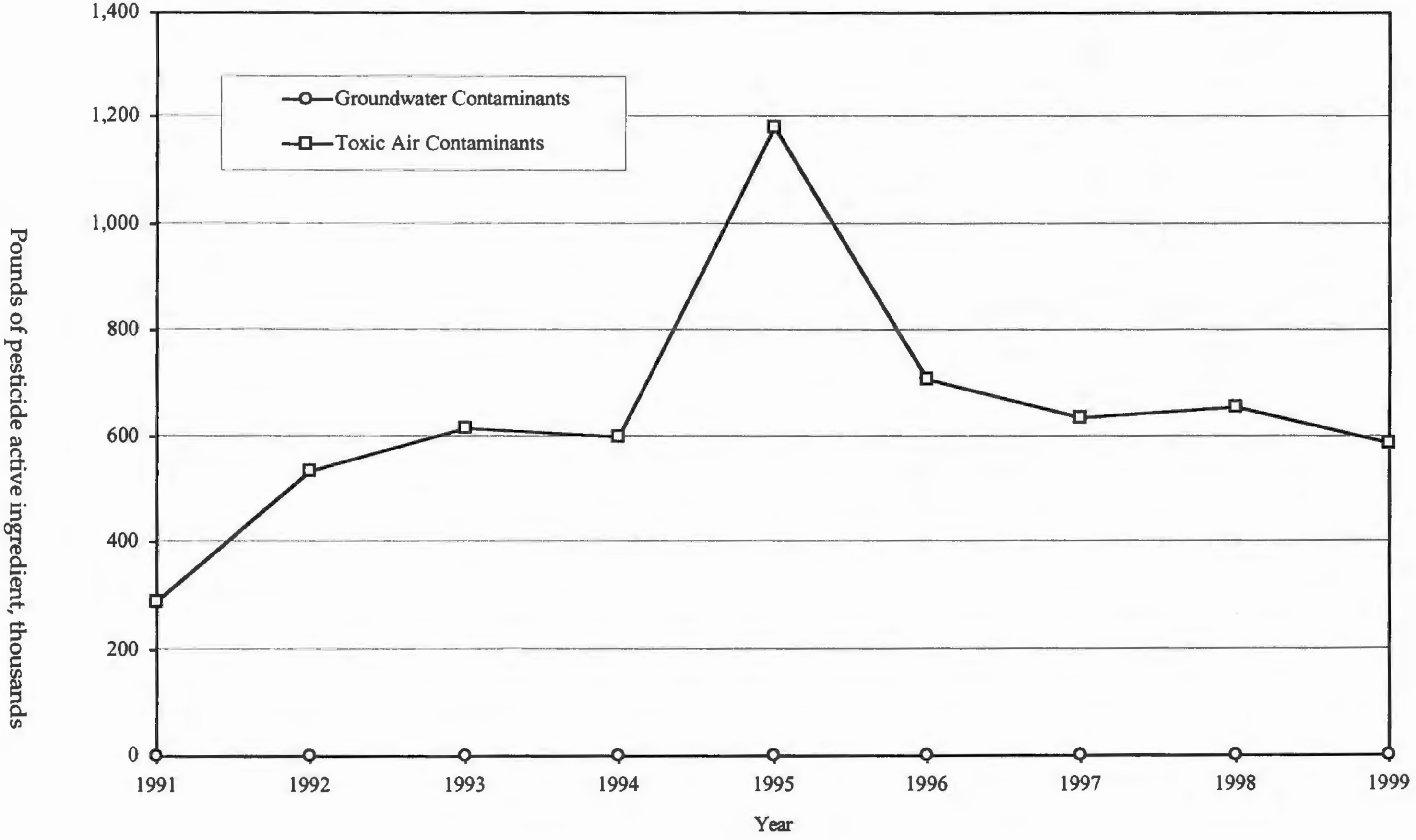
Source: Compiled by the authors from California Department of Pesticide Regulation, PUR database, 2001.

Fig. 12.8 Pesticide use on California head lettuce, 1991–1999



Source: Compiled by the authors from California Department of Pesticide Regulation, PUR database, 2001.

Fig. 12.9 Pesticide use on California head lettuce: human health, 1991–1999



Source: Compiled by the authors from California Department of Pesticide Regulation, PUR database, 2001.

Fig. 12.10 Pesticide use on California head lettuce: the environment, 1991–1999

and processing tomatoes, reflecting in part industry size. Real expenditure per acre was around $200 per acre in 1999, after peaking at $243 per acre in 1995. This rate of expenditure per acre was almost three times the average for California as a whole (Table 4.6).

Total pesticide use (from the PUR database) in iceberg lettuce increased from 1.7 million pounds of active ingredient in 1991 to 2.7 million pounds in 1995 before falling to 1.6 million pounds in 1999 (Table 12.2a). High use of pesticides in 1995 and 1996 can be explained by a large increase in the use of fumigants (methyl bromide and chlorpicrin) in 1995 and a large increase in metam sodium in 1996. On the basis of weight and proportion of planted area treated, maneb was the most widely used pesticide.

There has been little trend in the use of pesticides in lettuce. While total use was slightly less in 1999 than in 1991, the number of acres harvested also declined slightly during this period. Hence the per acre rate of application was nearly the same in 1999 as it was in 1991 (Figure 12.7).

According to Wilhoit et al. (1999), fumigants accounted for almost 50 percent of the pounds of active ingredient applied to leaf lettuce but less than 1 percent of either the number of applications or the number of acres treated. Insecticides accounted for over 60 per cent of applications and acres treated, with fungicides accounting for about 25 percent and herbicides accounting for about 7 percent. For our group of 62 pesticides, fumigants generally accounted for 20 to 25 percent of total pesticide use on lettuce, but this rose to 43 percent in 1995 (Figure 12.2b). Again by weight of active ingredients, insecticides accounted for 25 to 30 percent of pesticides used, herbicides about 5 percent and fungicides about 45 to 50 percent. According to Hamilton (2001), 13 insecticides and 11 herbicides and fungicides widely used in the lettuce industry are subject to review under FQPA.

Health risk and Environmental Outcomes

Although lettuce uses pesticides heavily, there appears to have been little change in use of categories of pesticides important to human health. (See chapter 3 and the glossary for a discussion of these categories as defined in California statutes.) The use of carcinogens and reproductive toxins was lower in 1999 than in 1991, while the use of cholinesterase inhibitors was slightly higher. There were spikes in the use of carcinogens and reproductive toxins in 1995 and 1996 associated with the use of fumigants and metam sodium (Figure 12.9). The use of air contaminants doubled from 1991 to 1999, closely tracking the use of fumigants, with a large spike in 1995, while there was no use of pesticides on the groundwater protection list "a" (Figure 12.10).

12.5 Costs and Benefits of UC Pest Management Research and Extension in Lettuce

In Chapter 3 (Table 3.8), we estimated that expenditure on research and extension in pest management in the head lettuce industry grew from $1.0 million in 1970 to $2.5 million in 1997 (in year-2000 dollars). The compound value of this stream of investments from 1970 to 1997 at a discount rate of 2 per cent was $63.5 million in 2000.

While the UC system has made significant investments in research and extension in pest management in lettuce, we had greater difficulty than we did with the other case-study commodities in identifying one or more signal advances in lettuce pest management attributable to the UC system. No doubt UC extension and research activities have been instrumental in the more rapid adoption by growers of higher-yielding, more-resistant varieties. However, it appears that until recent years much of the resistance breeding work was done outside the UC system. In recent years, UC has undertaken some breeding for resistance based on multiple genes (Michelmore 1995). We have not attempted to value these new varieties, as it seems likely that the benefits to growers are only just beginning to be realized.

For reasons already discussed above, unlike some other commodities, there seems to have been little success in developing an IPM program for lettuce that has resulted in significant savings to growers. None of the scientists we interviewed disagreed strongly with this view. UC Cooperative Extension budgets for Monterey County indicate that the share of insect and disease control expenditure in total preharvest expenditure fell from about 20 percent during the 1970s to about 10 percent from 1975 to 1985, but it has since risen again to over 20 percent. Such a trend was not obvious in other growing areas, and our reservations about the budget data were explained in Chapter 7.

Hamilton (2001) compared the cost of traditional pesticide programs with a program using biologically based chemicals for a small number of trials of various types of lettuce and celery between 1998 and 2000 in the Salinas Valley as part of the Central Coast Vegetable IPM Project. He concluded that while yields under the alternative spray programs were similar, the program based on biological chemicals was from $40 to $50 per acre more expensive, depending on the crop and the time of year. He noted that pest control expenses amounted to between 25 and 33 percent of preharvest production costs. The benefits from the use of biological chemicals came from being able to enter fields sooner after pesticide applications, wearing less protective clothing, and fewer risks to worker health.

Toscano et al. (1982) led a UC research program that demonstrated yield penalties from the high use of pesticides in the early stages of lettuce development in some varieties. This research probably reduced by a number of years the time it would have taken growers to "learn" this from other sources, but there was no indication of extent of the "yield penalty" problem in the lettuce industry. Another likely ongoing contribution of the UC system was the adaptation of guidelines for the efficacious use of pesticides to specific pest problems in specific locations in California and of recommendations for the management of resistance problems related to varieties and pesticides. We did not attempt to measure these benefits.

As noted, an important virus of lettuce, lettuce mosaic virus, has largely been controlled by regulation related to seed quality and cultural and field hygiene practices. It is likely that these regulations are still valuable because of the externalities associated with a virus that can spread to neighbors quickly. It seems likely that UC research was influential in developing this system of regulation.

In summary, the yields of lettuce have trebled since 1950. No doubt improvements in disease and pest management have made a significant contribution. However, we have not been able to partition this yield increase between improved pest management and other sources of yield growth, such as planting densities and more-even maturity. Further, while the UC system has undoubtedly made a contribution by helping growers identify varieties, pesticides, and resistance-management strategies most suitable to their particular environments, it would seem that the development of new varieties and pesticides has occurred outside the UC system. We have not been able to identify signal contributions made by the UC system to pest control in lettuce. Some small-plot trial work suggests that biological chemicals can be used to control pests with little yield loss. However, it would seem that the short production cycle of lettuce, together with the low consumer tolerance of damage from pests and diseases, militate against the development of IPM programs based on a knowledge of the interactions between pests and their predators and pesticides and cultural control measures.

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GLOSSARY AND ACRONYMS

active ingredient	(*a.i.*) the chemical or chemicals in a *pesticide product** that kills or otherwise controls the target pests by preventing, destroying or mitigating.
adjuvants	chemicals, with or without toxic properties of their own, that are added to a *pesticide product* to improve effectiveness or aid in application. Adjuvants include wetting agents, emulsifiers, spreaders, adhesives, and deflocculating agents. Defined in California Food and Agriculture Code Section 12758.
AES(s)	Agricultural Experiment Station(s), nationwide in conjunction with land-grant colleges.
a.i.	*active ingredient.*
APCA	licensed California Agricultural Pest Control Adviser; anyone who makes recommendations on agricultural use of *pesticides* or solicits services or sales for agricultural use. Biannual license renewal requires 40 hours continuing education course credit. (See also *QAC* and *QAL*.)
applied research, CRIS	according to *CRIS*, the primary goal of applied research is the practical application of knowledge to meet a recognized need.
arthropod	phylum of invertebrate animals that have segmented bodies and jointed appendages, and usually, exoskeletons. Includes insects, spiders, crustaceans, mites, and millipedes.

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* *glossary cross referencing is in italics*

basic research, CRIS	according to *CRIS* nomenclature, has a primary goal of gaining fuller knowledge or understanding of a subject.
biocontrol	same as *biological control.* Pest control strategy that uses living natural enemies, antagonists or competitors, and other self-replicating biotic entities. "Classical biological control" refers to the intentional introduction of a nonindigeneous biocontrol agent for long-term pest control.
biological control	same as *biocontrol.*
biopesticides	*DPR* tracks biopesticides in a category distinct from the *reduced-risk pesticides.* Their list of biopesticides consists of microorganisms (such as *Bacillus thuringiensis,* first used in 1938), naturally occurring compounds, and synthetic compounds that are essentially identical to naturally occurring compounds not toxic to the target pest (such as *pheromones* that disrupt mating, or scents that lure to traps) (PUR, 1999; http://www.epa.gov/pesticides/biopesticides/what_are_biopesticides.htm).
BIOS	Biologically Integrated Orchard System, a demonstration project of *SAREP* and the Community Alliance with Family Farmers.
Birth Defect Prevention Act (1984) (BDPA)	required all registered pesticides have complete and adequate chronic health effects studies on file with *DPR.* Of the 200 priority active ingredients identified for further study under the California act, 55 were no longer registered or had been suspended by June 1999 (http://www.cdpr.ca.gov/docs/dprdocs/sb950q&a/sb950rep99.htm).

broad-spectrum pesticide	in contrast to pesticides that narrowly target a single pest, one broad-spectrum pesticide controls a range of possibly present pests; methyl bromide is a broad-spectrum fungicide that has been used to control nematodes, weeds, insects, fungi and other pathogens. In general, *carbamates* are broad spectrum.
CA&ES	College of Agricultural and Environmental Sciences, UC Davis.
CAES	California Agricultural Experiment Station. The University of California Vice President—Agriculture is CAES director.
carbamates	*cholinesterase inhibitors* used as pesticides, often broad spectrum (insecticide, nematicide, and herbicide, etc.); derivative of carbamic acid.
carcinogens	cancer-causing agents. *DPR* tracks usage of pesticides listed by USEPA as B2 carcinogens (probable human carcinogen based on animal studies) and those on the state's *Proposition 65* list of chemicals "known to cause cancer."
CDFA	California Department of Food and Agriculture.
cholinesterase	an enzyme that regulates the neurotransmitter acetycholine necessary for proper nerve function.
cholinesterase inhibitors	cholinesterase is inhibited or damaged by *carbamates* and *organophosphates* taken into the body by any route, which results in overstimulation of the nerves and muscles and also death. *DPR* tracks use of cholinesterase-inhibiting active ingredients, currently organophosphate and carbamate pesticides.

* *glossary cross referencing is in italics*

classes of pesticides, functional description	either by target function (e.g., fungicide, insecticide, herbicide) or by application method (e.g., fumigant, spray).
cotton plowdown	a statutory requirement specifying cotton plants be shredded and residue be covered by soil (i.e., plowed down) by a specified weather-dependent date. Implemented to reduce overwintering populations of pink bollworm.
CRIS	USDA Current Research Information System.
DANR	Division of Agriculture and Natural Resources, University of California.
diapause	a period of physiologically controlled dormancy in insects.
DPR	Department of Pesticide Regulation, a department within the California Environmental Protection Agency.
EPA, US	U.S. Environmental Protection Agency.
exotic pests	nonindigeneous, introduced, non-native, alien, invasive, foreign, immigrant, transboundary pests or diseases. Intentionally or inadvertently introduced by humans, other species, or natural forces.
externality	an economic action that imposes costs or benefits on others, but for which the full costs or benefits are not accounted for by the economic actor. External costs or external benefits are often associated with ill-defined property rights or the result of high transaction costs.
FDA	U.S. Food and Drug Administration.
FFDCA	Federal Food, Drug and Cosmetic Act.
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act.

Food Quality Protection Act of 1996 (FQPA)	amendments to *FIFRA* and *FFDCA*; establishes health-based standard of "a reasonable certainty of no harm" and requires EPA to consider cumulative effects of aggregated sources and exposures, especially for children, when setting *pesticide tolerance* levels for residues in food. Old pesticides must be evaluated for compliance with the new standards by 2006.
fumigant	as used by *DPR* (1999) and therefore in this study when citing DPR data, used to control a wide range of organisms.
fungicide	as used by *DPR* (1999) and therefore in this study when citing *DPR* data, a pesticide whose primary use is controlling pathogens.
groundwater protection list "a"	chemicals legally designated in California Code of Regulations, Title 3, Division 6, Subchapter 1, Article 1, Section 6800(a) as having been detected in groundwater or soil, independent of amounts found or whether they have been proven harmful to health. The pesticides atrazine, simazine, bromacil, diuron, prometon, betazon (Basagran® and norflurazon are listed (3/23/01 amendment).
hedonic analysis	analysis of price (typically statistical) based on the underlying or intrinsic characteristics of the good and the economic benefits they convey.
herbicide	as used by *DPR* (1999) and therefore in this study when citing *DPR* data, a pesticide whose primary use is against plant pests or for desiccating plants.
IGRs	*insect growth regulators.*

* *glossary cross referencing is in italics*

index	a measure of a price or quantity (or other variable) relative to a base period value.
information-based IPM technologies	pest control strategies utilizing pest monitoring together with knowledge about the climate, developmental biology of the pest, and ecosystem interaction.
insect growth regulators	as a *pesticide*, used to control developmental or reproductive processes; e.g., embryos or larvae may not mature.
insecticide	as used by *DPR* (1999) and therefore in this study when citing *DPR* data, a pesticide whose primary use is for controlling any invertebrate animal (not just insects).
integrated pest management (IPM)	as defined by the *UC IPM Project*, IPM "is an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. Pesticides are used only after monitoring indicates they are needed according to established guidelines, and treatments are made with the goal of removing only the target organism. Pest control materials are selected and applied in a manner that minimizes risks to human health, beneficial and nontarget organisms, and the environment."
IPM Project, UC	University of California Integrated Pest Management Project, established in 1980 by the California Legislature; in 2002 began using the name Integrated Pest Management Program. One of a number of Statewide Special Projects and Programs within the Division of Agriculture and Natural Resources.

IR-4 Program	Interregional Research Project No. 4; *Minor Use Program.*
LD_{50}	the lethal dose for 50 percent of the test organisms, hence a measure of acute toxicity or poisoning. In presenting mammalian toxicity, usually oral toxicity, it is expressed as milligrams of toxicant per kilogram of body weight (mg/kg).
marginal value product	additional value earned from using an additional unit of an input such as a pesticide.
market failure	occurs when unregulated private markets fail to provide the socially efficient quantity of some good or service, generally because prices fail to send appropriate signals.
minor use pesticides	pesticides used on small acreage crops (less than 300,000 acres nationally) or with insufficient economic incentive for registrant to provide supporting data to US EPA.
Minor Use Program	Interregional Research Project No. 4, commonly called *IR-4*. Develops data supporting minor use pesticide registrations.
nominal value or price	a variable denoted in currency units not adjusted for inflation.
non-rival	a good or service that may be used by one consumer and also provided to others at no additional cost. For example, border control of pest entry may be provided as a service to one or many in a region with no added costs based on the number of farms or consumers benefiting.
OEHHA	California Office of Environmental Health Hazard Assessment.

** glossary cross referencing is in italics*

oil pesticides	"As a broad group oil pesticides and other petroleum distillates are on US EPA's list of B2 carcinogens or the State's Proposition 65 list of chemicals 'known to cause cancer.' However, these classifications do not distinguish among oil pesticides that may not qualify as carcinogenic due to their degree of refinement" (DPR, 1999 PUR). *DPR* tracks oil pesticides separately from others known to cause cancer, because many serve as alternatives to high-toxicity chemicals.
opportunity cost	costs of the use of a good or service or some other action measured in terms of what is foregone by this use or action. All costs are appropriately considered opportunity costs.
organophosphate pesticides (OPs)	*cholinesterase inhibitors* which affect functioning of nervous system, are highly toxic to vertebrates, and chemically unstable or nonpersistent. Derived from phosphoric acid esters, OPS are used as an insecticide, nematicide, fungicide, or defoliant. State and federal regulators are concerned about OP runoff to surface waters because of toxicity to aquatic species and, under *FQPA*, *EPA* is reviewing tolerances for residues in food.
pest	pests can be predatory animals (e.g., insects, nematodes, birds, rodents), unwanted aquatic or terrestrial plants (weeds), or disease producing microorganisms (e.g., fungi, bacteria, viruses) that cause damage or economic loss or transmit or produce disease. They may be indigenous or introduced (exotic). As defined in California Food and Agriculture Code Section 12754.5, plant pests also include, "Anything that the director, by regulation, declares to be a pest."

pesticide	Legal definitions of "pesticide" are found in Title 7 U.S. Code Section 136 and the California Food and Agriculture Code Section 12753. Section 12753 defines "pesticide" to include "(a) Any spray adjuvant. (b) Any substance, or mixture of substances which is intended to be used for defoliating plants, regulating plant growth, or for preventing, destroying, repelling, or mitigating any pest, as defined in Section 12754.5, which may infest or be detrimental to vegetation, man, animals, or households, or be present in any agricultural or nonagricultural environment whatsoever." Thus pesticides include insecticides, fungicides, rodenticides, repellents, attractants, weed killers, defoliants, dessicants antimicrobials, and swimming pool chemicals whose intended use may or may not be to kill the target pest.
pesticide categories tracked by DPR	*reproductive toxins, carcinogens, oils, cholinesterase inhibitors, groundwater protection list "a"* plus Norflurazon, *toxic air contaminants, and reduced-risk, biopesticides.*
pesticide product	any product that has a unique EPA registration number based on formulation and labeling. It can contain one or more *active ingredients.* Different brand names of identical composition normally would each have a unique product registration. Products containing different formulations of the same active ingredient, for example a wettable powder product in contrast to an emulsifiable concentrate containing product, would each be different products. Similarly a different product registration is required for different percentages of

** glossary cross referencing is in italics*

	the same active ingredient. Differences in container volumes or weights do not trigger a different product registration, unless they are for distinctly different markets, for example, household and agricultural. There were 11,392 products and 887 active ingredients actively registered for use in California on May 1, 2002.
pesticide tolerances	as set by *EPA*, maximum safe pesticide residue levels that may remain in or on food. FQPA preempts states from setting standards. Enforced by *FDA* and *USDA*.
pheromones	a substance secreted by an organism to affect the behavior or development of other members of the same species. Sex pheromones that attract the opposite sex for mating are used in monitoring certain insects.
PISP	California Pesticide Illness Surveillance Program.
price taker	an individual firm or consumer or group of firms or consumers who do not influence price by the quantity they consume.
"problem" categories of pesticides	two categories used in this study: 1) human health hazards (legally listed *reproductive toxins, carcinogens and cholinesterase inhibitors*); 2) environmental health hazards (legally listed *toxic air contaminants* and potential groundwater contaminants, i.e., *groundwater protection list "a"*).
production function	a mathematical relationship that shows the amount of output that results from the application of specified quantities of inputs.

productivity	a measure of the quantity of output per unit of input. The term includes simple ratios of a single output to a single input or ratios of indexes of multiple outputs to indexes of multiple inputs. Creation of the indexes of inputs or outputs is complex.
productivity growth	the change over time in productivity measured by either individual inputs and outputs or in terms of indexes. Also equal to the difference between the rate of growth in output minus the rate of growth in total input.
Proposition 65 (Prop 65)	California Safe Drinking Water and Toxic Enforcement Act (1986); mandated that the state publish a list of chemicals "known to the State to cause cancer or reproductive toxicity" and to update this list annually. Cal-EPA's Office of Environmental Health Hazard Assessment (*OEHHA*) is the lead agency implementing the Act. *DPR* evaluates data for pesticides being considered for listing and tracks annual usage of listed pesticides.
public good	a good for which consumption is both *nonrivalrous* and for which it is difficult to exclude consumption by others if the good is provided to others.
PUR	pesticide use report; California's pesticide use reporting system.
QAC	Qualified Applicator Certificate. Required by persons who use state or federal *restricted-use pesticides* or supervise those who do. Biannual renewal requires 20 hours continuing education course credit.

** glossary cross referencing is in italics*

QAL	Qualified Applicator License. Required for persons who supervise *pesticide* application (general or restricted use) by a licensed Pest Control business. Biannual renewal requires 20 hours continuing education course credit.
quarantine	a restraint because of health and safety concerns. Refers either to the 1) prohibition of movement from a particularly defined region; 2) period of time during which plants or animals or products are held, observed, or tested prior to treatment, destruction, return or release; or 3) law or regulation prohibiting entrance or allowing entrance contingent upon meeting requirements.
reduced-risk pesticides	those pesticides that have been given reduced-risk status by the U.S. EPA during the expedited registration process since 1994 because they are perceived as posing less risk to people and the environment than pesticides not requesting this classification. Chemicals registered prior to 1994, even if by today's criteria they might be considered as reduced-risk, did not receive such a classification and are not tracked as such by *DPR*. Reduced risk pesticides may be highly toxic to biocontrol organisms.
reproductive toxins	chemicals known to cause "reproductive toxicity" that are listed by *OEHHA* pursuant to *Proposition 65*.
restricted-use material	*pesticides* that are believed to have a high potential to cause harm to other crops, public health, farm workers, domestic animals, honeybees, the environment, and wildlife. U.S. EPA restricts by *pesticide product* while *DPR* restricts by *active ingredient*. Prior to *DPR*, *CDFA* was responsible for listing and restricting "Injurious Herbicides and Injurious Materials."

restricted-use material	According to *DPR*, (website, November 2, 2001) the current California list of restricted materials includes roughly 100 active ingredients (some of which may no longer be registered). Listed by chemical are 44 California-restricted ingredients, another 50 unique to the groundwater protection list, dusts in containers greater than 25 pounds, and by reference, all *(FIFRA) Section 18* emergency products and all federally "restricted-use pesticide" (RUP) products. With some exceptions in order to possess or apply a restricted-use material, an individual pesticide applicator must first obtain a permit from the County Agricultural Commissioner. The permit may specify limitations on use based on the application site, timing, and environmental conditions, and may require supervision.
RPA	Research Problem Area, *CRIS* nomenclature.
RUP	US EPA *restricted-use pesticide* (product).
SAREP	University of California Sustainable Agriculture Research and Education Program. A *DANR* Statewide Special Program established in 1986 to focus on sustainable production systems.
Section 18, FIFRA	Under Section 18 of *FIFRA*, absent the lengthy registration process, for emergency situations states are allowed to issue emergency exemptions for pesticide use under specific circumstances and for limited periods. County Agricultural Commissioner offices, pest control advisors, university experts, and growers provide the supporting documentation and justification. May not be requested by manufacturers.

** glossary cross referencing is in italics*

SLN registrations	Special Local Need. State-specific pesticide registrations under FIFRA Section 24(c) for uses additional to federal registrations where need is demonstrated and federal tolerances established.
toxic air contaminants list	as listed in California Code of Regulations, Title 3, Division 6, Chapter 4, Subchapter 1, Section 6860. Pesticides are listed as toxic air contaminants if found in ambient air at concentrations higher than certain levels. Established levels differ for pesticides that are believed to have adverse health effects and those that are not (CA Code of Regulations, Section 6890). *DPR* tracks pesticide active ingredients on this list.
USDA	United States Department of Agriculture.