# TRENDS IN CROP PESTICIDE USE: COMPARING 1992 AND 1997

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#### I. Introduction

Analysis of trends in pesticide use can help identify the effects of regulatory, research and farm policies that either directly or indirectly influence the pest management choices farmers make. The utility of such analyses is made clear when, for example, they dominate national and state discussions regarding regulatory policy. Advocacy groups have cited pesticide use trends data to claim that regulatory policies to reduce use have failed and that pesticide usage continues to increase. In certain cases, such criticism of policy has led regulatory agencies to conduct their own analyses of reasons that pesticide use changes over time. Alternatively, aggregate pesticide use changes have also been cited as evidence that Integrated Pest Management (IPM) programs are successful in reducing pesticide use.

Thus far, however, analyses of changes in pesticide use have been superficial and incomplete. Although the federal government has collected a substantial amount of pesticide use data for major field crops, vegetable and fruit crops during the period 1990-1999, very little analysis has been undertaken to explain observed differences in use amounts from year to year. Available federal analyses typically cite major changes in usage for a few major crops only. For other pesticide use studies, it has been sufficient to cite aggregate statistics without any underlying analysis of changes. In those cases where further analysis has been undertaken, the focus has been on single states (California) or on only a few crops nationally (cotton, soybeans).

<sup>&</sup>lt;sup>1</sup> See: PIRG, "Release of New Data Showing Record High Pesticide Use," May 28, 1996; "Pesticide Use Climbing, According to EPA Draft Report," <u>Chemical and Engineering News</u>, June 3, 1996; PAN, <u>Hooked on Poisons: Pesticide Use in California 1991-1998</u>, 2000; and Benbrook, Charles, <u>Pest Management at the Crossroads</u>, Consumers Union, 1996.

<sup>&</sup>lt;sup>2</sup> See: Wilhoit, Larry, *et al.*, <u>Pesticide Use Analysis and Trends from 1991 to 1996</u>, California Department of Pesticide Regulation, PM99-01, May 1999.

<sup>&</sup>lt;sup>3</sup> The almond IPM program in California is credited with a 45% annual volume reduction in insecticide use (1979-1987). See: Klonsky, Karen, *et al.*, "California's Almond IPM Program," <u>California Agriculture</u>, September-October 1990.

<sup>&</sup>lt;sup>4</sup> See: USDA, <u>Agricultural Resources and Environmental Indicators 1996-1997</u>, Economic Research Service, July 1997.

A comprehensive analysis of trends in pesticide use is a difficult task due to the diversity of crops, pests and associated pesticide use. There are several hundred individual active ingredients commonly used in agriculture. They are used for a wide variety of purposes: weed control, insect control, disease control, nematode control, plant growth regulation, plant desiccation and soil fumigation, which in and of itself has multiple purposes. Numerous crops that are produced in the U.S. are grown in vastly different regions with different conditions and therefore different production practices. The pesticide usage patterns for potatoes grown in Florida, for example, are quite different from those grown in Washington State.

Further complicating the understanding of pesticide use trends is the subjective nature of the evaluation. While data can provide clues to what has happened, they are often insufficient to provide definitive answers. The data for a particular state may show that one fungicide in apples goes up in use and another one goes down, but the data alone do not indicate whether one fungicide replaced the other, or whether the changes were independent, caused by other factors. The only way to try to understand such an observed use pattern is to contact knowledgeable individuals (such as extension service agents) who regularly work with the crop in the state in question, and ask for an explanation.

Statistical analysis of changes in pesticide use is also difficult because of the subjectivity of the analysis, and because of the numerous and confounding factors influencing use, such as the fact that most pesticides control multiple pests. A general absence of data on factors such as pesticide pricing and incidence of pest populations also makes statistical analysis difficult.

## II. NCFAP Studies

## A. Pesticide Use Databases

In 1995, the National Center for Food and Agricultural Policy (NCFAP) released a comprehensive national pesticide use database that delineated the use of 200 active ingredients on 87 crops in the 48 continental states for the time period circa 1992. In November, 2000, NCFAP released an updated version of the database for the time period circa 1997. The NCFAP database is a compilation of records from published federal surveys of farmers and of estimates collected from extension service specialists, commodity organizations, food companies, independent crop consultants, state governments and agricultural chemical companies. The same methodology was used for both the 1992 and the 1997 NCFAP compilations.

A comparison of the 1992 and 1997 national usage totals is shown in Table 1. As can be seen, the overall change in annual agricultural crop pesticide use between 1992 and 1997 is an estimated increase of 93.7 million pounds. The aggregate use of fungicides, herbicides, insecticides and other pesticides increased by 2, 7, 33 and 51 million pounds, respectively.

The NCFAP database lists the use of individual active ingredients by crop and state (e.g., the use of atrazine on corn in Iowa). Table 2 summarizes the individual record changes between 1992 and 1997 and the change in pounds of pesticide active ingredient they represent. As can be seen, the 3,739 records included in the 1992 database, but not in the 1997 database, indicate a reduction of 53.5 million pounds. (These are records for canceled or withdrawn uses and for uses that no longer were reported for 1997.) The 5,309 new records added to the 1997 database account for an additional 99.4 million pounds of use. (These are records for newly introduced active ingredients and uses and for previously registered uses that were reported as being used in 1997, but not in 1992.)

<sup>&</sup>lt;sup>5</sup> The 1992 and 1997 versions of the NCFAP database are available at www.ncfap.org.

There are 11,838 records for which usage is estimated for both 1992 and 1997. In the aggregate, these records indicate a usage increase of 47.8 million pounds of active ingredient between 1992 and 1997.

Closer examination of the 11,838 records that are common to both the 1992 and the 1997 databases reveals the number reflecting decreases (6,349) in the estimated total pounds of active ingredient used is greater than the number reflecting increases (5,489). Table 2 shows a distribution of the changes in pounds of usage for the 11,838 records. For 2,748 records, the increase in poundage from 1992 to 1997 was greater than 100%, while at the other extreme, 2,762 records for 1997 showed a decline in annual poundage of more than 50% the 1992 use level.

As Tables 1 and 2 suggest, behind each estimate of shifts in aggregate pesticide use are layers of increasingly detailed information about how and why those shifts occurred. The recent update of NCFAP's national pesticide usage database provides an opportunity to identify aggregate shifts in pesticide use between 1992 and 1997. The NCFAP trends study takes advantage of that opportunity by investigating and summarizing the details behind these shifts.

## B. <u>Trends Study</u>

The NCFAP trends study focuses on active ingredients that have undergone noticeable changes in usage patterns between 1992 and 1997 at the national aggregate level, as estimated in the NCFAP national pesticide use database. For each active ingredient, changes at the national level are examined and the specific crop uses that most contribute to the national trends are identified. These specific crop uses are then examined and the circumstances that influenced each is described.

## 1. Organization

The trends report is divided into four sections, one for each pesticide category. The pesticide categories are the same as those used in the pesticide use database: fungicides, herbicides, insecticides and other (primarily fumigants and plant growth regulators). Each section contains an introductory description of the pesticide category; use data, presented in tabular form, from the selected crops that appear to most influence national usage of an active ingredient; and short explanations of the highlighted changes in use. Within each pesticide category, the explanations are organized by crop; within each crop, they are organized by state.

The major factors that account for differences in usage patterns from year to year, as highlighted in this report, are identified and discussed in the report's summary conclusions.

#### 2. Sources

For the report of pesticide use trends, NCFAP recontacted many of the extension service agents who provided estimates for both 1992 and 1997 NCFAP pesticide use databases, and asked for their explanations of observed changes. Additional extension service agents were contacted and asked to comment on changes in NCFAP estimates that are based on other data sources, such as surveys by USDA NASS or California's Department of Pesticide Regulation.

In addition, NCFAP conducted a literature survey of commodity-focused publications (such as <u>Citrograph</u> and <u>Grape Grower</u>), regional farm publications (such as <u>Delta Farm Press</u> and <u>AgAlert</u>), scientific literature (such as <u>Weed Technology</u> and <u>Plant Disease</u>) and conference proceedings (such as from the Beltwide Cotton Conferences and the Florida State Horticultural Society) for articles that describe pesticide use patterns.

Another important source of information was USDA's series of "Crop Profiles" for individual crops and states. 6 All references are listed at the end of the report.

#### 3. Data Presentation

For each of the four pesticide categories, three data tables are presented. The first set of tables (Tables 3, 6, 9, 12) shows the aggregate national usage estimates for active ingredients included in either the 1992 or 1997 NCFAP usage files. It also includes estimates of the percent change from 1992 to 1997 in national aggregate use of each active ingredient.

The second set of data tables in each pesticide category (Tables 4, 7, 10, 13) shows the total change, nationally, of pounds applied for each active ingredient. The crop changes that were major contributors to each total change are also listed. Rather than include every pound of change for every active ingredient, only major crop changes are listed.

By listing pesticide use by active ingredient and by crop in the second table, different patterns become evident. One pattern the data may suggest is that for some active ingredients there were counterbalancing changes in different crops. For example, in the table on fungicides (Table 4), chlorothalonil's use in peanuts went down by 3 million pounds, but went up in potatoes by 3.7 million pounds. Elsewhere, patterns may suggest substitution of one active ingredient for another within a crop, as seen in California carrots in the section on other pesticides (Table 13): methyl bromide usage decreased while 1,3-D usage increased.

The third set of data tables in each section (Tables 5, 8, 11, 14) shows the same selected active ingredient use records from the NCFAP database that are included in the second set of tables, but organized by crop, active ingredient and state. The inclusion of state as a category in the third set of tables more thoroughly illustrates the changing use patterns identified in the second, which are, in turn, elaborated on the data in the first. As the

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<sup>&</sup>lt;sup>6</sup> Available at http://ipmwww.ncsu.edu/opmppiap

reader progresses from the first to the third table for each pesticide category, use patterns for each active ingredient are broken down to reveal more detail about what is driving national trends.

It should be noted that NCFAP determines the total pounds of an active ingredient used in a year by calculation [(number of acres) x (percent acres treated) x (average annual rate applied per treated acre)]. In many cases, changes in total pounds used are explained by a change in the percent acres treated. The third table in each section presents records for which this is the case. Of course, changes in the two other variables (the average annual rate applied and the number of acres of the crop in the state) also can account for changes in the overall pounds of active ingredient used. When changes in total acres or rates account for the bulk of the differences in pounds used, those changes are also noted in the third table.

After following usage of a particular active ingredient through the tables, the reader may then refer to the text, which provides short descriptions organized by crop, for the explanation of observed usage shifts. Again, descriptions only include the states that account for the majority of a given usage shift. Estimates of pounds of usage are not provided in the third set of tables. These tables are meant to illustrate the changes in the factors which resulted in changes in pounds of use. Alternatively, a reader interested in pesticide use trends from the perspective of a particular crop rather than a particular active ingredient may start with the text and then go to the tables for pesticide use data on that crop.

TABLE 1: U.S. Crop Pesticide Use: 1992 and 1997					
		Millions L	bs/Yr		
	1992	<u>1997</u>	<u>Change</u>	% Change	
Fungicides	129.3	131.5	+2.2	+2	
Herbicides	454.2	461.4	+7.2	+2	
Insecticides	149.1	182.4	+33.3	+22	
Other Pesticides	<u>159.6</u>	<u>210.6</u>	<u>+51.0</u>	<u>+32</u>	
Total	892.2	985.9	+93.7	+10	

TABLE 2: Summary of Changes in Individual Records and Pounds of Active Ingredients (1992 and 1997 NCFAP Databases)				
	# of Records	Change in Lbs Al		
1992 Database Only 1997 Database Only Both 1992 and 1997 Databases	3,739 5,309 11,838	-53.5 million pounds +99.4 million pounds +47.8 million pounds		
% Change in Pounds of	<u>Use</u>	# of Records		
>100 1 to 100 -1 to-50 -51 to –99		2,748 2,741 3,587 2,762		
Total		11,838		

## III. Fungicides

## A. Introduction

Rainfall was above average in many regions in the country circa 1997. The incidence of many plant diseases is correlated closely with the amount and distribution of rainfall [100]. Rainfall and moisture determine not only the severity of diseases, but also whether certain diseases will even occur in a given year. By increasing moisture above ground and in the soil, rain facilitates movement and development of pathogens on stems, leaves, and roots. Both bacterial pathogens and fungal spores often are disseminated in water drops, splashing rain, in rainwater moving from the surfaces of infected tissues to those of healthy ones or as free water in the soil [100]. Even airborne pathogens are affected by rain, which extracts them from the air and deposits them onto plants. In fungal disease development, disease spores are transported by water, and their germination depends on being covered by a film of water. Fungicides are used to protect plants from a variety of pathogens. In years of high rainfall and consequently high disease pressure, fungicide use tends to increase in efforts to produce harvestable crops.

For the purposes of this study, the term fungicide refers to any pesticide used for the management of disease causing plant pathogens, including bacteria and fungi.

## B. <u>Crop Analysis</u>

#### 1. Almonds

Increased fungicide use for almonds in California generally was correlated with the end of the drought years in 1993 and with high precipitation in 1995-1997. Anthracnose problems had been relatively unknown, but in 1995, 1996 and 1997, cool wet spring weather began causing major outbreaks [159]. Propiconazole was registered for

anthracnose under emergency exemptions in 1996, 1997 and 1998, and was used widely because it was more effective than alternatives [4].

The use of captan and maneb increased and replaced some ziram use due to more control efficacy against anthracnose. Increased use of myclobutanil and benomyl replaced some iprodione use because iprodione does not work as well on scab during wet years.

## 2. Apples

In Eastern states apple scab is the primary disease target of most fungicide sprays. In the early 1990's, many growers were using apple scab programs that depended on the sterol inhibitor (SI) fungicides (including fenarimol). However, SI resistant strains of the fungus were soon detected. Some growers stopped using SI's while other growers were advised to mix the SI's with other fungicides, such as mancozeb, captan and metiram [161]. Scab resistance to dodine was confirmed in the early 1990's. It is no longer efficacious and has declined in use. Growers substituted mancozeb and metiram. Mancozeb also was used widely in the East to control summer diseases (sooty blotch, fly speck, black rot) in the early 1990's. However, label changes in the early 1990's set maximum rates of 3 pounds per acre per application for mancozeb – a rate too low to control black rot [162]. In addition, restrictions on the use of the EBDC's (mancozeb and metiram) through the summer growing season (e.g., 77 day preharvest interval) makes them unavailable for summer disease control. Research demonstrated that benomyl was the most effective fungicide for controlling the summer disease complex [163]. However, it is recommended that benomyl be used in combination with captan or ziram to minimize resistance development and to maximize both eradicant and residual activity against fly speck [164].

In Michigan, some apple processors have concerns regarding captan usage and have placed restrictions on its use [165]. As a result, ziram increasingly has been the fungicide used most frequently in combination with benomyl for summer diseases in Michigan.

Thiram, triforine and dinocap are less effective than alternatives for control of the apple

disease complex, and their minor use in the early 1990's was discontinued for the most part by 1997 [296].

In Washington State, a major trend of the past 10 years has been the increased planting of Gala, Fuji and Braeburn apple trees and the removal of Red Delicious trees [168]. The Red Delicious trees were more susceptible to apple scab; the newer varieties are more susceptible to powdery mildew [169]. As a result, Washington State growers have decreased their use of fungicides targeted primarily at apple scab (mancozeb, ziram) and increased their use of fungicides targeted primarily at powdery mildew (fenarimol, triflumizole) [170]. Triflumizole usage also has displaced some of myclobutanil's use. Growers have reduced their use of triadimefon because of concerns that it adversely affects fruit size [170].

In the 1980's a new disease appeared in North Carolina apple orchards: alternaria blotch. In 1995, research indicated that some control of alternaria blotch on apples was obtained with applications of fosetyl-Al, which was subsequently registered and used in North Carolina [15].

Streptomycin usage to control fireblight in apples declined because of increasingly widespread resistance in the West. As a result, oxytetracycline usage in apple orchards increased and has been used under Section 18 emergency exemptions [14] [167]. Another registered pesticide for fireblight control in apples whose usage increased is fosetyl-Al.

#### 3. *Carrots*

Iprodione's use in California carrots grew in the 1990's in a rotation with chlorothalonil for resistance management of alternaria leaf blight [10]. The registration of metalaxyl in 1992 for cavity spot control in carrots provided growers for the first time with an effective control [89]. In the mid-1990's, carrot growers increased their use of metalaxyl as a soil drench for control of cavity spot [90].

## 4. *Celery*

Late blight of celery is a seedborne fungal pathogen that favors very wet conditions for development. The increased rainfall in California in 1997/98 led to an increase in propiconazole and chlorothalonil use for late blight control [127]. The introduction of propiconazole has provided growers with a more effective late blight control fungicide and its increased use replaced the less effective thiophanate methyl and the voluntarily canceled anilazine [127] [128]. Pink rot of celery reaches the highest incidence during cool wet periods, such as those characterizing the 1997/98 time period. DCNA is the primary celery fungicide used to control pink rot, and its use increased as a result of higher disease incidence.

## 5. *Cherries*

DCNA's registration for cherries was canceled in the 1990's. In the early 1990's the sterol inhibitor (SI) fungicides (fenarimol and myclobutanil) were very popular for control of cherry leaf spot and brown rot. Their usage has declined as the more effective fenbuconazole was introduced in the 1990's [126]. For the most part, fenbuconazole also has replaced iprodione, that was used for brown rot. (Fenbuconazole is half the price of iprodione.) [126] The use of captan in Michigan cherries has gone up due to concerns regarding resistance developing to sterol inhibitors. Captan is tank mixed increasingly with the SI's or used in a rotation program. The use of chlorothalonil is restricted to early season or post harvest application to the trees. Chlorothalonil's use has increased in an effort to preserve the SIs for leaf spot [126].

## 6. Citrus

Copper fungicides are used widely in Florida citrus, particularly for melanose and greasy spot control [93]. Although the percent of citrus acres treated with copper increased slightly in the mid-1990's, the factor that accounts for most of copper's increased pounds

of use in Florida is the doubling of Florida's citrus acreage between 1992 and 1997 (583,000 to 959,000).

Florida citrus growers began to treat a small percentage of acreage (2%) with ferbam for citrus scab, alternaria and in combination with benomyl for effective control of postbloom fruit drop [94]. The addition of ferbam helps reduce the possibility of selecting benomyl resistant strains [155].

#### 7. Cotton

Etridiazole and PCNB are used as in-furrow fungicides to control seedling diseases of cotton. In the mid-1990's, the recommendation increasingly was to use hopper box fungicide applications, rather than in-furrow applications [3]. Consequently the use of in furrow applications of etridiazole and PCNB declined.

## 8. *Grapes*

A substantial amount of resistance has built up to triadimefon in California grape vineyards, and, therefore, it's use has decreased greatly [1]. In grapes, copper use rose in California due to its inclusion in resistance management programs for powdery mildew [1].

California grape growers gained new registrations for the use of two fungicides for disease management: azoxystrobin and triflumizole. Grape growers integrated use of the new fungicides into disease control programs for resistance management. Increased use of myclobutanil replaced much of the early 1990's use of fenarimol and triadimefon. Two factors made myclobutanil increasingly popular: longer residual action (20 days rather than 10 to 14 days) and greater systemic action. The use of sulfur declined as growers increasingly used products like myclobutanil with a longer residual control period. Thus, there was less need to apply sulfur as often as in the early 1990's.

Unrelenting rains in 1997 also prevented California grape growers from making as many sulfur applications as was typical in the early 1990's.

In New York, Pennsylvania and Michigan, use of ziram has increased since 1992 and use of ferbam has decreased. In the early 1990's, juice processors in the Great Lakes grape producing region stopped accepting fruit treated with EBDCs and captan. Ferbam use increased to fill in the gap for black rot control. In 1996, ziram, a product with active ingredients and disease activity similar to ferbam, but cheaper and easier to use than ferbam, was registered for use on grape black rot, and growers switched from ferbam to ziram [45]. Ferbam leaves a black residue in grapes; ziram is whitish in appearance.

#### 9. Hazelnuts

Eastern Filbert Blight (EFB) was not a problem in hazelnuts in Oregon prior to the 1980's. Late in 1986, a major EFB infection center was discovered east of Portland, Oregon. Since that time, the disease has spread throughout Oregon's hazelnut production area [157]. Without controls an orchard becomes unproductive within four years of infection. Complete tree death usually occurs within five to seven years. In 1992, Oregon growers had use of two fungicides that provided some control of EFB: chlorothalonil (under an emergency registration) and copper. As the disease has spread, the use of the two fungicides has increased. Chlorothalonil received an Special Local Needs registration in 1996. Oregon growers also were allowed to use fenarimol under a Section 18 in 1997 for control of EFB. Complete protection from infection has been obtained with three to five fungicide applications applied in an 8 to 17 day schedule [158].

## 10. *Hops*

In 1997, powdery mildew was detected for the first time in the hop growing region of the Northwest [7]. Several fungicides have been allowed under Section 18 emergency provisions (1997-2000), including myclobutanil and tebuconazole [8].

#### 11. Lettuce

Following detection of downy mildew resistant populations to applications of metalaxyl in the early 1990's, California lettuce growers adopted a program of alternative treatments of maneb and fosetyl-Al [4] [11].

#### 12. Peaches

Propiconazole was registered for use in California peach orchards for brown rot control in 1996 [86]. Research demonstrated that propiconazole was highly effective in controlling brown rot and was competitively priced with alternatives. Propiconazole's use led to reductions in the use of other fungicides which peach growers had been using for brown rot control: benomyl, iprodione, thiophanate methyl, vinclozolin and triforine. Some reduction in the use of benomyl and thiophanate methyl can be attributed to increased resistance that had been documented in the Sacramento and northern San Joaquin Valley [87]. Chlorothalonil, copper and ziram are used primarily to control peach leaf curl. Increased use of copper for peach leaf curl control during the dormant season has led to reduced use of chlorothalonil and ziram during the growing season [88].

Georgia peach growers began using the newly-registered fungicides fenbuconazole and propiconazole on a significant portion of their state acres in the mid-1990's for control of brown rot and scab. The systemic nature of the new fungicides provided residual disease protection when other contact fungicides may wash off [91]. Reductions in use of other brown rot/scab fungicides occurred as a result: benomyl, captan, ferbam, sulfur, triforine and thiophanate methyl. The reductions in benomyl and thiophanate methyl usage were also the result of increases in the populations of resistant strains of brown rot and scab [92].

#### 13. Peanuts

For many years chlorothalonil has been the backbone for peanut leafspot control in the Southeast because of its high degree of efficacy. In recent years, newer fungicides (azoxystrobin, flutolanil, tebuconazole) have been used increasingly because they provide good leafspot control, as well as white mold control [26]. Chlorothalonil's usage has been reduced as it does not control white mold. The use of PCNB provides partial control of white mold; PCNB decreased in usage following the introduction of the new fungicides. In the early 1990's, a small percentage of peanut acreage (2-3%) was treated with carboxin for control of stem rot [28]. Carboxin has limited effectiveness in controlling stem rot (15%), and as new more effective products were introduced (azoxystrobin, flutolanil, tebuconazole), carboxin field usage ceased. Now carboxin is used exclusively in seed treatments.

#### 14. Pears

Unusually high spring rainfall in 1995 created a significant threat for the development of pear scab. The California Department of Pesticide Regulation approved the immediate registration of triflumizole, the only fungicide capable of eradicating pear scab following an infection [2]. Triflumizole is also the only sterol inhibitor fungicide that does not cause growth regulator effects on developing pears, leading to squat, short necked pears [2].

Streptomycin usage to control fireblight in pears declined because of increasing widespread resistance in the West. As a result, oxytetracycline usage in pear orchards increased and has been used under Section 18 emergency exemptions [14] [167]. Another registered alternative for fireblight control in pears whose usage increased was fosetyl-Al.

#### 15. Pecans

Triphenyltin hydroxide has been the primary fungicide used in pecan orchards for some time. TPTH acts a protectant; the introduction of propiconazole and fenbuconazole, both of which act as both protectant and eradicant for pecan scab and provide better early season control than TPTH, resulted in a reduction in TPTH's use in pecans [12].

#### 16. *Pistachios*

The fungal diseases panicle and shoot blight were first identified in California in the Sacramento Valley in the late 1980's and by the mid-1990's had spread into the San Joaquin Valley, the heart of the nation's pistachio production area. Since registered chemicals were inadequate, an emergency Section 18 registration was provided for tebuconazole [6].

#### 17. Potatoes

During the 1990's, late blight of potatoes reemerged as an important disease in the U.S. The immediate cause of the reemergence of late blight is the recent immigration of exotic strains of the late blight fungus [101]. Up until the 1980's, the fungus in the U.S. consisted of only one kind – the so called A1 mating type (that can only exist on a living potato family host, such as vines, foliage, stems and tubers). In the 1980's, a second mating type (A2) immigrated to the U.S. from Mexico. Sexual mating between A1 and A2 types produced fungal structures called oospores, that can survive extremes in temperature and moisture and exist outside a living host. Thus, it became possible for the fungus to survive in soil and plant debris for long periods – months and perhaps even years. In the early 1990's, the A2 fungus and new forms of the fungus resulting from A1/A2 mating spread throughout all potato growing areas of the U.S. [102]. The new exotic strains were nearly all resistant to metalaxyl, that had been the only systemic late blight fungicide available in the U.S. with excellent after-infection activity [101]. The exotic strains quickly spread throughout the U.S. in the 1990's. The exotic strains are

more aggressive than the traditional strains. For example, they have a faster lesion expansion rate. As a result, the exotic strains require more fungicides for adequate suppression of late blight symptoms than was required previously. The new strains are not more resistant to protectant fungicides than the old strains. EPA was petitioned for emergency registration for fungicides with some systemic activity. The petitions were delivered in February 1995, and were granted for the majority of the 1995 season and for subsequent years, as well [101]. The Section 18 late blight fungicides are propamocarb (used with chlorothalonil), dimethomorph (used with mancozeb) and cymoxanil (used with maneb). Other late blight fungicides whose use increased during the 1990's are: chlorothalonil, metiram, mancozeb, copper and TPTH. Growers also used metalaxyl (mefenoxam) mixed with chlorothalonil or mancozeb [103].

#### 18. *Rice*

In 1997 and 1998, emergency registrations were granted for rice growers to use azoxystrobin, in order to control sheath blight fungus which was pervasive and unable to be controlled by available fungicides. In addition to providing effective control of sheath blight, azoxystrobin also controls another major rice disease, blast [9] [57]. The use of azoxystrobin in rice resulted in the decline of use of three fungicides that have efficacy against only one of the two diseases: benomyl (blast), propiconazole (blast) and iprodione (sheath blight).

Fine crystalline formulations of copper sulfate have long been an effective control for algae and tadpole shrimp in California rice fields. Beginning in 1992, California rice growers had to reduce progressively the amount of acreage they burned by 10% a year. Rice farmers traditionally burned straw for control of diseases and disposal of straw [95]. Straw left on the soil's surface can contribute to algae blooms [96]. Copper use increased in rice because of restrictions placed on the major alternative for tadpole shrimp control (methyl parathion), and because of increasing problems with algae in some rice-growing areas [4].

## 19. Soybeans

Increased planting of early maturing soybean cultivars in the Southeast helps to avoid diseases that are problems at the end of the season [125]. Thus, there is reduced soybean acreage treated with foliar fungicides, such as thiophanate methyl.

## 20. Spinach

Under conditions of prolonged leaf wetness and cool temperatures, epidemics of downy mildew can progress very rapidly in spinach [145]. The wet weather conditions of the 1997 time period led to increased use of fungicides for downy mildew control in California spinach: mefenoxam, metalaxyl and maneb.

#### 21. Strawberries

Captan use increased in California strawberry fields because the frequent rains promoted gray mold growth. In addition, in 1994, the USEPA reduced the interval between the application of captan and harvest, thereby allowing captan usage for a greater period of time during the growing season [4]. The increase in captan applications in strawberries also compensated for the cancellation of anilazine. Thiram's use for disease control in strawberries increased because of its role in managing resistance to other fungicides, such as iprodione, vinclozolin and benomyl, wherein it is tank mixed or alternated [29]. The use of sulfur declined in California strawberries following the introduction of myclobutanil for powdery mildew control. Sulfur is phytotoxic above 75°F. Increased use of myclobutanil may also have been due to weather conditions that promoted development of powdery mildew [4]. Reduced use of thiophanate methyl and vinclozolin in strawberries is attributed to resistance problems.

## 22. Sugarbeets

Due to increasing levels of resistance in the populations of the sugarbeet cercospora leafspot pathogen to applications of triphenyltin hydroxide, it was used increasingly in the 1990's on shorter application intervals than formerly, and frequently at higher rates. In 1997, sugarbeet growers in Minnesota and North Dakota increased their use of thiophanate methyl, mancozeb and maneb in order to compensate for the reduced effectiveness of triphenyltin hydroxide [5].

In California, sulfur and triadimefon are applied to sugarbeets to control powdery mildew. A significant decrease in the pounds of fungicide used in California occurred 1992-1997 largely because the total number of sugarbeet acres in California declined by one-third.

## 23. Sweet Corn

Propiconazole was labeled in 1994 for use on sweet corn and quickly replaced some of mancozeb's use. Propiconazole has systemic action and keeps new infection points of rust from erupting. The systemic nature of propiconazole means it is not washed off by rain and provides longer protection than mancozeb [14]. Another reason that mancozeb decreased in use was concerns regarding EBDC residues on sweet corn wastes from the cannery (husks and cobs) that are fed to livestock and dairy animals [160].

## 24. Tobacco

Prior to 1979, blue mold principally was a disease that occurred occasionally in tobacco plant beds in the U.S. In 1979 and 1980, widespread and devastating epidemics of blue mold occurred in all tobacco production areas of the U.S. Metalaxyl received a registration in 1980 and has been used widely by tobacco growers ever since. The first metalaxyl resistant blue mold isolates in the U.S. were detected in 1991. Fortunately, metalaxyl resistant strains did not dominate the fungus population in 1991, and no major

outbreaks of blue mold occurred through 1994. In 1997, however, blue mold occurred in nearly all the tobacco production areas of eastern North America [64] [65]. With only a few exceptions, blue mold lesions were the result of metalaxyl resistant strains. Fourteen states requested and were granted permission to apply Acrobat MZ to control metalaxyl resistant strains of the blue mold fungus. Acrobat MZ consists of two active ingredients: dimethomorph and mancozeb.

#### 25. Tomatoes

The increase in sulfur in California tomatoes can be explained by a higher incidence of disease (powdery mildew) resulting from spring rains and by increased mite pressure [4]. Copper is used to control bacterial diseases in California tomato fields. An increase in copper in California tomato fields in the 1990's resulted from a series of wet springs, that tend to aggravate bacterial diseases [139].

In 1997, California tomato growers received a Section 18 emergency registration for the use of myclobutanil to control powdery mildew. California growers had been using triadimefon in the early 1990's under Section 18's for powdery mildew.

Populations of the late blight fungus have developed resistance to metalaxyl, and, as a result, it is used less in California tomato fields [29]. Metalaxyl or mefenoxam is used in a prepack with chlorothalonil early in the season [141]. Propamocarb has replaced much of metalaxyl's use for late blight control in California tomato fields.

Propamocarb is used in a combination product (Tattoo) with chlorothalonil, thus accounting for some of the increased acreage treated with chlorothalonil. Tomato acreage previously treated with anilazine was switched to chlorothalonil following its voluntary cancellation.

In the 1990's, late blight of tomatoes spread throughout California's tomato growing regions with increasing incidence and severity [140]. California tomato growers were

advised to apply protectant fungicides, such as chlorothalonil and mancozeb in anticipation of favorable conditions for late blight development [140] [29].

A new aggressive late blight strain emerged in California tomato fields in the 1990's – capable of persisting throughout an entire growing season, even in the hot and dry conditions of the Central Valley [142].

Azoxystrobin was first used by tomato growers in 1997. Because of its systemic activity and long residual in controlling blight and anthracnose, the use of azoxystrobin has resulted in lower rates and fewer applications of the protectant fungicides chlorothalonil and mancozeb [143].

Tomato growers in Florida have encountered economic difficulties as a result of NAFTA and increased imports of Mexican tomatoes. Mancozeb is less expensive than either chlorothalonil or maneb, and Florida growers have switched many applications to mancozeb in order to save on expenses [144].

#### 26. Walnuts

Maneb was registered under an emergency exemption in California for walnuts 1994-1998. Maneb has been used in walnuts in areas of copper resistant walnut blight bacteria [4] [53].

## 27. Wheat

In the southeast (e.g., Georgia) propiconazole's use on wheat increased 1992-1997 while the use of mancozeb and triadimefon declined. Research documented that a single application of the systemic propiconazole provided control of the three major wheat diseases (leaf blotch, powdery mildew and leaf rust) for 14 to 21 days [61]. Growers had been experiencing frequent control failures with mancozeb since it is a protectant and must be applied prior to infection [61]. Mancozeb also is ineffective following rain since

it washes off. Thus, two applications of mancozeb generally were required for effective control [62]. Carefully timed mancozeb applications will control two of the diseases: leaf blotch and leaf rust. It is necessary for growers to mix mancozeb with triadimefon in order to provide effective control of powdery mildew [63]. In 1998, the registrant of triadimefon withdrew its label for wheat.

Continued moist weather during the growing season favors development of the fungus that causes head scab of wheat. Above normal precipitation in July (1993-1998) contributed to recurring localized epidemics of wheat scab in North Dakota and Minnesota [81]. Corn is a host and an important reservoir of the scab fungus. Thus, the increase in corn conservation tillage acres with possible concomitant increase in presence of infected corn residue on the soil surface may be contributing to recent epidemics in wheat growing areas [81]. In 1992 (a drought year), wheat losses to scab in North Dakota were zero, while in 1997 (a wet year), wheat losses to scab in North Dakota totaled 45 million bushels [82] [85]. Wheat growers in North Dakota and Minnesota have been advised to consider using foliar fungicides to control scab. These states received 24c labels, that allow the use of propiconazole up to heading, thereby improving its ability to suppress scab [83]. In addition, EPA has granted emergency exemptions for tebuconazole (1997-2000) for control of head scab in North Dakota and Minnesota [84].

Thiabendazole was used on 7-9% of Oregon's and Washington's wheat acreage in 1992, primarily for control of strawbreaker footrot/eyespot. The manufacturer voluntarily dropped the label for foliar applications. Benomyl usage declined due to increased resistance problems. The use of propiconazole and thiophanate methyl have increased slightly as replacements. However, overall fungicide use in Northwest wheat declined in the 1990's because of the increased planting of several wheat varieties with acceptable resistance to eyespot (Masden, Gene, Rohle, Hyak) [80] [78] [79].

TABLE 3: NATIONAL PESTICIDE USE BY ACTIVE INGREDIENT PESTICIDE TYPE: FUNGICIDES

FESTICIDE TTFE. TONGICIDES	IRSALA	PPLIED PER YEAR	% CHANGE
ACTIVE INGREDIENT	1992	1997	70 CHANGE
ANILAZINE	168,835		-100
AZOXYSTROBIN		228,614	-
BENOMYL	1,198,371	675,500	-44
CAPTAN	3,197,989	3,992,782	+25
CARBOXIN	46,968		-100
CHLOROTHALONIL	11,566,092	11,916,713	+3
COPPER	8,270,289	13,682,409	+65
CYMOXANIL		45,886	-
DCNA	169,333	188,683	+11
DIMETHOMORPH		51,536	-
DINOCAP	10,902		-100
DODINE	264,664	151,538	-43
ETRIDIAZOLE	193,896	91,669	-53
FENARIMOL	47,600	46,272	-3
FENBUCONAZOLE		32,818	- 
FERBAM	219,486	317,125	+44
FLUTOLANIL		24,960	-
FOSETYL-AL	533,646	904,718	+70
IPRODIONE	873,547	689,648	-21
MANCOZEB	8,062,374	9,585,777	+19
MANEB	3,525,322	3,039,930	-14
MEFENOXAM	055.400	210,101	-
METALAXYL	855,400	659,997	-23
METIRAM	539,206	1,385,330	+156
MYCLOBUTANIL	136,849	174,482	+27
OXYTETRACYCLINE	30,163	33,536	+11
PCNB PROPAMOCARB	1,662,371	819,086	-51
PROPICONAZOLE	281,355	173,885 493,998	- +75
STREPTOMYCIN	100,029	493,996 50,434	+75 -50
SULFUR	82,883,332	77,788,188	-50 -6
TEBUCONAZOLE	02,000,002	478,568	-0
THIABENDAZOLE	155,403	470,500	-100
THIOPHANATE METHYL	498,283	453,792	-100 -9
THIRAM	199,251	179,809	-10
TRIADIMEFON	135,112	53,098	-61
TRIFLUMIZOLE	100,112	92,481	-
TRIFORINE	73,644	23,625	-68
TRIPHENYLTIN HYD	424,910	660,971	+56
VINCLOZOLIN	135,035	121,959	-10
ZIRAM	2,804,087	1,992,552	-29
FUNGICIDES TOTAL	129,263,743	131,512,471	+2

TABLE 4: Differen	ices in F	ungicide Use An	nounts: 1992 a	nd 1997	
			(1000 LB AI/Y	R)	
Active Ingredient	<u>Total</u>		Major Crop	Changes	
Anilazine	-169	Tomatoes -100	Celery -41	Strawberries	: -24
Azoxystrobin	+229	Tomatoes +15	Grapes +24	Rice +125	Peanuts +55
Benomyl	-523	Rice -404	Wheat -107	Apples +13	Peaches -24
Bonomy	020	Almonds +31	Wildat 107	Apples 116	1 Caones 24
Captan	+795	Almonds +408	Apples +378	Strawberries	s +136
o spiss.		Cherries +22	Peaches -182	0	
Carboxin	-47	Peanuts -47			
Chlorothalonil	+350	Potatoes +3686	Peanuts -2981	Tomatoes -2	220
Omorouna.com		Hazelnuts +17	Celery +41	Peaches -62	Cherries +61
		Carrots -9	00.0.9		
Copper	+5412	Tomatoes +283	Citrus +1822	Rice +1846	Grapes +520
			Peaches +342	Walnuts -156	Hazelnuts +20
Cymoxanil	+46	Potatoes +45			
DČNA	+20	Celery +60	Grapes -10	Cherries -14	
Dimethomorph	+51	Potatoes +15	Tobacco +37		
Dinocap	-11	Apples -6	Grapes -4		
Dodine	-114	Apples -115			
Etridiazole	-102	Cotton -102			
Fenarimol	-2		Grapes -8 Ch	erries -1 F	lazelnuts +1
Fenbuconazole	+33	Peaches +7	Cherries +8	Pecans +18	idzeiridie i i
Ferbam	+98	Citrus +160	Grapes -43	Peaches -59	
Flutolanil	+25	Peanuts +25	Orapes -45	1 Gaories -03	<u>'</u>
Fosetyl-Al	+371	Tomatoes +24	Apples ±106	Pears +26	Lettuce +54
Iprodione	-184	Almonds -81	Apples +106 Carrots +39	Rice -126	Peaches -42
iprodione	-104	Strawberries +15	Carrols +39	NICE - 120	reaches -42
Mancozeb	+1523	Potatoes +1330	Apples +330	Sugarbeets +71	15 Wheat -471
Wallcozed	T1323	Sweet Corn -326	Tobacco +356	Sugarbeets +1	io vineat-471
Maneb	-486	Tomatoes -419	Sugarbeets +1	96 Lettu	ce +342
Maries	-400	Walnuts +208	Almonds +220		UC +U42
Mefenoxam	+210	Potatoes +26	Tobacco +139		Spinach +6
Metalaxyl	-195	Tomatoes -13	Tobacco -101	Lettuce -8	Spinach -4
ivicialaxyi	-195	Potatoes +14	Carrots +17	Lettuce -0	Spiriacri -4
Metiram	+846	Potatoes +382	Apples +464		
Myclobutanil	+37	Almonds +10	Grapes +10	Hops +5	Tomatoes +3
wyciobulariii	T31	Strawberries +4	Cherries -1	11005 +3	TOTTIALUES TO
Oxytetracycline	+4	Apples +3	Pears +7		
PCNB	-843	Peanuts -454	Cotton -390		
Propamocarb	+174	Potatoes +167	Tomatoes +7		
	+174	Sweet Corn +11	Pecans +5	Wheat +150	Almonds +5
Propiconazole	+213				Almonus +5
Ctrontomyoin	ΕO	Peaches +14	Celery +6	Rice -25	
Streptomycin	-50	Apples -44	Pears -6	Quaarhaata	2120
Sulfur	-5095	Peaches -1118	Grapes -3833	Sugarbeets	-3130
Tobuconazolo	. 470	Tomatoes +1905 Pistachios +11	Strawberries -5	Wheat +144	Hone : 1
Tebuconazole	+479		Peanuts +319	vviieat +144	Hops +1
Thiabendazole	-155	Wheat -155	Cugarbasta : 0	/ Ctrassile	orrigo E
Thiophanate Methyl	-44	Soybeans -88	Sugarbeets +6		erries -5
This are	40	Peaches -86	Celery -2	Wheat +10	
Thiram	-19	Apples -77	Strawberries +		\/\b+ 00
Triadimefon	-82	Grapes -35	Sugarbeets -12	Tomatoes -4	Wheat -30
Triflumizole	+92	Apples +34	Grapes +51	Pears +7	

Triforine	-50	Peaches -45
-		·

			(1000 LB AI/Y	R)	
Active Ingredient	Total		Major Crop		
Triphenyltin Hyd	+236	Potatoes +47	Pecans -11	Sugarbeets +2	200
Vinclozolin	-13	Strawberries -17	Peaches -10		
Ziram	-812	Almonds -1167	Grapes +107	Apples +285	Peaches -38

<b>TABLE 5: Fungicide Use</b>	<b>Patterns by Cro</b>	p and State	(Selected Records)

	% Acre	s Treated
	<u>1992</u>	<u>1997</u>
I. Almonds		
a. <u>California</u>		
Benomyl	7	16
Captan	6	25
Iprodione	56	41
Maneb	10	17
Myclobutanil	-	13
Propiconazole	-	7
Ziram	80	15
II. Apples		
a. <u>Michigan</u>		
Benomyl	8	28
Captan	93	71
Dinocap	2	<del>-</del>
Dodine	12	1
Fenarimol	48	34
Mancozeb	18	46
Metiram	42	39
Thiram	9 2	-
Triforine Ziram	6	39
	O	39
b. New York		
Benomyl	20	44
Captan	79	93
Dodine	18	3
Fenarimol	53	26
Mancozeb Metiram	79 6	80 24
Ziram	13	13
	13	13
c. North Carolina		
Fosetyl-Al	-	10
d. <u>Washington</u>		
Fenarimol	26	50
Fosetyl-Al	-	14
Mancozeb	21	12
Myclobutanil	63	32
Oxytetracycline	1	10
Streptomycin	17	2
Triadimefon	22	2
Triflumizole	-	39
Ziram	24	10

TABLE 5:	<b>Fungicide Use Patterns by Crop and State</b>
	(Selected Records) (Cont.)

	% Acres Treated		
	<u>1992</u>	<u>1997</u>	
III. Carrots			
a. <u>California</u>			
Chlorothalonil	66	14	
Iprodione	19	37	
Mefenoxam	-	29	
Metalaxyl	13	22	
IV. Celery			
a. <u>California</u>			
Anilazine	62	-	
Chlorothalonil*	72	92	
DCNA**	60	69	
Propiconazole	-	90	
Thiophanate Methyl	9	-	
* Rate tripled			
** Rate doubled			
V. Cherries			
a. <u>Michigan</u>			
Captan	10	25	
Chlorothalonil	51	86	
DCNA	11	-	
Fenarimol	25	15	
Fenbuconazole	- 4.4	60	
Iprodione Mydebytanil	44 80	6 27	
Myclobutanil	00	21	
VI. Citrus			
a. <u>Florida</u> *			
Copper	58	63	
Ferbam	-	2	
* Acreage doubled			
VII. Cotton			
a. <u>Mississippi</u>			
Etridiazole	25	10	
PCNB	24	15	
VIII. Grapes			
a. <u>California</u>			
Azoxystrobin	-	4	
Copper	15	77	
Fenarimol	79	47	
Myclobutanil	32	61	
Sulfur*	91	86	
Triadimefon	33	2	

TABLE 5:	<b>Fungicide Use Patterns by Crop and State</b>
	(Selected Records) (Cont.)

	% Acres Treated		
	<u>1992</u>	<u>1997</u>	
Triflumizole * Rate reduced by 29%	-	39	
b. <u>New York</u> Ferbam Ziram	33 -	14 21	
IX. Hazelnuts a. Oregon Chlorothalonil Copper Fenarimol	19 18 -	37 38 18	
X. Hops a. <u>Oregon</u> Myclobutanil Tebuconazole	- -	20 45	
XI. Lettuce a. <u>California</u> Fosetyl-AI* Maneb Metalaxyl * Rate increased 15%	80 52 12	46 80 7	
XII. Peaches a. California Benomyl Chlorothalonil Copper* Iprodione Propiconazole Thiophanate Methyl Triforine Vinclozolin Ziram * Rate doubled	23 37 76 87 - 9 59 12 52	5 5 75 34 51 7 5 4 24	
b. Georgia Benomyl Captan Fenbuconazole Ferbam Propiconazole Sulfur* Thiophanate Methyl Triforine	28 39 - 60 - 100 62 16	17 29 11 - 76 84 -	

TABLE 5: Fungicide Use Patterns by Crop and State (Selected Records) (Cont.)			
	% Acres	s Treated	
	<u>1992</u>	<u>1997</u>	
* Rate declined by 20%			
XIII. Peanuts a. <u>Georgia</u> Azoxystrobin	_	20	
Carboxin	2	-	
Chlorothalonil*	97	90	
Flutolanil PCNB	- 4	3	
Tebuconazole	<del>4</del>	- 57	
* Rate declined by 35%		51	
XIV. Pears a. California Triflumizole	-	5	
b. <u>Washington</u>			
Fosetyl-Al	<u>-</u> 	12	
Oxytetracycline	51	54	
Streptomycin Triflumizole	7	4 24	
XV. Pecans a. <u>Georgia</u> Fenbuconazole Propiconazole TPTH	- 52 97	10 60 70	
XVI. Pistachios a. <u>California</u> Tebuconazole	-	28	
XVII. Potatoes a. <u>Idaho</u>			
Chlorothalonil*	23	85	
Copper*	10	30	
Cymoxanil	-	39	
Dimethomorph Managazah*	-	3	
Mancozeb* Maneb	9 5	79 16	
Metalaxyl	-	21	
Propamocarb	-	7	
Triphenyltin Hyd  * Rate doubled	16	20	
b. New York Chlorothalonil*	25	44	

TABLE 5:	<b>Fungicide Use Patterns by Crop and State</b>
	(Selected Records) (Cont.)

	% Acres Treated	
	<u>1992</u>	<u>1997</u>
Copper	-	45
Cymoxanil	-	3
Dimethomorph	-	2
Mancozeb*	86	90
Maneb Mefenoxam	38	45 12
Metalaxyl	37	-
Metiram	-	14
Propamocarb	-	8
TPTH	-	20
* Rate doubled		
XVIII. Rice		
a. <u>California</u>		
Copper	25	43
b. <u>Mississippi</u>		
Azoxystrobin	<u>-</u>	25
Benomyl	5	2
Iprodione	12 15	2
Propiconazole	15	2
IXX. Soybeans		
a. <u>Mississippi</u> Thiophanate Methyl	2	
	2	-
XX. Spinach		
a. <u>California</u> Maneb		19
Mefenoxam	-	29
Metalaxyl	29	38
XXI. Strawberries a. <u>California</u>		
Anilazine	36	_
Captan*	43	79
Myclobutanil	13	53
Sulfur**	56	66
Thiophanate Methyl	35	2
Thiram*	100	67
Vinclozolin * Pata doubled	43	31
* Rate doubled ** Rate declined by 25%		
XXII. Sugarbeets		
a. <u>California</u> * Sulfur	100	89
Juliui	100	00

TABLE 5: Fungicide Use Patterns by Crop and State (Selected Records) (Cont.)			
	% Acres	s Treated	
	<u>1992</u>	<u>1997</u>	
Triadimefon * Acreage declined by 33%	10	4	
b. Minnesota Mancozeb Maneb Thiophanate Methyl TPTH* * Rate doubled	12 - - 77	56 14 17 70	
XXIII. Sweet Corn a. Illinois Mancozeb Propiconazole	41 -	20 33	
b. <u>Minnesota</u> Mancozeb  Propiconazole	35 -	13 24	
XXIV. Tobacco a. <u>Tennessee</u> Dimethomorph Mancozeb Mefenoxam Metalaxyl	- - - 100	20 30 40 20	
XXV. Tomatoes a. California Anilazine Chlorothalonil* Copper Mancozeb Metalaxyl** Myclobutanil Propamocarb Sulfur*** Triadimefon * Rate reduced by 40% *** Rate increased by 12%	17 38 18 10 19 - - 58 13	- 69 67 50 23 30 10 63	
b. Florida Chlorothalonil* Mancozeb** Maneb*** * Rate reduced by 17% ** Rate increased by 61%	66 62 29	59 60 32	

TABLE 5: Fungicide Use Patterns by Crop and State (Selected Records) (Cont.)			
	% Acres	% Acres Treated	
	1992	1997	
*** Rate reduced by 33%			
c. Ohio Azoxystrobin Chlorothalonil* Mancozeb** * Rate reduced by 36% ** Rate reduced by 55%	100 100	60 97 62	
XXVI. Walnuts a. <u>California</u> Maneb Copper	- 100	31 59	
XXVII. Wheat a. <u>Georgia</u> Mancozeb Propiconazole Triadimefon	9 2 18	- 18 5	
b. <u>Minnesota</u> Propiconazole Tebuconazole	2	12 21	
c. <u>Washington</u> Benomyl Propiconazole Thiabendazole Thiophanate Methyl	9 - 9 2	1 3 - 5	

#### IV. Herbicides

## A. Introduction

Some active ingredients classified as herbicides are also used for crop desiccation. Herbicides used for weed control purposes can be applied preemergence in order to control weed seeds as they germinate, or postemergence in order to kill emerged weeds. Herbicides vary in the length of residual activity that they provide once they reach the soil. One key feature of herbicides is their selectivity. Not all herbicides can be used safely with all crops. The herbicide should kill weed species, but not crops that may be close relatives of the weed species.

## B. <u>Crop Analysis</u>

## 1. Alfalfa

In the 1990's, imazethapyr was registered for control of many grass and broadleaf weeds in alfalfa [198]. Imazethapyr is applied postemergence and provides more effective control than previously used postemergence broadleaf herbicides, particularly 2,4-DB, and displaced much of its use [199].

## 2. Apples

During the early 1990's, in many eastern apple orchards, growers removed older trees and replanted orchards with higher density dwarf trees. The new orchards typically have 200 to 1,500 trees per acre, compared with older orchards with 50 to 80 trees per acre. In older orchards with larger trees, many growers tolerated weeds. In 1991, a relatively small percentage of apple orchard acreage was treated with any herbicide: New York (32%), Michigan (28%), and Pennsylvania (45%) [58]. The use of herbicides increased

steadily in the 1990's, so that by 1997, a much higher percentage of apple acreage was treated with herbicides: Michigan (70%), New York (58%), and Pennsylvania (70%). Research demonstrated the importance of weed control on apple tree growth in the new high density orchards [309]. The high density orchards with trees 8 to 10 feet tall, are designed to utilize available soil and water resources fully, thus there is less tolerance for weeds [310]. Smaller trees with smaller roots are more sensitive to weed pressure [311]. As a result of the shift to high density orchards, herbicide use in apples went up in the 1990's.

## 3. Blueberries

Annual grasses have been increasing in Maine's wild blueberry fields. Growers traditionally have relied on a single preemergence application of hexazinone for most of their weed suppression and have been using lower rates to prevent hexazinone from leaching into groundwater. (In the 1980's, the average rate of hexazinone application was 2.0 lb/AI/A; by 1997, the rate was 1.0 lb/AI/A.) The reduced rate has not been sufficient to control these grasses because they germinate later in the season and there is not enough herbicide residue to control them [261]. Research indicated that the newly registered blueberry herbicides clethodim and sethoxydim provided effective control of emerged grasses and prevented them from going to seed [261]. In the early 1990's, there was considerable use of glyphosate in Maine wild blueberry fields for control of woody species. As a result, these species have been rendered less of a problem, and the use of glyphosate has been reduced to maintenance treatments.

#### 4. Broccoli

DCPA was used widely by California broccoli growers as a preemergence herbicide for control of certain groups of weeds, most notably, hairy nightshade, knotwell, lambsquarters, nettleleaf, goosefoot and purselane [19]. Production of DCPA was ended in the mid-1990's. As supplies of DCPA dwindled, California broccoli growers increased their use of two other preemergence herbicides: bensulide and oxyfluorfen.

## 5. Canola

The major factor accounting for the large increase in the use of trifluralin in canola is the large expansion in acreage that occurred in the 1990's. In North Dakota, canola acreage increased from 16,000 acres in 1992 to 376,000 acres in 1997 (an increase of 2,100%). Trifluralin was the only fully registered herbicide for canola in the early 1990's and is used at-planting for control of grassy weeds on about one-third of the canola acres. Ethalfluralin is applied similarly to trifluralin and was available to North Dakota canola growers under a Section 18 in 1997, at which time it was applied to the other two-thirds of the acreage. Ethalfluralin provides somewhat more effective control of kochia, volunteer cereals and lambsquarters than does trifluralin [276].

Clopyralid, quizalofop and sethoxydim are all applied as postemergence herbicides and control weed species not well controlled by the at-planting treatments, including Canada thistle, wild oats, wild buckwheat and foxtails. These herbicides were introduced for canola growers' use in the mid-1990's.

#### 6. *Citrus*

Since 1992, juice orange prices have been so low that growers have been cutting costs on herbicide applications. Growers have reduced their applications of diuron, norflurazon and oryzalin because of their expense [301]. Glyphosate was applied to greater acreage in 1997 than in 1992, but at a lower rate. Low rate technology that was developed includes chemical mowing of only row middles [301]. The price of glyphosate also declined, making it more competitive with paraquat, the use of which declined. Bromacil was used on two-thirds of Florida's citrus acreage in 1992, but only 40% in 1997 due to a ban prohibiting bromacil usage in sandy, well-drained soils, effectively eliminating it as an alternative for the majority of groves in Florida's Central production area [301].

## 7. Corn

Atrazine remained the number one herbicide used by U.S. corn growers in the 1990's. In many states there was an increase in the percentage of corn acres treated with atrazine. In other states there were increases in the total pounds of atrazine used on treated acres during the season. The increase in atrazine use is due to its increased use as a tank mix material added in with other herbicides – particularly postemergence herbicides [266] [269]. Generally, there was an increase in the percentage of corn acres treated with both preemergence and postemergence herbicide applications. The increase in postemergence treatments was due to the introduction of several effective postemergence herbicide active ingredients that met several weed control needs of corn growers. The inclusion of atrazine with these postemergence herbicides adds a level of consistency to the control and expands its activity to include other weed species. One of the new postemergence active ingredients is halosulfuron, which provides excellent control of nutsedge and velvetleaf [270].

In some areas corn growers replaced atrazine pre and post treatments with other products because of restrictions placed on atrazine's use (in some cases, atrazine's rate restrictions significantly reduced its effectiveness on certain weed species), and because of the prevalence of triazine resistant weed species. A combination of clopyralid and flumetsulam has been used as both a pre and post atrazine replacement in some areas, such as Iowa [266]. Another atrazine replacement used by some corn growers is imazethapyr, which can be used only with certain corn cultivars that have been genetically enhanced to resist imazethapyr (IMI-corn) [267].

Another active ingredient that was introduced as a substitute for atrazine is postemergence applications of metribuzin, which is used at a low rate and has a shorter half-life [268].

The registrant of cyanazine agreed to a phaseout of its use that began in the 1990's. As a result, most corn-growing states recorded declines in cyanazine corn use in the 1990's. Cyanazine was replaced in three ways: (1) in some states growers substituted atrazine for cyanazine [272]; (2) in other states where cyanazine typically had been used with atrazine, growers substituted a mixture of metolachlor or dimethenamid and atrazine [268]; (3) for previously used postemergence cyanazine applications, growers substituted combinations of herbicides, such as rimsulfuron, thifensulfuron, nicosulfuron, prosulfuron and dicamba with atrazine [269].

A reduction occurred in the use of bromoxynil used postemergence for broadleaf weed control. Newer products (such as the combination of primisulfuron and prosulfuron) provided more consistent weed control and outcompeted bromoxynil [266]. Bromoxynil needs to be applied when weeds are very small. Newer products have some systemic activity, allowing growers more flexibility in timing of applications [271]. Bromoxynil cannot be tank mixed because of crop injury concerns, so growers are inclined to go with active ingredients that can be tank mixed (such as dicamba).

Certain postemergence products grew in use because of particular weed control problems. For example, waterhemp became more of a problem in corn fields in the 1990's, leading to greater use of dicamba in states such as Iowa. Nicosulfuron is particularly effective in controlling johnsongrass and shattercane, that were not controlled as well by other products [268].

The major change in the 1990's in the preplant or at-planting use of corn herbicides was the almost complete replacement of alachlor use by acetochlor. Acetochlor needs less rainfall to activate than alachlor, so it provides more consistency with weeds in the spring. Acetochlor is more consistent in controlling foxtails and small seeded grasses; alachlor provides shorter duration of control compared with acetochlor [266] [272].

Propachlor continued its decline in the 1990's. Propachlor is hard to handle; it tends to clog nozzles [267]. Acetochlor and metolachlor both provide longer residual control than

does propachlor. Tridiphane had a very small market in the early 1990's. It was removed from the market due to its expense and ineffectiveness [267].

The use of pendimethalin declined in corn in the 1990's. Crop injury is a concern with pendimethalin. It was replaced for early postemergence by new postemergence products, such as nicosulfuron and dicamba [270].

The increase in triazine resistant kochia in Colorado, Nebraska and Kansas has resulted in corn farmers using non-triazine herbicides, including pyridate and dicamba, to achieve effective control of triazine resistant kochia [68].

Another factor accounting for the shift to postemergence herbicide applications in some Northern states, such as Minnesota, was a desire to shift from preemergence treatments for grass control because growers have such a small window for planting in time to miss early fall cold weather. They wanted to decouple planting and herbicide applications so that there would be nothing to delay a timely planting. Thus, as effective postemergence products became available, growers shifted from pre to postemergence use [270].

In corn, conservation tillage practices increased in the 1990's. Although butylate and EPTC perform well for control of grasses, their need for mechanical incorporation resulted in metolachlor and acetochlor replacing most of their use [73]. There has been an increase in the use of glyphosate and paraquat, that are used prior to planting to remove weeds from the field. A prepack of prosulfuron and primisulfuron (Exceed) was introduced, thereby providing postemergence control of a broad weed spectrum. Exceed controls shattercane and johnsongrass.

Imidazolinone tolerant/resistant corn varieties, known as IMI corn, were developed using conventional plant breeding techniques (tissue culture selection and mutagenesis). Research demonstrated that imazethapyr would provide more consistent control of many broadleaf weeds, such as velvetleaf, compared with atrazine [74]. However, control of common lambsquarters was inconsistent with imazethapyr. Therefore, a mixture of

imazethapyr and dicamba was introduced in 1995 to control common lambsquarters and ALS resistant weeds [75]. Imazethapyr also is marketed in a prepack with atrazine (Contour).

Flumetralin and clopyralid primarily are used together in a prepack for postemergence applications. Flumetralin is highly effective on velvetleaf and is used in velvetleaf areas. Clopyralid targets problem broadleaf weeds, like Canada thistle.

#### 8. Cotton

Methazole was used postemergence for broadleaf weed control in the early 1990's [346]. Following its cancellation in 1994, cotton growers in some states (North Carolina) increased their use of fluometuron postemergence while growers in other states (Alabama) increased their use of prometryn postemergence to substitute for methazole [347].

Norflurazon has an important role as a preemergence or preplant incorporated treatment in managing DNA resistant weed species [339]. Research demonstrated that clomazone in preemergence application could substitute for norflurazon, that, typically, is incorporated, thus facilitating reduced tillage cotton [344]. Clomazone also provides wide spectrum control and, when added to fluometuron increases efficacy on species such as sicklepod [358]. Clomazone provides superior control of certain DNA resistant weed species (such as goosegrass) and also improves control of seedling johnsongrass [340]. As a result, clomazone displaced some of norflurazon's use in states such as Mississippi.

The use of postemergence grass and broadleaf weed control herbicides increased in the mid-1990's due to their effectiveness in controlling weeds that were increasingly resistant to other commonly used herbicides. The use of lactofen in combination with MSMA provides effective control of MSMA resistant cocklebur. The use of clethodim is recommended for control of johnsongrass seedlings that have shown resistance to several

of the other postemergence grass herbicides, including sethoxydim and fluazifop [341]. Quizalofop and clethodim provide effective control for most grass species infesting southern cotton fields [358]. Fenoxaprop is particularly effective on johnsongrass and has gained a niche in Louisiana. The use of linuron decreased as a layby treatment in Arkansas where growers switched to diuron because of reduced cost, less injury and better residual control [358]. Diuron's use also went up in Georgia, combined with MSMA postemergence for the same reasons.

In the 1990's, more cotton producers adopted the practice of planting into a "stale" seedbed, that is similar to conventional planting, except that a "burndown" herbicide is required to remove weeds. The increase in stale seedbed planting led to an increased use of glyphosate, paraquat and oxyfluorfen in the mid-1990's.

Prior to 1996, cotton growers were without a selective postemergence herbicide for control of annual broadleaf weeds, that would not cause maturity delays or reduce crop yields [342]. As a result, in the early 1990's, cotton growers relied on two- and sometimes three-way mixtures of soil applied herbicides to get adequate early season control and a positive height differential when cotton would be taller than broadleaf weeds. This height differential was necessary for postemergence directed applications of relatively non-selective herbicides (including DSMA and MSMA) for weed control. This treatment was followed by layby herbicides for full season weed control.

In 1995, 1996 and 1997, cotton growers gained the use of three postemergence herbicides that could be used safely over the top of cotton plants without harm: pyrithiobac, bromoxynil and glyphosate. Bromoxynil applications provide excellent control of broadleaf weeds with excellent crop safety to cotton. Pyrithiobac controls primarily broadleaf weeds and some grasses. Glyphosate controls a broad spectrum of grasses and broadleaves. Glyphosate and bromoxynil can be used safely over the top of genetically engineered cotton cultivars. Pyrithiobac, bromoxynil and glyphosate replaced some of the spraying of DSMA and MSMA under cotton. DSMA and MSMA are less effective and can seriously injure cotton [343]. Over the top applications are preferred to post

directed applications because more acreage can be sprayed faster with less possibility for crop injury.

Pyrithiobac provides control of MSMA/DSMA resistant cocklebur and DNA resistant pigweed [340].

Sixty-seven and seventy-two percent of North and South Carolina growers, respectively, who used pyrithiobac in 1996 reported that it was used as a replacement treatment whereas the remaining growers used it in addition to their standard treatments [345].

Endothall's use as a defoliant declined following the introduction of a new product (Finish) that combined two active ingredients that were effective as both a boll opener and a defoliant in a single application.

## 9. Cranberries

In Massachusetts, cranberry growers reduced the rate at which they applied dichlobenil due to research that indicated a potential for root growth inhibition, that can be detrimental to the cranberry plant [258].

## 10. Dry Beans

In the early 1990's chloramben was the major preemergence herbicide used in Michigan dry bean production (90% acreage treated). Chloramben provided effective control of most of the important grass and broadleaf weed species infesting dry beans [284]. Following the voluntary cancellation of chloramben, dry bean growers increased their use of other preplant incorporated and preemergence herbicides, including EPTC, dimethenamid, ethalfluralin, and pendimethalin. These herbicides are less effective on certain weed species, such as common ragweed, than was chloramben. As a result, certain weed species have increased in dry bean production and growers have increased their use of postemergence compounds, such as bentazon, imazethapyr, quizalofop and

sethoxydim to control weeds that are not controlled adequately season long with the herbicides used early [285]. In addition, dry bean growers have had emergency exemptions for formesafen for postemergence control of common ragweed, pigweed and black nightshade [285].

#### 11. Green Beans

Historically, New York green bean growers relied on preplant incorporated EPTC and trifluralin for initial weed control. This combination was supplemented with dinoseb after planting for control of many of the troublesome broadleaf weeds that were not controlled in the preemergence program. Following the ban on dinoseb in 1986, growers switched to the use of chloramben, that was cancelled voluntarily by its manufacturer in the late 1980's [262]. New York green bean growers used existing stocks of chloramben until they were depleted in the early 1990's. With an extended period of poor control, following the loss of dinoseb and chloramben, the population of broadleaf weeds, particularly nightshade, velvetleaf and ragweed, burgeoned to almost epidemic populations in New York's green bean fields. Yield losses caused by uncontrolled weeds in New York's green bean fields were estimated at \$400,000 in 1992. New York State green bean growers were granted a Section 18 for the use of fomesafen for broadleaf weed control 1993-1997. Many New York growers follow a fomesafen application with bentazon if lambsquarters become a problem. Some decline occurred in the use of EPTC and trifluralin for the preemergence treatments. Growers increased their use of metolachlor (for nutsedge, in particular) and pendimethalin (for nightshade, in particular) [263].

## 12. Hot Peppers

In the early 1990's, chile peppers were grown with a heavy dependence on cultivation and hand labor for weed management. Since hand labor for weed management is expensive and inconsistent and entails a substantial amount of record-keeping, liability and supervision, chile growers began using herbicides in greater amounts [150].

Research demonstrated that if herbicides were used only an additional 162 hours/acre would be required to maintain weed free conditions while handweeding alone required 314 hours/acre [151]. Hot pepper growers increased their use of napropamide, metolachlor, sethoxydim and trifluralin and reduced their use of hand weeding.

### 13. Lettuce

Very few herbicides have proven efficacious for controlling weeds in the muck soils in Florida's lettuce growing area. Many herbicides are inactivated by the high level of organic matter in the soil. Until the mid-1980's, Florida lettuce growers relied on CDEC for preemergence weed control in lettuce. Following the voluntary cancellation of CDEC in the mid-1980's, Florida lettuce growers incurred additional cost for handweeding. In the early 1990's, Florida growers were spending approximately \$375 per acre for handweeding. In the winter of 1992-1993, a crisis situation occurred because of abnormal winter weather conditions; high rainfall and temperatures prevented timely handweeding and pigweeds took over certain fields completely. Approximately \$900,000 in lost lettuce production occurred because of failure to control pigweeds [303]. Research demonstrated that imazethapyr would control broadleaf weeds (including pigweeds) in the high organic soils, and a label was granted by EPA [302]. Imazethapyr costs approximately \$20 per acre and has replaced much of the handweeding. Other herbicides were registered for Florida lettuce in the 1990's: sethoxydim for postemergence grass control and thiobencarb for broadleaf weed control.

## 14. Onions

The discontinuation of DCPA's production led to its decline as a preemergence soil applied herbicide in onion production. In California, the major replacements for DCPA have been by postemergence herbicides bromoxynil, oxyfluorfen and pendimethalin [152] [153] [176]. In Texas, oxyfluorfen's use went up as a DCPA replacement. However, Texas growers also have increased their use of bensulide, that is applied to the soil preplant and provides effective control of several broadleaf species.

#### 15. Peanuts

In the mid-1990's, imazapic was registered for peanut weed control. Research demonstrated that imazapic can be applied early postemergence for the control of many weeds infesting U.S. peanut fields, including yellow nutsedge, purple nutsedge and sicklepod [32]. Imazapic was shown to have good efficacy on grass weeds that escape from the application of a soil applied grass herbicide, including Texas panicum, crabgrass, johnsongrass and broadleaf signalgrass.

Imazapic has been shown to provide more consistent and better control of yellow and purple nutsedge in field experiments than previously registered herbicides in peanut [304]. Imazapic also has been shown to have a longer period of effectiveness for controlling annual broadleaf weeds than imazethapyr postemergence. Since imazapic has both residual and contact postemergence activity, the residual activity means that the utility of imazapic is maintained further into the season [305]. Imazapic replaced much of the use of imazethapyr, an herbicide with similar chemistry, because it provided more effective control of many broadleaf and grass weeds that were not controlled by imazethapyr [306]. Imazapic also replaced several early postemergence applications that combined paraquat, 2,4-DB and bentazon. Research demonstrated that the use of only imazapic would substitute for these combinations [308]. Prior to the introduction of imazapic, many peanut growers used vernolate for selective control of nutsedge. Vernolate is short-lived and must be incorporated into the soil. Imazapic replaced almost all of the vernolate usage in peanuts [304] [307]. Chlorimuron had been used widely later in the peanut season for Florida beggarweed control, which imazapic also controls [307]. Benefin's registration was cancelled for peanuts, and it was replaced by increased usage of another dinitroanaline at planting grass control herbicide, pendimethalin [307].

#### 16. Pistachios

Pistachio acreage in California increased by 78% between 1992 and 1997, accounting for the large poundage increase in the use of the herbicides oryzalin and oxyfluorfen.

#### 17. Potatoes

For many years metribuzin has been the most widely used herbicide in potato fields in the Northwest. Metribuzin controls a broad spectrum of broadleaf and grass weeds common to the Pacific Northwest, but its use has led to increased populations of metribuzin tolerant weed species, such as hairy nightshade [195]. Rimsulfuron is a sulfonylurea herbicide that was introduced for potatoes in 1996 and displaced some of the use of metribuzin because of its effectiveness in controlling hairy nightshade and other broadleaf and grass weeds [196]. However, since sulfonylurea resistant kochia is widespread in the Pacific Northwest, rimsulfuron needs to be combined with other herbicides for kochia control. Research demonstrated that mixtures of rimsulfuron with EPTC, pendimethalin or metolachlor improved control of grasses (such as foxtail) and kochia [197].

In North Dakota, nightshade problems in potatoes increased after 1992 because of wet winters. Metribuzin is still effective in North Dakota on nightshade, and its use increased [275]. The newly-registered rimsulfuron also has been used for nightshade control in North Dakota.

Diquat usage increased for potato vine desiccation due to the late blight problems of the 1990's. Vine desiccation is effective in preventing late season development and spread of the disease.

In the late 1980's and early 1990's, rice growers in the mid-South were granted emergency registrations for the uses of bromoxynil and triclopyr for control of broadleaf weeds. In 1993, the request for bromoxynil was denied while triclopyr went forward to a full federal registration and was used on the acreage previously treated with bromoxynil [16] [17].

Bensulfuron is the most widely used herbicide for aquatic and broadleaf weed control in California rice. However, its use declined in the 1990's because of the development of resistant weed populations. California rice growers have increased their use of 2,4-D, MCPA, propanil and triclopyr for control of the aquatic broadleaf species [96]. Molinate has been the preferred herbicide for control of the major grassy weeds in California rice fields (watergrass and barnyardgrass). Molinate's use declined following the discovery of bensulfuron resistant weeds, not because it is less effective on the grasses, but because of its inability to control other weeds [96]. Thiobencarb is somewhat less effective than molinate on watergrass and barnyardgrass but controls bensulfuron resistant small flower umbrella sedge [96]. Thus, thiobencarb's use has been increasing, resulting in less use of molinate. Fenoxaprop was introduced in the 1990's in California rice to control barnyardgrass and watergrass that escape previous treatments and to control spangletop [96].

Barnyardgrass is the number one weed problem in Southeastern rice fields. Where barnyardgrass is uncontrolled, yield losses can range up to 50%. Multiple applications with propanil have been used since the 1960's to control barnyardgrass. However, in the early 1990's, propanil resistant barnyardgrass was detected. Propanil use has decreased since the early 1990's as a result. Growers make fewer applications with propanil. Quinclorac has been the most effective herbicide for propanil resistant barnyardgrass. A popular treatment has been a mixture of propanil (at reduced rates) plus quinclorac [147]. Another popular treatment for barnyardgrass control is the use of a delayed preemergence application of pendimethalin [148]. The use of thiobencarb has declined in the Delta

states because of injury first detected in rice fields in 1991 (delayed phytotoxicity syndrome) [149].

The decline in propanil's usage also effected a decline in the use of molinate, that works best as a sequential herbicide following propanil. The use of quinclorac replaced some of the molinate that had been used for salvage barnyardgrass control. Fenoxaprop use also has increased for postemergence grass control. Bensulfuron's usage increased for broadleaf weed control.

# 19. Sorghum

In Texas a Special Local Needs Label exists for atrazine's use in sorghum at a lower rate than specified on the Section 3 label. This label allows for the use of atrazine in coarse soils at an effective rate for control of several broadleaf weed species. Because of the need for grass control, it became increasingly common for Texas sorghum growers to use a combination of atrazine plus metolachlor, pendimethalin or dimethenamid. Several weed species have arisen as problems in sorghum due to increases in populations resistant to the triazines, pigweed and kochia [287]. As a result, it has been increasingly common for sorghum growers to apply postemergence applications to sorghum (bromoxynil, dicamba, 2,4-D, prosulfuron) [286]. Prosulfuron has proven popular in many sorghum growing regions because of its safety of use with sorghum [288].

Overall poundage of atrazine on sorghum declined in the 1990's due to a reduction in the number of sorghum acres (27% reduction in national acreage).

## 20. Soybeans

The Conservation Tillage Information Center reported that in 1990, 5% of the total full season soybean acreage in the Midwest was planted using no-till methods. That figure increased to 30% in 1997.

Increased limited tillage operations led to an increase in 2,4-D and glyphosate for use as burndown herbicides. Several postemergence grass control herbicides gained some use in the 1990's for burndown applications prior to planting in no-till soybeans: sethoxydim, lactofen, clethodim and quizalofop [326].

The mid-1990's saw a continued increased use of imazethapyr, that provided broad-spectrum control of many grass and broadleaf weeds [327]. An increasingly popular treatment was to apply imazethapyr postemergence, following pendimethalin applied preemergence [328]. The increase in pendimethalin use replaced some of the use of trifluralin, that requires preplant incorporation. Pendimethalin's increased usage is attributed to its availability in formulated mixtures with imazethapyr and its use for surface applications with reduced tillage. Increased use of imazethapyr in the 1990's led to reductions in the use of ethalfluralin, bentazon, metribuzin, linuron and chlorimuron. Imazethapyr controls a broader spectrum of both grass and broadleaf weeds than do ethalfluralin, bentazon, chlorimuron and metribuzin. Crop safety is less of a concern with imazethapyr than with metribuzin and linuron.

In the mid-1990's, certain weed species in the Midwest developed populations resistant to the ALS herbicides (including imazethapyr). Common waterhemp became a widespread problem in the Midwest because of resistance to ALS inhibiting herbicides [329]. Postemergence applications for control of waterhemp increased in the 1990's. It was increasingly common to apply the broadleaf herbicides acifluorfen, fomesafen or lactofen for waterhemp control postemergence [330] [331]. When velvetleaf was a problem, flumiclorac applications were made postemergence. Postemergence imazethapyr does not adequately control common lambsquarters, that became an increasing problem in several of the northern soybean-growing states, such as Wisconsin. In these states the use of thifensulfuron as a stand-alone treatment increased in the 1990's. Thifensulfuron is the only postemergence herbicide for soybeans that consistently provides more than 90% control of lambsquarters [334].

In the Midwest, there was a growth in the use of postemergence grass control herbicides, including quizalofop, clethodim, fenoxaprop and sethoxydim. Availability of effective postemergence herbicides led some soybean producers to switch entirely to postemergence weed control programs. Another factor that resulted in increased use of postemergence grass herbicides was price reductions. In particular, a newly formulated product containing sethoxydim, Poast Plus, was introduced, and priced approximately one-third less than the original sethoxydim product, Poast [332] [333].

Flumetsulam proved popular in areas with velvetleaf problems. Another desirable feature of flumetsulam is that it is registered for both soybeans and corn, that significantly reduces concerns regarding crop damage due to carryover.

The introduction of glyphosate for postemergence over-the-top applications to Roundup Ready Soybeans led to its immediate wide-scale adoption in southeastern states in 1997. Standard herbicide programs for southern states for sicklepod control had included metribuzin or imazaquin applied preplant incorporated or preemergence. However, sicklepod control with soil applied herbicides is inconsistent and often inadequate, leading to the necessity of applying other herbicides postemergence [335]. Certain problem weeds, such as morningglory, required additional postemergence directed sprays of 2,4-DB. One concern with metribuzin and 2,4-DB is the potential of injury to the soybean crop. Research in Southeastern states showed that a split application of glyphosate would provide consistent control across all weed species at a reduction in cost of \$20 to \$30 per acre compared with previously used programs [336] [337].

Increased post emergence glyphosate applications replaced many previously-used herbicides that could damage soybeans (such as metribuzin, 2,4-DB and linuron) [358]. In addition, the broad spectrum control of glyphosate replaced postemergence herbicides that cover a smaller weed control spectrum (such as fluazifop, chlorimuron, imazaquin).

In the Southeast, there was a shift away from alachlor to metolachlor for control of grassy weeds at planting in soybeans. The main reason for the shift is metolachlor's greater

effectiveness in controlling red rice [338]. Since a soybean/rice rotation is popular, and since red rice cannot be controlled when the rice crop is planted, the priority is to use the best methods for red rice control during the soybean growing year.

The use of paraquat in Southeastern state soybeans increased due to its use in combination with sodium chlorate to control weeds at harvest in early maturing soybeans, that were planted on increasing acreage in the 1990's [36].

Clomazone provides good grass control and control of many broadleaf weeds in soybeans. In the 1990's, some problems with movement outside the target, some incorporation requirements and timing restrictions impacted its use [333].

In the 1960's, chloramben dominated the soybean herbicide market. It's use began to decline in the 1970's, as less expensive herbicides became available and was used on only a small percentage of the nation's soybean acreage in 1992. In the mid-1990's, chloramben's registration for soybeans was cancelled.

## 21. Spinach

Prior to its voluntary cancellation, diethyl-ethyl was used widely by spinach growers for weed control purposes. Following its cancellation, spinach growers increased their applications of cycloate and phenmedipham and received emergency exemptions for the use of metolachlor, a replacement for control of pineappleweed and galinsoga [166].

## 22. Sugarbeets

Between 1992 and 1997, sugarbeet growers in the Red River Valley of North Dakota significantly increased their applications of postemergence herbicides due to the introduction of new active ingredients that broadened the weed spectrum and provided greater total weed control. Generally, the newly registered active ingredients were used in various combinations with older postemergence products, such as desmedipham,

phenmedipham and ethofumesate. In the Red River Valley, sugarbeet growers reported using 17 different postemergence treatment combinations in 1992, while in 1997, they reported the use of 43 different postemergence combinations [146]. In 1992, sethoxydim was the only postemergence grass control herbicide available to sugarbeet growers. In 1996, quizalofop and clethodim were registered and used by sugarbeet growers for postemergence grass control. Their increased use resulted in some decrease in sethoxydim's use. Triflusulfuron was registered for sugarbeet growers in the mid-1990's. Triflusulfuron is selective in sugarbeet when applied postemergence for control of many important broadleaf weeds and suppression of several annual grasses. When applied with combinations of desmedipham and phenmedipham, triflusulfuron improves control of important weeds in sugarbeets, such as redroot pigweed, kochia, common mallow, velvetleaf and smartweeds. Following triflusulfuron's widespread use in 1996 and 1997, sugarbeet growers reported a significant decline in the importance of redroot pigweed as a problem [146]. Clopyralid was introduced for broadleaf control, as well, in the mid-1990's. The addition of clopyralid improves control of Canada thistle, cocklebur, ragweed and nightshades.

The most popular postemergence combination reported in 1997 (on 80% of the acres) was a combination of clopyralid, triflusulfuron, ethofumesate, desmedipham and phenmedipham. Cycloate usage increased as a soil applied herbicide, mainly making up for the loss of diethyl ethyl.

The increase in postemergence herbicide applications in sugarbeets between 1992 and 1997 led to a significant reduction in the number of acres that had to be handweeded.

The large increase in ethofumesate usage is attributed to its inclusion in a prepack combination product (Progress) with desmedipham and phenmedipham, that was introduced in the 1990's for improved control of lambsquarters and kochia.

# 23. Sugarcane

The rate of atrazine use in Louisiana sugarcane increased in the 1990's as growers increasingly made a layby and/or a fall application of atrazine in addition to the standard practice of a spring application [289]. These additional applications of atrazine helped to reduce weed populations to manageable levels late in the season and for the overwintering sugarcane. Research demonstrated that sugarcane cannot recover completely from intense winter weed competition. Thus, the increased emphasis on controlling overwintering weeds with fall atrazine applications.

Sugarcane growers in Louisiana make an early spring application of herbicides to remove overwintering weeds. In the early 1990's, the most commonly used active ingredient for these early season applications was 2,4-D. A new product that combines dicamba and 2,4-D proved more effective in controlling overwintering broadleaf weeds, leading to an increase in both 2,4-D and dicamba usage in the 1990's [289]. Particular weed species resulted in increased usage of certain herbicide active ingredients in Louisiana sugarcane. Paraquat is the only available control for ryegrass, that became more of a problem for sugarcane production as it moved farther north in Louisiana [322]. Diuron increased in usage as a postemergence treatment for itchgrass, that also became more of a problem in the 1990's. Research demonstrated the value of asulam applications for control of rhizome johnsongrass, leading to asulam's increased use in earlier season applications [323]. Metribuzin increased in use because of declining prices in the 1990's. Glyphosate usage in Louisiana sugarcane occurs during the fallow year that follows its three-year crop cycle. Prior to the mid-1990's, the primary method of reducing weed growth during the fallow year was multiple cultivations. However, the cultivation led to runoff of nutrients and sediments to estuaries, resulting in eutrophication [290]. It became a common practice in the 1990's for sugarcane growers to substitute glyphosate applications for removing weeds from fields coming out of fallow and going into sugarcane production.

# 24. Sunflowers

Trifluralin and ethalfluralin are the primary at-planting herbicides used for grass control in North Dakota sunflowers. Ethalfluralin's use increased in the 1990's while trifluralin's decreased, due, in part, to the introduction of a new granular formulation of ethalfluralin, that facilitated its use in heavy crop residue. Granular formulations grew in popularity among farmers who were leaving more crop residue on the soil surface [273]. Sethoxydim is used postemergence to control weeds that escape the at-planting treatments. Sethoxydim's use increased in the 1990's because of the decreasing efficacy of ethalfluralin and trifluralin on certain weed species – particularly foxtails [274]. Sethoxydim is used for a cleanup for the weeds that are not being controlled sufficiently by the at-planting treatments. Imazamethabenz is used solely for postemergence control of wild mustard. Wild mustard is more of a problem in a wet year, accounting for its greater use in 1997 in North Dakota [275].

### 25. Sweet Corn

Most of the sweet corn in Florida is grown on organic soils. Herbicides cleared for use for preemergence control of germinating annuals (particularly grasses) are more restricted for organic soils than for mineral soils [264]. In addition, certain herbicides are not used in Florida because of concerns regarding crop injury. In the 1990's, alachlor was removed from use in Florida because of confirmed groundwater contamination. Florida growers gained a special local needs label for the use of metolachlor on organic soils. Research demonstrated that a combination of metolachlor and atrazine allowed for a reduction in the application rate of atrazine with no resulting loss of weed control. Pendimethalin was labeled for use in sweet corn, and some Florida sweet corn growers have substituted pendimethalin for alachlor for control of grass weeds. Florida sweet corn growers have stopped the use of 2,4-D because of drift concerns and resulting liability [265].

In New York, the use of 2,4-D in sweet corn declined because of grower concerns regarding damage to sweet corn varieties. There are so many new varieties, and since 2,4-D has different effects on each, growers do not want to risk damage [263]. Bentazon use increased in the 1990's in New York sweet corn to control triazine resistant lambsquarters. Bentazon is the only postemergence corn herbicide available for it. In the Midwest, sweet corn growers began using nicosulfuron for postemergence control of giant foxtail and other grassy weeds. Nicosulfuron is the only postemergence herbicide that controls giant foxtail postemergence in sweet corn [312].

#### 26. Sweet Potatoes

In the late 1980's chloramben and diphenamid were cancelled voluntarily by their registrants. In 1992 growers were still using existing supplies on crops such as sweet potatoes. The use of clomazone in sweet potatoes increased as the supplies of chloramben and diphenamid were depleted.

Increased clomazone usage also substituted for DCPA, that was no longer being manufactured and for a substantial portion of the use of napropamide. Clomazone has a broader spectrum of weed control than does napropamide and also does not require rainfall within 24 hours, as does napropamide [325]. EPTC became available to North Carolina sweet potato growers in the mid-1990's and is used primarily for nutsedge control. Fluazifop and sethoxydim are both postemergence grass control herbicides with a similar range of effectiveness. In the early 1990's, only fluazifop was registered for sweet potatoes. Following the registration of sethoxydim in the mid-1990's, many sweet potato growers substituted sethoxydim for fluazifop [325].

## 27. Tobacco

Excellent crop tolerance has been demonstrated to sulfentrazone by both flue-cured and burley tobacco types. A combination of sulfentrazone for broadleaf weed control, with

pendimethalin and clomazone for grass weed control produces excellent control of the most important weeds in tobacco [30] [281].

Increased use of pendimethalin largely replaced the use of benefin – a similar dinitroanaline grass control herbicide, that was withdrawn for tobacco use. Diphenamid and isopropalin were also used in the early 1990's for control of grasses in tobacco. Their registrations were withdrawn, and their use was replaced largely with clomazone [282]. The use of sulfentrazone led to reductions in the use of pebulate and napropamide because of superior control of troublesome weed species, such as nutsedge. Although pebulate and sulfentrazone provide similar nutsedge control for the first few weeks, late season nutsedge control is superior with sulfentrazone [283].

#### 28. Tomatoes

Throughout the 1990's black nightshade was one of the most difficult weeds to control in California processing tomatoes. Research demonstrated that use of rimsulfuron provided effective black nightshade control and eliminated the need for additional hand weeding that was required with alternative herbicide treatments [206]. Metribuzin use increased for control of black nightshade. In the 1990's, the use of trifluralin at layby became a standard practice for control of annual grasses, broadleaves and seedling bindweed [207]. Research in the 1990's demonstrated that the rate of trifluralin could be reduced in tomatoes and still provide effective weed control [208].

In the 1990's, Florida tomato growers received a special local need registration to use diquat as a plant desiccant herbicide to burn down tomato foliage following final harvest. Research demonstrated that rapid and complete vine desiccation significantly aided in insect, nematode and disease pest management in the following season [205].

#### 29. Wheat

Retention of crop residue on the soil surface was promoted widely in the 1990's for controlling erosion. The 1990 Food, Agriculture, Conservation and Trade Act mandated that producers farming highly erodible land must have an approved conservation plans implemented by 1995 in order to remain eligible for other USDA programs [277]. Many growers selected crop residue management as a key practice for meeting the requirements. By limiting tillage for weed control purposes, more residue is left on the surface to prevent erosion. Between 1989 and 1997, the percentage of small grain acreage in the West under conservation tillage systems increased from 57% to 76% of the acreage [278]. The reduction in tillage for weed control was accompanied by an increase in herbicide use: U.S. winter wheat acreage receiving herbicide treatments rose from 33% in 1992 to 46% in 1997 [173].

The overall rise in herbicide use in wheat meant an increase in the percentage of acres treated with most standard wheat herbicides, such as bromoxynil, dicamba, 2,4-D and MCPA. Herbicides used for burndown of weeds prior to planting (glyphosate and paraquat) also increased.

Trifluralin and diclofop, two active ingredients for which resistant weed populations became more of a problem in the 1990's, showed reductions in wheat acreage treated. Wild oats resistance to diclofop in the Northwest has led to increased applications of chlorsulfuron, fenoxaprop, imazamethabenz and triallate [279] [69] [70].

The use of fenoxaprop in wheat for control of foxtails increased in North Dakota and Minnesota due to an increase in acreage infested with trifluralin resistant foxtails and due to the introduction of a new fenoxaprop product formulated with a safener to reduce injury to wheat plants [66].

The increased use in fenoxaprop resulted in reductions in the use of trifluralin, diclofop and triallate in North Dakota [278].

In Idaho, diclofop was replaced largely by a more popular mix of difenzoquat and imazamethabenz, that is more effective and avoids injury to subsequent potato crops, that often was seen with diclofop [280].

Repeated use of long residual sulfonylurea herbicides in wheat has shifted populations of kochia to biotypes in some areas that are not controlled by sulfonylureas. The continued increase in kochia populations resistant to ALS herbicides in North Dakota and Oregon has resulted in greater use of dicamba for resistance management [67].

Canada thistle became a greatly increased problem in North Dakota and Minnesota following 1992, leading to a significant increase in the use of clopyralid [275].

Diuron can persist in the soil for long periods of time and be phytotoxic to rotational crops. The use of diuron in the Pacific Northwest declined as growers switched to shorter residual herbicides, such as metsulfuron, thifensulfuron and tribenuron [280]. Tribenuron use increased in North Dakota because it is inexpensive and, combined with 2,4-D, forms a popular mix [275].

Downy brome has become a major problem in the Northwest, leading to increases in the use of mixtures of chlorsulfuron and metsulfuron and in the use of triasulfuron [279].

TABLE 6: NATIONAL PESTICIDE USE BY ACTIVE INGREDIENT PESTICIDE TYPE: HERBICIDES

ACTIVE INGREDIENT	<u>LBS AI APP</u> 1992	LIED PER YEAR 1997	% CHANGE
2,4-D	41,938,491	40,589,955	-3
2,4-DB	980,980	603,975	-38
ACETOCHLOR		32,591,175	-
ACIFLUORFEN	1,477,973	1,846,789	+25
ALACHLOR	51,591,633	15,159,641	-71
AMETRYN	321,656	445,571	+38
ASULAM	726,577	551,775	-24
ATRAZINE	72,315,295	74,560,407	+3
BENEFIN	478,205	161,983	-66
BENSULFURON	30,134	31,884	+6
BENSULIDE	449,951	545,406	+21
BENTAZON	7,171,284	7,749,130	+8
BROMACIL	1,333,728	614,219	-54
BROMOXYNIL	3,444,727	2,920,222	-15
BUTYLATE	8,468,938	2,251,426	-73
CHLORAMBEN	1,335,274	100.015	-100
CHLORIMURON	236,871	190,345	-20
CHLORSULFURON	46,013	59,745	+28
CLETHODIM	80,003	670,721	+737
CLOMAZONE	1,801,776	2,531,160	+40
CLOPYRALID	89,112	891,662	+900
CYANAZINE	32,189,859	20,233,056	-37
CYCLOATE	938,925	877,657	-7 66
DCPA	1,746,892	596,723	-66
DESMEDIPHAM	152,864	205,144	+35
DICAMBA	9,064,161	10,447,441	+15
DICHLOBENIL	65,424	43,711	-32
DICLOFOP	1,597,585	974,268	-39
DIETHATYL ETHYL	454,336 475,043	246 209	-100
DIFENZOQUAT	175,042	346,308	+97
DIMETHENAMID	105 000	5,991,003	-100
DIPHENAMID DIQUAT	105,009 161,449	266,858	+65
DIURON	3,994,531	4,370,448	+9
DSMA	1,257,802	4,370,446 842,665	-33
ENDOTHALL	134,016	86,622	-36
EPTC	14,457,278	8,791,984	-39
		2,422,198	
ETHALFLURALIN ETHOFUMESATE	2,738,309 378,488	409,666	-12
FENOXAPROP	390,976	984,697	+8 +152
FLUAZIFOP	897,988	608,520	-32
FLUMETSULAM	097,900	308,892	-32
FLUMICLORAC		43,158	-
FLUOMETURON	3,907,191	5,313,290	+36
FOMESAFEN	425,657	1,100,341	+158
GLYPHOSATE	16,793,371	34,817,639	+107
HALOSULFURON	10,133,311	53,919	+107
I IALOGOLI ONON		55,313	-

TABLE 6: NATIONAL PESTICIDE USE BY ACTIVE INGREDIENT PESTICIDE TYPE: HERBICIDES (CONT.)

	LBS AI A	LBS AI APPLIED PER YEAR		
ACTIVE INGREDIENT	1992	1997		
HEXAZINONE	460,058	332,116	-28	
IMAZAMETHABENZ	231,898	458,875	+98	
IMAZAPIC		19,002	-	
IMAZAQUIN	924,799	756,915	-18	
IMAZETHAPYR	914,090	1,253,046	+37	
ISOPROPALIN	129,287		-100	
LACTOFEN	227,475	389,388	+71	
LINURON	2,026,683	516,133	-75	
MCPA	4,540,632	5,360,932	+18	
MCPB	42,475	27,542	-36	
MCPP	32,584	13,415	-59	
METHAZOLE	510,692		-100	
METOLACHLOR	59,383,910	67,336,211	+13	
METRIBUZIN	3,440,715	3,320,231	-3	
METSULFURON	18,576	45,336	+137	
MOLINATE	4,886,748	3,669,398	-25	
MSMA	6,021,679	4,867,366	-19	
NAPROPAMIDE	500,695	448,400	-10	
NAPTALAM	162,366	185,376	+14	
NICOSULFURON	169,743	211,881	+25	
NORFLURAZON	2,670,328	2,459,703	-8	
ORYZALIN	822,759	899,044	+9	
OXYFLUORFEN	457,644	705,255	+54	
PARAQUAT	4,658,597	6,884,630	+48	
PEBULATE	673,046	343,322	-49	
PENDIMETHALIN	20,281,766	27,284,718	+35	
PHENMEDIPHAM	183,311	196,442	+7	
PICLORAM	2,042,016	1,322,430	-35	
PRIMISULFURON	47,013	133,171	+183	
PROMETRYN	1,448,310	1,675,421	+16	
PRONAMIDE	239,773	206,779	-14	
PROPACHLOR	4,316,315	904,932	-79	
PROPANIL	9,132,883	8,035,946	-12	
PROSULFURON	240 504	73,076	- CE	
PYRAZON PYRIDATE	340,501	118,294	-65 +92	
PYRITHIOBAC	84,556	161,697	+92	
QUINCLORAC	111 GEG	208,136	- +158	
QUIZALOFOP	111,656 216,204	287,704 340,818	+156	
RIMSULFURON	210,204	19,774	+57	
SETHOXYDIM	1,350,566	1,717,271	- +27	
SIDURON	745	1,717,271	-100	
SIMAZINE		5,224,439	+31	
SULFENTRAZONE	3,978,487	69,073	+31	
TEBUTHIURON	111,215	115,712	+4	
TERBACIL	298,026	342,277	+15	
THIFENSULFURON	93,563	105,145	+13	
THIFENSULFURUN	93,363	100,140	+13	

TABLE 6: NATIONAL PESTICIDE USE BY ACTIVE INGREDIENT PESTICIDE TYPE: HERBICIDES (CONT.)

	LBS AI APPLIED PER YEAR		
ACTIVE INGREDIENT	1992	1997	
THIOBENCARB	1.473.511	1.925.093	+31
TRIALLATE	1,590,727	2,178,254	+37
TRIASULFURON	6,942	57,320	+714
TRIBENURON	33,126	63,114	+91
TRICLOPYR	115,514	590,366	+413
TRIDIPHANE	262,516		-100
TRIFLURALIN	25,686,076	22,263,693	-13
TRIFLUSULFURON		23,023	-
VERNOLATE	520,412	181,789	-65
HERBICIDES TOTAL	454,218,983	461,432,823	+2

TABLE 7: Differe	nces in H	erbicide Use Am	nounts: 1992 aı	nd 1997	
			(1000 LB AI/YF	3)	
Active Ingredient	Total		Major Crop (		
2,4-D	-1349	Other Hay -2762 Sweet Corn -28	Pasture -2263 Wheat +1503	Soybeans + Rice +166	+1437 Apples +73
2,4-DB	-377	Peanuts -115	Alfalfa -205	Soybeans -3	
Acetochlor	+32591	Corn +32591	7 III alia 200	Coybcans c	,
Acifluorfen	+368	Soybeans +401			
Alachlor	-36432	Soybeans -4041	Corn -31369		
Ametryn	+123	Sugarcane +97	Corn +26		
Asulam	-175	Sugarcane -145	Sod -30		
Atrazine	+2245	Sorghum -1065	Sugarcane +503	Corn +2037	Pasture -611
Benefin	-316	Peanuts -287	Tobacco -57		
Bensulfuron	+2	Rice +2			
Bensulide	+96	Broccoli +28	Onions +24		
Bentazon	+578	Dry Beans +269	Peanuts -353	Corn +967	Soybeans -316
		Sweet Corn +30			
Bromacil	-719	Citrus -719			
Bromoxynil	-525	Corn -553	Cotton +76	Rice -43	Wheat -22
		Onions +11			
Butylate	-6217	Corn -6121			
Chloramben	-1335	Dry Beans -695	Soybeans -465	Swee	et Potatoes -32
		Green Beans -25			
Chlorimuron	-47	Soybeans -46	Peanuts -1		
Chlorsulfuron	+14	Wheat +11	Barley +2		
Clethodim	+591	Soybeans +420	Cotton +98	Sugarbeets -	+62
Clomazone	+729	Soybeans -24	Cotton +475	Tobacco +2°	17
		Sweet Potatoes +			
Clopyralid	+803			rbeets +116	Canola +5
Cyanazine	-11957		Corn -12082		
Cycloate	-61	Sugarbeets -58	Spinach -4		
DCPA	-1150	Broccoli -134	Onions -507	Sweet Potate	oes -40
Desmedipham	+53				
Dicamba	+1383	Sorghum +146	Corn +965 V	Vheat -84	Sugarcane +26
Dichlobenil	-21				
Diclofop	-623	Wheat -745			
Diethetyl Ethyl	-454	Spinach -61	Sugarbeets -39	)2	
Difenzoquat	+171	Barley +71	Wheat +100		
Dimethenamid	+5991	Soybeans +938	Corn +4444	Sorghum +4	17
		Dry Beans +67			
Diphenamid	-105	Tobacco -81	Sweet Potatoes	s <b>-</b> 15	
Diquat	+106	Potatoes +95	Tomatoes +11	Ammles : 00	\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
Diuron	-376	Citrus +166	Cotton +500	Apples +98	Wheat -744
DSMA Fredethell	-415				
Endothall	-47	Cotton -60	Corn F000		
EPTC Etholfluralin	-5666	Potatoes +336	Corn -5089	F 0	flowers : 070
Ethalfluralin	-316	Soybeans -820 Canola +171	Dry Beans +15	o Suni	flowers +270
Ethofumesate	+31	Sugarbeets +18			
Fenoxaprop	+594		Wheat +248	Cotton +62	
Fluazifop	-289	Soybeans -112	Cotton -191	Onions +4	
Flumetsulam	+309	Soybeans +140	Collon +169	OTHORS T4	
Flumiclorac	+43	Soybeans +43	Oom Flog		
Fluometuron	+1406	Cotton +1406			
i luometuron	<del>+ 1400</del>	JULIUII T 1400			

TABLE 7: Differences in Herbicide Use Amounts: 1992 and 1997 (Cont.)					
			(1000 LB AI/YF	₹)	
Active Ingredient	<u>Total</u>		Major Crop (	<u>Changes</u>	
Fomesafen	+675	Soybeans +655	Dry Beans +18	Green B	eans +2
Glyphosate	+18024	Soybeans +10443	Citrus +838	Cotton +842	Wheat +1409
		Sugarcane +137	Apples +173	Corn +1857	
Halosulfuron	+54	Sorghum +1	Corn +53		
Hexazinone	-128	Alfalfa -106			
Imazapic	+19	Peanuts +19			
Imazamethabenz	+227	Sunflowers +52	Wheat +47	Barley +128	
Imazaquin	-168	Soybeans -168		•	
Imazethapyr	+339	Soybeans +269	Peanuts -13	Corn +52	Alfalfa +27
Isopropalin	-129	Tobacco -129			
Lactofen	+162	Soybeans +101	Cotton +61		
Linuron	-1510	Soybeans -1398	Potatoes +45	Cotton -220	
MCPA	+820	Wheat +866	Rice +107		
MCPB	-14	Green Peas -9			
MCPP	-20	Sod -17			
Methazole	-511	Cotton -511			
Metolachlor	+7952	Sorghum +1253	Corn +6541	Soybeans +	-365
		Hot Peppers +10		•	
Metribuzin	-120	Sugarcane +139	Potatoes +31	Corn +134	Wheat +266
		Soybeans -764			
Metsulfuron	+26	Pasture +20	Barley +1	Wheat +5	
Molinate	-1217	Rice -1217			
MSMA	-1154	Cotton -1311			
Napropamide	-52	Hot Peppers +39	Tobacco -100	Sweet Po	tatoes -13
Naptalam	+23	Watermelons +76	Cucumbers -50	)	
Nicosulfuron	+43	Sweet Corn +2	Corn +41		
Norflurazon	-211	Cotton -328	Apples +155	Citrus -56	
Oryzalin	+76	Pistachios +33	Apples +111	Citrus –76	
Oxyfluorfen	+248	Pistachios +18	Onions +4	Cotton +56	Broccoli +5
Paraquat	+2226	Soybeans +334	Cotton +244	Corn +752	Wheat +402
		Peanuts -39	Citrus -38	Apples +90	
Pebulate	-330	Tomatoes -39	Tobacco -280		
Pendimethalin	+7003	Onions +31	Peanuts +90	Rice +432	Corn -1124
Phenmedipham	+14	3	Spinach +1		
Picloram	-720	Pasture -668			
Primisulfuron	+85	Corn +85			
Prometryn	+227	Cotton +215			
Pronamide	-33	Lettuce –37			
Propachlor	-3411	Sorghum -1120	Corn -2268		
Propanil	-1097	Rice -1097			
Prosulfuron	+73	Sorghum +7	Corn +65		
Pyrazon	-221	Sugarbeets -212			
Pyridate	+77	Peanuts -50	Corn +126		
Pyrithiobac	+208	Cotton +208			
Quinclorac	+176	Rice +176			
Quizalofop	+125	Sugarbeets +19	Soybeans +54	Cotton +27	Canola +12
Rimsulfuron	+20	Potatoes +3	Corn +16	Tomatoes +1	
Sethoxydim	+366	Sunflowers +30			Soybeans +287
	,	Sugarbeets -16	Lettuce +1	Hot Peppers -	+1
Siduron	-1	Sod -1			
Simazine	+1246	Apples +268	Grapes +105	Corn +451	Citrus +843

Γ

			(1000 LB AI/YR	)
Active Ingredient	Total		Major Crop C	hanges
Sulfentrazone	+69	Tobacco +69		
Tebuthiuron	+5	Pasture +5		
Terbacil	+44	Sugarcane +48		
Thifensulfuron	+11	Corn +6	Wheat +4	
Thiobencarb	+452	Lettuce +1	Rice +451	
Triallate	+588	Barley +372	Wheat +182	
Triasulfuron	+50	Wheat +38		
Tribenuron	+30	Barley +7	Wheat +22	
Triclopyr	+474	Pasture +372	Rice +135	
Tridiphane	-263	Corn -263		
Trifluralin	-3423	Soybeans -3531	Sunflowers -87	Wheat -440
		Hot Peppers +7		
Triflusulfuron	+23	Sugarbeets +23		
Vernolate	-338	Peanuts -400		
Total	+7213			

TABLE 8: Herbicide Use Patterns by Crop and State (Selected Records)			
	% Acres Treated		
	1992	<u>1997</u>	
I Alfalfa a. Minnesota 2,4-DB Imazethapyr	5 -	1 4	
b. <u>Wyoming</u> 2,4-DB Imazethapyr	15 1	3 10	
II Apples a. Michigan 2,4-D Diuron Glyphosate Norflurazon Paraquat Simazine	7 3 11 3 17 15	23 12 44 9 27 32	
b. New York 2,4-D Diuron Glyphosate Norflurazon Oryzalin Paraquat Simazine	12 9 12 3 - 21 10	18 19 36 15 8 25 40	
III Blueberries a. Maine Clethodim Glyphosate Hexazinone* Sethoxydim * Rate Reduced by 15%	- 50 45 -	10 2 48 10	
IV Broccoli a. <u>California</u> Bensulide DCPA Oxyfluorfen	1 82 2	6 29 15	
V Canola a. North Dakota* Clopyralid Ethalfluralin Quizalofop Sethoxydim	- - -	6 65 22 45	

TABLE 8: Herbicide Use Patterns by Cro	p and State (Selecte	ed Records) (Cont.)
	% Acres	Treated
	1992	<u>1997</u>
Trifluralin * Acreage increased by 2,100%	29	35
VI Citrus  a. Florida*  Bromacil**  Diuron***  Glyphosate****  Norflurazon+  Oryzalin  Paraquat  * Acreage increased by 64%  ** Rate declined by 65%  *** Rate declined by 36%  **** Rate declined by 20%  +Rate declined by 50%  VII Corn	69 68 68 20 4 14	40 59 77 23 2 5
a. Illinois Dimethenamid EPTC Halosulfuron Imazethapyr Nicosulfuron Paraquat Primisulfuron Prosulfuron	- 2 - - 5 3 1	7 - 4 5 7 5 7 5
b. lowa     Acetochlor     Alachlor     Atrazine     Bentazon     Bromoxynil     Butylate     Clopyralid     Cyanazine     Dicamba     Dimethenamid     Flumetsulam     Propachlor     Rimsulfuron     Thifensulfuron     Tridiphane	- 20 68 3 19 1 - 26 26 - - 3 - - 2	40 2 72 7 13 - 9 16 37 7 9 - 2 2

TABLE 8: Herbicide Use Patterns by Crop and State (Selected Records) (Cont.)				
	% Acres Treated			
	1992	1997		
c. <u>Kansas</u>				
Atrazine	78	83		
Bromoxynil	8	3		
Dicamba	9	16		
Glyphosate	1	5		
Primisulfuron	7	12		
Prosulfuron	-	10		
Pyridate	-	2		
d. Minnesota				
Metribuzin	_	2		
Nicosulfuron	16	32		
Pendimethalin	8	3		
Propachlor	5	-		
Rimsulfuron	-	2 2		
Thifensulfuron	-	2		
e. <u>Wisconsin</u>				
Atrazine	48	64		
Clopyralid	-	6		
Cyanazine	27	13		
Flumetsulam	-	13		
Metolachlor	18	22		
Pendimethalin	17	2		
VIII Cotton				
a. <u>Alabama</u>				
Methazole	20	-		
Prometryn	6	21		
b. <u>Arkansas</u>				
Bromoxynil	-	2		
Diuron	15	22		
DSMA	18	5		
Glyphosate	5	20		
Linuron	5	-		
MSMA	50	37		
Pyrithiobac	-	48		
c. <u>California</u>				
Endothall	20	7		
d. <u>Georgia</u>				
Diuron	20	55		
e. <u>Louisiana</u> Clethodim	_	10		
Cietilodilli	-	10		

5

Fenoxaprop

TABLE 8: Herbicide Use Patterns by Cre	op and State (Selecte	ed Records) (Cont.)	
	% Acres Treated		
	1992	<u>1997</u>	
Fluazifop Oxyfluorfen Quizalofop Sethoxydim	28 12 - 25	8 20 11 17	
f. <u>Mississippi</u> Clomazone Lactofen Norflurazon	11 10 69	24 25 41	
g. <u>North Carolina</u> Fluometuron* Methazole * Rate doubled	100 25	100	
h. <u>Tennessee</u> Glyphosate Paraquat	2 12	31 34	
IX Cranberries a. Massachusetts Dichlobenil* * Rate reduced by 33%	67	64	
X Dry Beans a. Michigan Bentazon Chloramben Dimethenamid EPTC Ethalfluralin Fomesafen Imazethapyr Pendimethalin Quizalofop Sethoxydim	5 90 - 40 - - - - -	15 - 10 70 30 15 10 10 5	
XI Green Beans a. New York Bentazon Chloramben EPTC Fomesafen Metolachlor Pendimethalin Trifluralin	10 76 - 17 2 82	20 - 67 40 39 8 79	

TABLE 8: Herbicide Use Patterns by C	rop and State (Selecte	ed Records) (Cont.)		
	% Acres Treated			
	1992	1997		
XII Hot Peppers				
a. New Mexico				
Metolachlor	26	60		
Napropamide	-	20		
Sethoxydim	-	15		
Trifluralin	-	60		
XIII Lettuce				
a. <u>Florida</u>				
Fluazifop	-	30		
Imazethapyr	-	30		
Thiobencarb	-	10		
XIV Onions				
a. <u>California</u>				
Bromoxynil	40	59		
DCPA	72	29		
Oxyfluorfen	55	67		
Pendimethalin	-	13		
b. <u>Texas</u>				
Bensulide	26	100		
DCPA	61	11		
Oxyfluorfen	15	100		
XV Peanuts				
a. <u>Georgia</u>				
2,4-DB	91	70		
Benefin	15	-		
Bentazon	87	75		
Chlorimuron	40	28		
Imazapic	-	30		
Imazethapyr	15	2		
Paraquat	90	75		
Pendimethalin	37	55		
Vernolate	22	1		
b. <u>Texas</u>				
2,4-DB	50	13		
Benefin	3	-		
Bentazon	15	2		
Imazapic	-	_ 18		
Imazethapyr	35	11		
Pendimethalin	30	49		
XVI Pistachios				
a. <u>California</u> *				
Oryzalin	49	51		

TABLE 8: Herbicide Use Patterns by Cro	p and State (Selecte	ed Records) (Cont.)
		Treated
	1992	1997
Oxyfluorfen * Acreage increased by 78%	44	62
XVII Potatoes a. Idaho	2	16
Diquat EPTC	3 44	50
Metolachlor Metribuzin Pendimethalin	3 89 19	9 75 30
Rimsulfuron	-	16
b. North Dakota Diquat	18	34
Metribuzin Rimsulfuron	16 -	53 14
XVIII Rice a. <u>Arkansas</u>		
Bensulfuron Bromoxynil	3 8 3	10
Fenoxaprop Molinate	31	5 20
Pendimethalin Propanil*	9 88	33 95
Quinclorac Thiobencarb	12 20	33 10
Triclopyr * Rate reduced by 30%	6	20
b. <u>California</u> 2,4-D	3	28
Bensulfuron Fenoxaprop	93 -	54 5
MCPA Molinate	6 89	34 59
Propanil Thiobencarb	1 12	7 43
Triclopyr XIX Sorghum	-	6
a. Texas*	5	18
Atrazine Bromoxynil	58 -	60 5
Dicamba Dimethenamid	1 -	10 5

TABLE 8: Herbicide Use Patterns by Cro	op and State (Selecte	ed Records) (Cont.)
	% Acres	Treated
	1992	<u>1997</u>
Metolachlor	19	35
Pendimethalin	1	5
Prosulfuron	_	8
* Acreage declined by 30%		
XX Soybeans		
a. <u>lowa</u>		
2,4-D	9	13
Acifluorfen	4	6
Bentazon	12	10
Chloramben	2	-
Chlorimuron	16	6
Clethodim	3	6
Clomazone	5	2
Ethalfluralin	3	-
Fenoxaprop	6	12
Flumiclorac	-	3
Fomesafen	_	3
Imazethapyr	52	62
Lactofen	2	9
Metribuzin	8	1
Pendimethalin	19	36
	5	9
Sethoxydim Trifluralin	48	36
	40	30
b. <u>Mississippi</u>		
2,4-DB	11	4
Alachlor	20	-
Glyphosate	13	53
Imazaquin	51	21
Metolachlor	4	18
Metribuzin	26	16
Paraquat	5	14
c. North Carolina		
2,4-DB	15	-
Chlorimuron	31	20
Fluazifop	20	5
Flumetsulam	-	6
Glyphosate	11	50
Imazaquin	27	16
Linuron	10	4
Metribuzin	12	5
Thifensulfuron	-	6
	_	U
d. Wisconsin		
Alachlor	17	6

TABLE 8: Herbicide Use Patterns by	y Crop and State (Selecte	ed Records) (Cont.)
	% Acres	Treated
	1992	1997
Chlorimuron	22	5
Dimethenamid	-	5
Fluazifop	6	3
Flumetsulam	-	33
Imazethapyr	16	57
Linuron	15	1
Metolachlor	4	17
Metribuzin	11	5
Quizalofop	3	10
Thifensulfuron	8	30
XXI Spinach		
a. <u>New Jersey</u>		
Cycloate	50	55
Diethatyl Ethyl	69	-
Metolachlor	-	90
Phenmedipham	-	45
XXII Sugarbeets		
a. North Dakota		
Clethodim	<u>_</u>	100
Clopyralid	21	54
Cycloate	8	23
Diethatyl Ethyl	6	-
Ethofumesate	6	32
Quizalofop	<del>-</del>	27
Sethoxydim	78	40
Triflusulfuron	-	100
VVIII Cumoroone		
XXIII Sugarcane		
a. <u>Louisiana</u> 2,4-D	32	80
Asulam	14	30
Astrazine*	100	95
Dicamba	-	30
Diuron	8	20
Glyphosate	-	40
Metribuzin	15	35
Paraquat	-	35
* Rate doubled		00
XXIV Sunflowers		
a. North Dakota		
Ethalfluralin	41	45
Imazamethabenz	1	10
Sethoxydim	3	7
Octrioxydiiri	J	1

Marces Treated   1992   1997	TABLE 8: Herbicide Use Patterns by C	rop and State (Selecte	ed Records) (Cont.)
1992   1997   Trifluralin		% Acres	Treated
XXV Sweet Corn   a. Florida   2,4-D   5   -			
a. Florida	Trifluralin	46	38
2,4-D			
Alachlor		_	
Atrazine*         64         78           Metolachlor         10         20           Pendimethalin         -         10           * Rate reduced by 25%         *         *           b. New York         2,4-D         20         3           2,4-D         20         3         Bentazon           c. Wisconsin         -         28           r. Wisconsin         -         22           XXVI Sweet Potatoes         -         22           a. North Carolina         -         22           Chloramben         11         -           Clomazone         44         60           DCPA         4         -           Diphenamid         9         -           EPTC         -         10           Fluazifop         57         20           Napropamide         39         5           Sethoxydim         -         18           XXVII Tobacco         a. Kentucky           Benefin         11         -           Clomazone         -         30           Diphenamid         8         -           Isopropalin         19         -			-
Metolachlor         10         20           Pendimethalin         -         10           * Rate reduced by 25%         -         10           b. New York         2,4-D         20         3           Bentazon         -         28           c. Wisconsin         Nicosulfuron         -         22           XXVI Sweet Potatoes         -         22           a. North Carolina         -         22           Chloramben         11         -           Clomazone         44         60           DCPA         4         -           Diphenamid         9         -           EPTC         -         10           Fluazifop         57         20           Napropamide         39         5           Sethoxydim         -         18           XXVII Tobacco         -         18           XXVII Tobacco         -         30           Diphenamid         8         -           Isopropalin         19         -           Napropamide         22         7           Pebulate         14         4           Pendimethalin*         50         5			- 70
Pendimethalin			
* Rate reduced by 25%  b. New York		-	
2,4-D			10
Bentazon       -       28         c. Wisconsin Nicosulfuron       -       22         XXVI Sweet Potatoes       3. North Carolina       -       22         Chloramben       11       -       -         Clomazone       44       60			
c. Wisconsin Nicosulfuron         -         22           XXVI Sweet Potatoes         3. North Carolina         -         22           Chloramben		20	
Nicosulfuron	Bentazon	-	28
XXVI Sweet Potatoes a. North Carolina Chloramben 111 - Clomazone 444 60 DCPA 4 - Diphenamid 9 - EPTC - 10 Fluazifop 57 20 Napropamide 39 5 Sethoxydim - 18  XXVII Tobacco a. Kentucky Benefin 11 - Clomazone - 30 Diphenamid 8 - Isopropalin 19 - Napropamide 22 7 Pebulate 14 4 Pendimethalin* 50 54 Sulfentrazone - 45 * Rate Doubled  b. North Carolina Clomazone - 35 Diphenamid 6 - Isopropalin 19 - Pendimethalin* 50 60		_	22
a. North Carolina         Chloramben       11       -         Clomazone       44       60         DCPA       4       -         Diphenamid       9       -         EPTC       -       10         Fluazifop       57       20         Napropamide       39       5         Sethoxydim       -       18         XXVII Tobacco       3       -         a. Kentucky       8       -         Benefin       11       -         Clomazone       -       30         Diphenamid       8       -         Isopropalin       19       -         Napropamide       22       7         Pebulate       14       4         Pendimethalin*       50       54         Sulfentrazone       -       45         * Rate Doubled       *       *         b. North Carolina       -       35         Clomazone       -       35         Diphenamid       6       -         Isopropalin       19       -         Pendimethalin       50       60		-	22
Chloramben         11         -           Clomazone         44         60           DCPA         4         -           Diphenamid         9         -           EPTC         -         10           Fluazifop         57         20           Napropamide         39         5           Sethoxydim         -         18           XXVII Tobacco         -         18           a. Kentucky         -         30           Benefin         11         -           Clomazone         -         30           Diphenamid         8         -           Isopropalin         19         -           Napropamide         22         7           Pebulate         14         4           Pendimethalin*         50         54           Sulfentrazone         -         45           * Rate Doubled         *         -           b. North Carolina         -         -           Clomazone         -         35           Diphenamid         6         -           Isopropalin         19         -           Pendimethalin         50			
Clomazone       44       60         DCPA       4       -         Diphenamid       9       -         EPTC       -       10         Fluazifop       57       20         Napropamide       39       5         Sethoxydim       -       18         XXVII Tobacco       -       18         a. Kentucky       -       -         Benefin       11       -         Clomazone       -       30         Diphenamid       8       -         Isopropalin       19       -         Napropamide       22       7         Pebulate       14       4         Pendimethalin*       50       54         Sulfentrazone       -       45         * Rate Doubled       *       -         b. North Carolina       -       -         Clomazone       -       35         Diphenamid       6       -         Isopropalin       19       -         Pendimethalin       50       60		11	_
DCPA         4         -           Diphenamid         9         -           EPTC         -         10           Fluazifop         57         20           Napropamide         39         5           Sethoxydim         -         18           XXVII Tobacco         -         18           XXVII Tobacco         -         30           a. Kentucky         -         -           Benefin         11         -           Clomazone         -         30           Diphenamid         8         -           Isopropalin         19         -           North Carolina         -         45           Valentrazone         -         45           * Rate Doubled         -         35           Diphenamid         6         -           Isopropalin         19         -           Pendimethalin         50         60			60
Diphenamid         9         -           EPTC         -         10           Fluazifop         57         20           Napropamide         39         5           Sethoxydim         -         18           XXVII Tobacco         -         18           X.XVII Tobacco         -         -           a. Kentucky         -         -           Benefin         11         -           Clomazone         -         30           Diphenamid         8         -           Isopropalin         19         -           Napropamide         22         7           Pebulate         14         4           Pendimethalin*         50         54           Sulfentrazone         -         45           * Rate Doubled         *         -           b. North Carolina         -         -           Clomazone         -         35           Diphenamid         6         -           Isopropalin         19         -           Pendimethalin         50         60			-
EPTC       -       10         Fluazifop       57       20         Napropamide       39       5         Sethoxydim       -       18         XXVII Tobacco       -       18         a. Kentucky       -       -         Benefin       11       -         Clomazone       -       30         Diphenamid       8       -         Isopropalin       19       -         Napropamide       22       7         Pebulate       14       4         Pendimethalin*       50       54         Sulfentrazone       -       45         * Rate Doubled       *       *         b. North Carolina       -       35         Diphenamid       6       -         Isopropalin       19       -         Pendimethalin       50       60		9	-
Napropamide       39       5         Sethoxydim       -       18         XXVII Tobacco       -       11         a. Kentucky       -       30         Benefin       11       -         Clomazone       -       30         Diphenamid       8       -         Isopropalin       19       -         Napropamide       22       7         Pebulate       14       4         Pendimethalin*       50       54         Sulfentrazone       -       45         * Rate Doubled       -       45         b. North Carolina       -       35         Diphenamid       6       -         Isopropalin       19       -         Pendimethalin       50       60		-	10
Sethoxydim       -       18         XXVII Tobacco       -       30         a. Kentucky       -       -         Benefin       11       -         Clomazone       -       30         Diphenamid       8       -         Isopropalin       19       -         Napropamide       22       7         Pebulate       14       4         Pendimethalin*       50       54         Sulfentrazone       -       45         * Rate Doubled       *       *         b. North Carolina       -       35         Diphenamid       6       -         Isopropalin       19       -         Pendimethalin       50       60			
XXVII Tobacco         a. Kentucky         Benefin       11       -         Clomazone       -       30         Diphenamid       8       -         Isopropalin       19       -         Napropamide       22       7         Pebulate       14       4         Pendimethalin*       50       54         Sulfentrazone       -       45         * Rate Doubled       *       *         b. North Carolina       Clomazone       -       35         Diphenamid       6       -         Isopropalin       19       -         Pendimethalin       50       60		39	
a. Kentucky Benefin 11 - Clomazone - 30 Diphenamid 8 - Isopropalin 19 - Napropamide 22 7 Pebulate 14 4 Pendimethalin* 50 54 Sulfentrazone - 45 * Rate Doubled  b. North Carolina Clomazone - 35 Diphenamid 6 - Isopropalin 19 - Pendimethalin 50 60	Sethoxydim	-	18
Benefin       11       -         Clomazone       -       30         Diphenamid       8       -         Isopropalin       19       -         Napropamide       22       7         Pebulate       14       4         Pendimethalin*       50       54         Sulfentrazone       -       45         * Rate Doubled       *       *         b. North Carolina       -       35         Diphenamid       6       -         Isopropalin       19       -         Pendimethalin       50       60			
Clomazone       -       30         Diphenamid       8       -         Isopropalin       19       -         Napropamide       22       7         Pebulate       14       4         Pendimethalin*       50       54         Sulfentrazone       -       45         * Rate Doubled       *       *         b. North Carolina       -       35         Clomazone       -       35         Diphenamid       6       -         Isopropalin       19       -         Pendimethalin       50       60		4.4	
Diphenamid       8       -         Isopropalin       19       -         Napropamide       22       7         Pebulate       14       4         Pendimethalin*       50       54         Sulfentrazone       -       45         * Rate Doubled       -       35         Diphenamid       6       -         Isopropalin       19       -         Pendimethalin       50       60		-	30
Isopropalin		8	-
Napropamide       22       7         Pebulate       14       4         Pendimethalin*       50       54         Sulfentrazone       -       45         * Rate Doubled       *       *         b. North Carolina       -       35         Clomazone       -       35         Diphenamid       6       -         Isopropalin       19       -         Pendimethalin       50       60			-
Pebulate       14       4         Pendimethalin*       50       54         Sulfentrazone       -       45         * Rate Doubled       *       *         b. North Carolina       -       35         Clomazone       -       35         Diphenamid       6       -         Isopropalin       19       -         Pendimethalin       50       60			7
Sulfentrazone * Rate Doubled  b. North Carolina Clomazone Clomazone Diphenamid Isopropalin Pendimethalin  - 45 - 45 - 45 - 45 - 45 - 45 - 45 - 4			
* Rate Doubled  b. North Carolina Clomazone - 35 Diphenamid 6 - Isopropalin 19 - Pendimethalin 50 60	Pendimethalin*	50	54
b. North Carolina Clomazone - 35 Diphenamid 6 - Isopropalin 19 - Pendimethalin 50 60		-	45
Clomazone - 35 Diphenamid 6 - Isopropalin 19 - Pendimethalin 50 60	* Rate Doubled		
Diphenamid 6 - Isopropalin 19 - Pendimethalin 50 60			6-
Isopropalin 19 - Pendimethalin 50 60		-	35
Pendimethalin 50 60			-
			- 60
Sulfentrazone - 26	Sulfentrazone	-	26

TABLE 8: Herbicide Use Patterns by Crop and State (Selected Records) (Cont.)		
	% Acres	Treated
	<u>1992</u>	<u>1997</u>
XXVIII Tomatoes  a. California  Metribuzin  Rimsulfuron  Trifluralin*  * Rate reduced by 30%	3 - 34	16 15 75
b. <u>Florida</u> Diquat	-	75
XXIX Wheat a. Idaho Diclofop Difenzoquat Diuron Fenoxaprop Imazamethabenz Metsulfuron Thifensulfuron Tribenuron	15 1 14 - 1 1 48 22	2 8 5 2 10 9 64 67
b. <u>Kansas</u> 2,4-D	6	19
c. Minnesota 2,4-D Bromoxynil Clopyralid Fenoxaprop Trifluralin	36 25 - 16 5	57 37 13 60
d. <u>Montana</u> Bromoxynil Glyphosate	<u>-</u> 1	7 23
e. North Dakota Bromoxynil Clopyralid Dicamba Diclofop Fenoxaprop Glyphosate MCPA Triallate Tribenuron Trifluralin	7 - 28 7 9 1 37 6 17	8 20 38 2 37 16 52 2 32 22

TABLE 8: Herbicide Use Patterns by C	Crop and State (Selected	d Records) (Cont.)
	% Acres Treated	
	<u>1992</u>	<u>1997</u>
f. <u>Oregon</u>		
2,4-D	39	77
Bromoxynil	7	10
Chlorsulfuron	48	63
Dicamba	20	47
Diclofop	13	3
Diuron	14	3
Glyphosate	12	18
Imazamethabenz	-	10
Paraquat	-	3
Triallate	-	5
Triasulfuron	7	24
g. <u>Texas</u>		
2,4-D	6	16
Dicamba	-	5
Triasulfuron	-	5

#### V. **Insecticides**

## A. Introduction

Insecticides, for the purpose of this study, include active ingredients used for the control of insects, mites, nematodes and snails. Insecticide use strategies increasingly have included efforts to manage the development of insecticide resistance within target pest populations. This usually means using multiple active ingredients, with differing modes of action, in rotation with each other. Eliminating unnecessary applications is also a technique for resistance management.

Insecticide use can be highly variable from year to year depending upon weather and other environmental factors.

Bacillus thuringiensis (Bt) foliar applications are included in the insecticide trends analysis, but the units of measurement that are used for rates of chemical active ingredients are not appropriate for Bt because its active ingredients are spores. Consequently, the percent acres treated with Bt are listed for crops, but not the amount of active ingredient applied. There was a slight reduction (-6%) in the total number of acres treated with Bt sprays. Numerous crops reported increased Bt sprays: almonds, apples, lettuce, peaches, broccoli, tobacco and tomatoes. The biggest reduction in Bt sprays was recorded for cotton (-700,000 acres) due to the planting of genetically engineered Bt cotton plants.

# B. <u>Crop Analysis</u>

## 1. Alfalfa

For California alfalfa, the pyrethroid cyfluthrin was registered for Egyptian weevil control in the 1990's and proved popular due to its low expense and because it is more

effective than older pyrethroids, such as permethrin [300]. The use of chlorpyrifos for weevil control increased in the 1990's, due, in part, to the introduction of a new product called Lock-On with a short pre-harvest interval (4 days). Increased use of chlorpyrifos and cyfluthrin for weevil control resulted in less use of permethrin and carbofuran. In the 1990's, beet armyworm became more of a problem in California alfalfa, leading to increased use of methomyl.

## 2. Almonds

The use of the organophosphate insecticide ethyl parathion during the dormant season was the key factor that allowed almond growers to reduce significantly their use of in-season sprays in the 1980's. Ethyl parathion's use for almonds was canceled after the 1991 growing season. Almond growers substituted other organophosphate insecticides for dormant season use in 1992: diazinon, chlorpyrifos and methidathion. In the mid 1990's, the dormant organophosphate sprays became the focus of environmental concerns. There was documented off-target movement to non-registered crops and protected wildlife. Dormant spray pesticides were found in the Sacramento and San Joaquin Rivers [200]. Almond growers reduced their use of the organophosphates in the mid-1990's and began substituting dormant season applications of the pyrethroids esfenvalerate and permethrin, that were shown to be highly efficacious in controlling the bloom period to control emerged overwintering larvae. It usually requires three to four Bt applications to achieve the same level of control as one organophosphate application [201] [202].

# 3. Apples

The fungal disease alternaria blotch appeared in North Carolina for the first time in the 1990's. Research demonstrated that defoliation associated with alternaria blotch is most severe when populations of the European red mite are high [257]. Mites act synergistically with the fungi to increase stress on the trees, greatly increasing

defoliation. Growers with moderate to severe alternaria blotch problems are advised to use miticides. The use of the miticides pyridaben, clofentezine, hexythiazox and abamectin all increased in North Carolina orchards, not only to help manage the defoliation interaction with alternaria, but also as replacements for propargite, that had been banned by USEPA in the 1990's.

In the 1990's, Washington apple growers increased their use of the organophosphate insecticides chlorpyrifos and methyl parathion, largely for control of populations of codling moth and leafrollers, that had become increasingly resistant to applications of azinphos-methyl [313] [315]. Methyl parathion and chlorpyrifos are highly toxic to the parasites that provide control of the Western tentiform leafminer [314]. As a result, additional sprays have been required for leafminer control. Abamectin and oxamyl are used primarily for leafminer control, and their usage increased in the 1990's. Chlorpyrifos, methyl parathion, oxamyl and abamectin are also toxic to mite predators. The increased use of these insecticides led to increased mite outbreaks in the 1990's [316] [317]. As a result, the use of miticides in 1997 (pyridaben, clofentezine, formetanate HCl) totaled about 50% of Washington apple orchards while in 1992 the use of miticides (propargite, oxythioquinox and formetanate HCl) totaled about 34% of acres treated. Both oxythioquinox and propargite were cancelled in the 1990's.

Washington State growers used phosphamidon for aphid control in the early 1990's. Following its cancellation, apple growers substituted the newly registered imidacloprid for aphid control [318]. Imidacloprid also displaced some usage of endosulfan for which resistant aphid populations increased in the 1990's.

New York apple growers used propargite to control mites in the early 1990's. Following its cancellation in 1996, growers were able to substitute products that had been newly registered in 1995-1997: clofentezine, hexythiazox, abamectin and pyridaben [320] [321]. Increased use of these miticides also substituted for much of the earlier use of miticides for which resistance had developed (dicofol, fenbutatin oxide, formetanate HCl) and for oxythioquinox, for which registration had been cancelled. The

newly registered imidacloprid replaced a significant portion of oxamyl's use for control of aphids, leafhoppers and leafminers. Imidacloprid's use for aphid control also replaced phosphamidon, which was cancelled. New York apple growers were granted an emergency exemption in 1997 for use of tebufenozide for control of the oblique banded leafroller, that had developed populations resistant to methomyl and permethrin – the use of which declined as a result.

#### 4. Artichokes

The artichoke plume moth is the key arthropod pest of California artichokes. In the early 1990's, growers typically made five to six applications of mixtures of methidathion and esfenvalerate for its control. The registration of diflubenzuron, that is effective on both eggs and larvae, resulted in the replacement of some of the methidathion/esfenvalerate tank mix applications [174].

#### 5. Blueberries

In blueberries, the registration of phosmet for use in aerial applications led to its increased use, thereby displacing some of azinphos-methyl's usage in blueberries. In certain geographic areas, phosmet is preferred because of reduced concerns regarding odors in comparison with azinphos-methyl [59].

## 6. Broccoli

In 1994, the registrant of mevinphos halted production for domestic use and asked EPA to cancel all of its registrations for the pesticide. At the time of its cancellation, mevinphos was used widely for controlling aphid infestations in California broccoli fields. In 1995, imidacloprid received a full registration for controlling aphids in broccoli and replaced mevinphos usage.

Imidacloprid replaced some oxydemeton-methyl and disulfoton use for aphids [223]. Imidacloprid also is used in the desert production regions for whitefly control. Diamondback moth populations increased steadily in broccoli fields in the mid-1990's and reached crisis proportions in 1997. Several factors accounted for the increase in DBM populations: (1) mild winters; (2) humid, rainy summer days; and (3) the increased planting of year round stock flowers, that provide the DBM with a year round host [224] [225]. An emergency exemption for spinosad for DBM control was granted for 1997. Tebufenozide was granted an emergency exemption for control of beet armyworm in 1997. Thiodicarb and tralomethrin became registered for looper control in the 1990's and provided effective alternatives to pyrethroids, such as permethrin.

# 7. Cabbage

In the 1990's, New York cabbage growers lost the use of methamidophos and mevinphos for control of aphids. Growers substituted applications of the newly registered imidacloprid and increased applications of oxydemeton-methyl for aphid control [230]. Decreased use of methomyl and permethrin in the 1990's is due largely to increases in resistant populations of diamondback moths for which growers substituted the newly registered spinosad [230] [231].

For worm control, cabbage growers substituted applications of the newly registered pyrethroid lambdacyhalothrin for applications of permethrin and methomyl. Lambdacyhalothrin is more effective than the previously used insecticides [232]. The increased use of chlorpyrifos is for cabbage maggot control, that is more of a concern with transplanted cabbage seedlings than with direct-seeded cabbage. New York cabbage growers increased their use of transplants in the 1990's [233].

# 8. Cauliflower

In 1994, the registrant of mevinphos halted production for domestic use and asked EPA to cancel all of its registrations for the pesticide. At the time of its cancellation,

mevinphos was used widely for controlling aphid infestations in California cauliflower fields. In 1995, imidacloprid received a full registration for controlling aphids in cauliflower and replaced mevinphos usage.

A severe outbreak of diamondback moth occurred in California cauliflower fields in 1997. Growers increased their use of naled for DBM control. A Section 18 emergency exemption was granted for use of spinosad for DBM control in California for 1997 [226]. The use of endosulfan declined in California cauliflower due to increased restrictions on its use in coastal counties. Cauliflower growers increased their use of Bt in insecticide mixtures for resistance management of loopers and worms. The registration of thiodicarb for beet armyworm control provided growers with an insecticide that was less harmful to beneficial insects than methomyl, whose use declined [227].

# 9. *Celery*

The broad spectrum organophosphate insecticide methamidophos was used widely in Florida's celery fields in 1992 for control of worms, leafminers and aphids. Following the withdrawal of methamidophos' registration for celery, Florida growers switched to another broad spectrum organophosphate insecticide, acephate. Cyromazine is used for leafminers in Florida celery. The number of applications of cyromazine declined in 1992-1997 because leafminers became much less of a problem [242].

For the 1991-1993 growing seasons, EPA granted emergency registrations for abamectin for control of leafminers in California celery. In 1992, California growers used abamectin on 17% of celery acres. One reason that abamectin's use was not higher in 1992 was an unusually cool season that slowed leafminer development significantly [192]. In the mid-1990's, leafminer was a more serious problem and use of abamectin increased. Celery growers also gained registrations for cyromazine and azadirachtin for leafminer control [228].

In the early 1990's, mevinphos and naled were two major insecticides used to control aphids in California celery. Mevinphos' use was canceled and the use of naled was withdrawn because of phytotoxicity problems [193]. Growers increased their use of oxamyl, an insecticide commonly applied through drip irrigation systems, that deliver the aphicide directly to the plant base. From there it is translocated throughout the plant. This mode of action is particularly effective against the black bean aphid, that tends to migrate to hidden areas not covered by foliar sprays [194]. The use of foliarly applied insecticides for aphid control declined: naled, endosulfan and diazinon.

For worm management celery growers gained the use of thiodicarb and spinosad in the 1990's. Their use increased because of their effectiveness and their reduced impacts on beneficial insects [227]. Celery growers increased their use of Bt for worm control – usually in mixtures to improve control and for resistance management [194].

#### 10. *Citrus*

Florida citrus experienced a dramatic increase in horticultural oil use, coupled with decreases in most other insecticides (aldicarb, diazinon, ethion, dicofol, formetanate HCl, fenbutatin oxide, methidathion, oxythioquinox). Horticultural oil is used to control several citrus pests, including mites, greasy spot and scale. When fruit is grown for the fresh market, synthetic pesticide use is higher in order to produce the unblemished fruit marketers seek. Fruit grown for processing does not have to be spotless, and so one or two treatments with oil is sufficient for successful production and marketing [42]. Between 1992 and 1997, profit margins in Florida citrus shrank. Prices received by growers declined by 30% [40]. Previously, most of the industry had been producing fruit as though it were going to fresh market even though the majority ended up being processed [43]. The need to reduce production costs led to a shift. More fruit was earmarked for the processed market at the beginning of the production season so the grower could reduce pesticidal inputs throughout the season to just oil, that was significantly lower in cost. An oil application costs two-thirds less than the application of

synthetic insecticide [41]. This contributed to the increase in oil use and decrease in use of other pesticides between 1992 and 1997 [44]. Because oil is used at a significantly higher per acre rate than synthetic chemical insecticides (74 lbs/A vs. 1-3 lbs/A), the overall impact on insecticide use was an increase of 50 million pounds per year.

In Florida citrus the use of abamectin increased. Abamectin's use targets mites, but it also has leafminer activity, which gives it a competitive edge [44]. Diflubenzuron, newly registered for citrus, has seen increased use in Florida. Diflubenzuron targets mites, but also has activity against adult root weevils – no other product is available for that pest [44]. Both abamectin and diflubenzuron provide longer residual control of mites than the traditional miticides.

There was a dramatic shift in the usage patterns for pesticides applied to control citrus thrips in California. Use of the older materials dimethoate and formetanate HCl both declined from 1992 to 1997, while use of cyfluthrin, through emergency registrations, increased. Replacement of the older materials with cyfluthrin was driven in part by some thrips populations developing resistance to them [130], and by the extreme cost-effectiveness of cyfluthrin [131] [132]. In 1994, it was estimated that California citrus growers saved \$900,000 by using cyfluthrin instead of making the extra applications of the less effective insecticides [131]. Use of organophosphates for citrus red scale (CRS) also increased in 1997, not so much in percent acreage treated but rather in pounds active ingredient applied per acre. Application rates for carbaryl, chlorpyrifos and methidathion all increased to maintain effectiveness against a CRS population that was becoming progressively more resistant to organophosphates and carbamates [179].

### 11. *Corn*

In the 1990's, there were some shifts in insecticides used to control the corn rootworm. The use of terbufos declined due to the continued increase in the use of the herbicides primisulfuron and nicosulfuron by corn growers. When these herbicides are used in corn treated with an application of terbufos, an adverse reaction occurs, resulting in yield

losses of 13 to 40% [243] [248]. The use of carbofuran declined for rootworm control following EPA's ban of granular carbofuran usage. The efficacy of flowable carbofuran products is not as great as the remaining granular insecticides, and its use declined [250] [245] [247]. Fonofos was no longer manufactured, and corn growers stopped using the product for rootworm control. Several new insecticides for rootworm control increased in use. Research showed that chlorethoxyfos, tebupirimphos and tefluthrin all performed as well as other rootworm insecticides [252]. Tebupirimphos is sold in a combination product with cyfluthrin, an active ingredient that supplies cutworm control. A decline occurred in corn acreage treated with chlorpyrifos, that had been used for at-plant rootworm and cutworm control. The reduced use of chlorpyrifos is largely associated with the decline in usage for cutworms as growers relied increasingly on scouting methods and rescue treatments with low cost pyrethroids (lambdacyhalothrin and permethrin) when economic thresholds are exceeded [247]. Research demonstrated that pyrethroid insecticides applied as rescue treatments were more effective than organophosphates or pyrethroids applied at planting for cutworm control [249].

In the Plains states, the use of aerial in-season applications of methyl parathion increased during the 1990's. These applications were targeted for control of adult corn rootworms prior to egg laying [251]. The methyl parathion sprays also controlled other in-season insect pests, such as European corn borer [246].

Spider mites are significant pests of corn in the Great Plains states, where periods of hot dry weather favor rapid mite population increases. In the early 1990's, a portion of the corn acreage in the Great Plains states was treated with propargite, disulfoton and dimethoate for mite control. These products lost much of their effectiveness in the 1990's and were replaced largely by bifenthrin [244].

## 12. Cotton

Spider mites were elevated to the status of key pests of cotton in the San Joaquin Valley. Two spider mite species developed resistance to two of the miticides used for control: dicofol and propargite [116]. This resistance led to increased use of abamectin for mite control in California.

The registration of amitraz and abamectin has made it possible for cotton growers to rotate insecticides/miticides for managing resistant mite species [117]. Due to decrease in susceptibility of lygus bugs to dimethoate and methidathion, their use has declined in the San Joaquin Valley over the last five years. Increasingly, growers are using aldicarb during the early fruiting period for lygus control [117].

In the early 1990's, production practices of San Joaquin Valley cotton growers shifted away from using nitrogen or water stress to manage plant growth and toward plant growth regulators. Greater amounts of nitrogen and irrigation were used to develop the most vigorous plant canopy during fruit production. Cotton aphids, that previously had been an early season problem kept under control by natural enemies, became a serious mid-season pest [120].

In the early 1990's, bifenthrin was the standard for cotton aphid control in California. Beginning in 1993, it was totally ineffective because of the rapid buildup of resistance leading to a significant increase in the use of chlorpyrifos [4] [23]. Some reduction in ODM use for aphid and lygus control in California cotton has occurred due to resistance concerns. Imidacloprid (registered in 1995) and naled have been used increasingly in the San Joaquin Valley for control of the cotton aphid.

In the early 1990's, the population dynamics of the silverleaf whitefly changed significantly in California's Imperial Valley and Arizona. Among the changes were tremendous increases in the population density and a propensity to infest additional crop/weed species. These changes resulted in the emergence of a devastating pest to cotton production [117].

1992 was the first year of the state-wide outbreak of whiteflies in Arizona cotton. Growers tried many different combinations of insecticides in order to control the outbreak, and usage of many insecticides was high in 1992, primarily for whitefly control – methamidophos, acephate and fenpropathrin. However, widespread resistance to this mixture was reported in 1995 [113]. In addition, the widespread use of insecticides for whitefly control led to destruction of natural enemies that normally control mites, necessitating a significant usage of the miticides dicofol and propargite in 1992 [133].

Amitraz was registered for cotton in 1993 and provided growers with a non-pyrethroid alternative for whitefly control [114]. The registration of imidacloprid for cotton provided California and Arizona cotton growers an alternative for sweet potato whitefly control [115].

1996 was the first year that the insect growth regulators buprofezin and pyriproxyfen were used for whitefly control, nearly eliminating the whitefly problem [356] [357] [21] [98] [99]. By 1997, pesticide use decreased dramatically as buprofezin, pyriproxyfen and imidacloprid replaced much of the use of acephate, methamidophos and fenpropathrin [133]. Mite control by natural predators was reestablished, and, thus, the use of dicofol and propargite was lower in 1997.

The tarnished plant bug is a major concern of Southeastern and Delta cotton growers. The feeding activities of the tarnished plant bug cause square shed, aborted plant tissues and damaged anthers and bolls, that subsequently result in delayed crop maturity and reduced yields. TPB populations resistant to the major classes of insecticides in the South were increasingly reported in the 1990's [110]. Reduced efficacy of oxamyl led to less use in Mississippi for TPB control. Research demonstrated that foliar applications of acephate and at-planting applications of imidacloprid produced effective control of TPB, and their use increased in Mississippi [111] [112].

Until the 1990's, beet armyworms were an occasional pest in cotton. In 1993, in Mississippi and Alabama, the beet armyworm was rated as the number one insect pest of Mississippi cotton. Some of the key factors that contributed to this severe outbreak included: a mild winter, high early season insecticide use, late planting, delayed crop

maturity and hot dry conditions during mid- to late summer [119]. Following poor performance of registered alternatives in 1993, Mississippi and Alabama growers were granted emergency registrations for tebufenozide for control of beet armyworm 1994-1998 [118].

Bt cotton was introduced in 1996 and provided Southeastern growers with an option for effective control of the tobacco budworm and cotton bollworm. In 1997, in the states of Alabama, Florida, Georgia, Louisiana and Mississippi, 40-60% of the cotton acreage was planted with Bt cotton [33]. As a result of Bt cotton plantings, the use of pesticides targeted against bollworm/budworm were reduced [33]. In the Southeast, the following insecticides were reduced in use for bollworm/budworm control: cypermethrin, bifenthrin, sulprofos, permethrin, esfenvalerate, lambdacyhalothrin, methomyl, profenofos, thiodicarb and tralomethrin.

Bt cotton provides effective control of the pink bollworm an important pest in Southwestern states. Its widespread planting in Arizona led to reductions in the use of ethyl parathion, methomyl, sulprofos and permethrin [133].

Tobacco budworm populations were low in Mississippi in 1997 due to wide-scale planting of Bt cotton. However, there were areas in the state where there were large populations of tobacco budworm in non-Bt cotton. The most effective insecticide for tobacco budworm control was spinosad [129]. Pyrethroids are still the choice for bollworm. The recently registered deltamethrin is one of the most effective.

The Hill portion of Mississippi initiated a Boll Weevil Eradication Program (BWEP) in 1997, resulting in an increased use of malathion. The increased use of malathion in the BWEP resulted in fewer application of methyl parathion and azinphos-methyl – both of which are used against boll weevils [121]. The malathion applications also produced coincidental control of tarnished plant bug, thereby explaining the lower use of oxamyl and dicrotophos. (Both of these products are effective against boll weevils and plant bugs.)

Carbofuran provided the most effective control of cotton aphids in Mississippi tests [122]. In the early 1990's the cotton aphid increased from the status of a secondary pest in much of the U.S. Cotton Belt to that of a primary pest of major concern. A key factor contributing to the change was documented resistance to organophosphate insecticides [123]. ODM usage decline is due to limited effectiveness in controlling cotton aphids. Mississippi cotton growers were granted an emergency registration to use carbofuran for cotton aphids [355].

Increased use of phorate applications as an at plant, in furrow thrips control material is associated with the introduction of the herbicide clomazone for cotton in 1993. An organophosphate (phorate or disulfoton) must be applied in furrow to reduce injury or safen the seedling from herbicide injury when clomazone is used [124].

In the 1990's, the reniform nematode spread rapidly throughout cotton growing states in the Southeast/Delta [136]. If uncontrolled, yield losses due to reniform nematode can be as high as 84% [137]. Aldicarb is the most widely used nematicide for reniform nematode control in the South. Nematode sampling programs have been promoted and have raised growers awareness regarding the presence of the reniform nematode [138].

#### 13. *Cranberries*

In the 1980's, ethyl parathion was the most commonly used insecticide in cranberries because of its effectiveness and low cost. In addition to controlling fruitworm, ethyl parathion was highly effective in controlling fireworm, sparganothis, fruitworm and cranberry tipworm. Following the ban of ethyl parathion at the end of the 1991 growing season, the use of chlorpyrifos and diazinon increased significantly as replacements [258].

## 14. *Grapes*

The 1991 ban of ethyl parathion left California grape growers without an effective control for grape mealybugs, which steadily worsened as a problem [135]. In January 1996, the State of California approved a Special Local Needs registration for chlorpyrifos to be used as a dormant or delayed dormant treatment for mealybug control [135].

Carbaryl use in California grapes in 1997 was one-third the 1992 level. In 1992, the western grapeleaf skeletonizer (WGLS) was still considered a serious pest with potential to cause high crop losses [351]. Growers were increasing use of several pesticides, including carbaryl, to reduce damage. Carbaryl's short preharvest (PHI) and reentry (REI) intervals gave it an advantage for late-season control [54]. In the mid 1990's, biological control agents, including parasitoids and a virus pathogen, reduced WGLS to minor pest status [54] [352] and pesticide applications for its control decreased accordingly.

The newly registered imidacloprid has been used widely by California grape growers for leafhopper control due to its long lasting effectiveness and minimal negative effects on natural enemies [352]. The increased use of imidacloprid has led to reductions in use of naled, endosulfan and methomyl.

In the early 1990's, concerns with the use of cryolite on grapes arose because of resulting fluoride residues in wine [353]. A tolerance was set by an international wine industry advisory board [354]. Research indicated that by limiting the number of cryolite applications that the tolerance could be met.

## 15. Green Peas

Following the cancellation of mevinphos for aphid control in green peas, the Washington State Department of Agriculture obtained an emergency exemption to increase the number of dimethoate applications from one to three per year at a higher rate of

application. The exemption was converted to a full registration in 1996. Dimethoate usage went up as the replacement for mevinphos for aphid control [256].

#### 16. Hazelnuts

The two key insect pests of hazelnut orchards in Oregon are filbert aphid and filbertworm. In the early 1980's it was common for Oregon hazelnut growers to apply one to two insecticide sprays each year for aphid control. A host-specific parasitic wasp was imported from Europe in 1984 and has established itself in most all of the hazelnut orchards in the state. In the early 1990's, some growers were still using diazinon, oxydemeton-methyl and endosulfan for aphid control. As the parasitic wasp continued to spread in the 1990's, the use of these insecticides decreased [215]. The use of azinphosmethyl, carbaryl, chlorpyrifos and permethrin for filbertworm control also declined in the 1990's because of two factors. First, use of pheromones and other scouting techniques has led to more precise timing of sprays, and second, research demonstrated that esfenvalerate applications would provide less than 1% net infestation at harvest. Because of its high degree of effectiveness in filbertworm control, the use of esfenvalerate increased in the 1990's [216].

# 17. *Hops*

Aphids and mites are major pests in the entire hop producing region of the Northwest. Control of these pests is dependent upon properly timed pesticide applications. Each of these pests requires from one to five pesticide applications annually to keep pest populations from reaching economically damaging levels. For many years diazinon was the insecticide used for aphid control. Because of increasing resistance problems to diazinon, imidacloprid and bifenthrin currently are the most important insecticides to the industry for control of aphids. In the early 1990's, various pesticides were made available to hop growers for aphid control under Section 18 emergency registrations. Chlorpyrifos was one of these products, but it proved relatively ineffective [214]. For mite control the mainstays for many years were dicofol and propargite. However, due to

resistance problems, the industry currently relies on applications of abamectin and hexythiazox.

#### 18. Lettuce

In 1994, the registrant of mevinphos halted production for domestic use and asked EPA to cancel all of its registrations for the pesticide. At the time of its cancellation, mevinphos was used widely for controlling aphid infestations in California lettuce fields. In 1995, imidacloprid received a full registration for controlling aphids in lettuce and replaced mevinphos usage.

Imidacloprid use also increased due to effectiveness in controlling whiteflies. The increasing aphid problems in lettuce in the 1990's led to increased use of endosulfan and diazinon [218]. Leafminer problems in lettuce greatly increased in the mid-1990's. In 1997, in the coastal lettuce growing region of California, leafminer counts of 8 million per acre were typical [217]. The three main insecticides used to manage leafminer larvae are abamectin, cyromazine and azadirachtin. Many growers used a late season application of a pyrethroid insecticide against adult leafminer flies, including tralomethrin. For management of lepidopteran pests, including loopers and armyworms, the introduction of spinosad led to some decline in the use of acephate. In the desert regions, growers increased their use of thiodicarb because of methomyl resistant populations of beet armyworm [217]. Many growers have begun including Bt with other insecticides, that usually improves control of beet armyworm and cabbage looper [219].

#### 19. *Mint*

In the 1990's, the location of mint acreage in Oregon shifted. In 1992, the acreage was divided about equally between the western part of the state (Willamette Valley) and the eastern part (Columbia and La Grande). During the 1990's, mint acreage declined in the western part of the state, due in part to high production costs. One aspect of the higher production costs in the western part of the state is higher insecticide costs due to heavier

pest pressure from root borers, flea beetles, nematodes and symphylan [254]. As a result, insecticide use is higher in the western part than the eastern part. As the acreage shifted, statewide insecticide usage estimates for Oregon mint became more reflective of the lower use in the eastern part of the state [255].

#### 20. Onions

Ethion was cancelled for use on onions in the mid-1990's. Before its cancellation, ethion was used more widely for control of onion maggots in the Pacific Northwest than the registered alternative, chlorpyrifos, in large part because it was cheaper, but also because chlorpyrifos could be phytotoxic to onion seed. Now that ethion is no longer registered on onion, growers in the Pacific Northwest treat onion maggot with chlorpyrifos, using alternative application techniques designed to reduce phytotoxicity [48] [49].

Onion thrips have become more and more of a problem in the Northwest. The registrant of the organophosphate insecticide oxydemeton-methyl canceled its label for onions, and it was replaced by use of the organophosphate insecticide oxamyl for control of thrips. Increased thrips resistance to the pyrethroids permethrin and cypermethrin has led growers to switch to the most effective pyrethroid alternative for thrips control: lambdacyhalothrin [187].

## 21. Peaches

Following the 1991 cancellation of ethyl parathion, which was used on 95% of Georgia peaches, most growers substituted the more expensive organophosphate methyl parathion [180]. However, in an attempt to reduce costs, some growers switched to the less expensive pyrethroid esfenvalerate. The esfenvalerate applications were detrimental to scale predators in Georgia peach orchards, and the use of oil for scale control increased in the mid-1990's [180].

In California, several insect pests of peaches have been traditional targets of organophosphate and carbamate applications: San Jose scale, oriental fruit moth, peach twig borer and codling moth. In the 1990's, the use of azinphos-methyl declined in California peaches due to resistant peach twig borer populations. The use of carbaryl decreased because of signs of resistance and pressure from processors of baby foods [181]. Methidathion use declined due to signs of resistant San Jose scale populations. The use of methyl parathion increased as a replacement for the insecticides with resistance problems [181]. The use of esfenvalerate in dormant season to control overwintering peach twig borer increased, as did the use of Bt at bloom to control peach twig borer larvae [181]. Peach growers used propargite in the early 1990's for mite control. Following its cancellation, California growers used clofentezine on about onethird of the acres previously treated with propargite. Overall, there has been a decline in the use of miticides (including fenbutatin oxide) in California peaches due to the decrease in the use of late-season, broad-spectrum sprays (a change in practice that has mitigated the disruption of important predators) and due to some growers' augmenting orchards with predators [324].

#### 22. Peanuts

For many years, the only pesticide that peanut growers had available for spider mite control was propargite. In 1996, fenpropathrin was registered for spider mite control in peanuts and has displaced some of the propargite usage [25]. Fenpropathrin controls spider mites as well as propargite and provides control of other pests. Peanut growers are advised to rotate the two miticides in order to control resistance problems.

Aldicarb use in Georgia peanuts declined and phorate use increased from 1992 to 1997 because of the increased incidence and severity of tomato spotted wilt virus (TSWV). The virus is transmitted by two thrips species, and while aldicarb is an effective thripsicide, its competitor, phorate, is more effective at also controlling the spread of TSWV [46]. Before establishment of TSWV as a yield-limiting factor in Georgia peanuts in the 1995 season, growers tended to use aldicarb over phorate because of the

latter's potential to burn young seedlings. Since TSWV became the overriding pest concern for growers, the benefits of phorate for thrips and disease transmission control outweigh the potential risks of leaf burn [47].

A breakdown product of chlorpyrifos has fungicidal property against white mold, a problem disease in peanuts. In 1992, there was no effective fungicide against white mold, so the activity from chlorpyrifos (20% control) was the best, and chlorpyrifos was applied in Georgia peanuts, primarily for white mold control [47]. By 1997, several new fungicides effective on white mold (tebuconazole and azoxystrobin) were registered for peanuts, so chlorpyrifos use declined [47].

#### 23. Pears

Insecticide use patterns in Oregon pears reflect several major changes in the mid-1990's for management of two major pest problems: mites and psylla. In the early 1990's, pear growers were controlling psylla with a prebloom application of a pyrethroid (esfenvalerate) or endosulfan. These applications were followed with oxythioquinox and amitraz for psylla control later in the season [212]. The effectiveness of the pyrethroids and endosulfan had been declining for 10 years due to resistance development in local populations. In the early 1990's, Oregon pear growers were granted emergency registrations for the pyrethroid cyfluthrin for psylla control. However, resistance developed rapidly to cyfluthrin, as well. In the mid-1990's, Oregon pear growers were allowed the use of fenoxycarb at prebloom (thereby replacing much of the esfenvalerate and endosulfan usage). It also provided season long psylla control in many orchards and eliminated the need for many of the amitraz and oxythioquinox sprays later in the season. Other insecticides with residual control, which pear growers have used increasingly for psylla control, include imidacloprid and pyriproxyfen.

For mite control in the early 1990's, Oregon pear growers typically relied on abamectin, fenbutatin oxide, formetanate HCl, oxamyl and dicofol to kill larvae and adult mites. However, resistant populations have developed to all of these miticides [27]. The

introduction of pyridaben, that acts as a mite larvicide/adulticide control, replaced much of the use of the earlier compounds. In addition, pear growers gained the use of hexythiazox, that controls mites at the egg stage [213].

#### 24. Pecans

In pecans, the use of endosulfan and disulfoton declined because aphid populations became resistant. Growers switched to the newly registered phosmet and chlorpyrifos [55]. Chlorpyrifos' and phosmet's usage also increased because pecan acreage with significant infestations of black peach aphid and pecan nut case bearer increased from the early to mid 1990's [55] [56].

Dicofol's use increased in pecans due to increased mite problems and the availability and active marketing of a less expensive generic formulation of the compound [55]. Dicofol replaced much of the use of the more expensive miticide fenbutatin oxide and ethion (label canceled for pecans in the mid 1990's).

#### 25. Potatoes

In 1990, the registrant of aldicarb voluntarily agreed to halt sales of aldicarb for use in potatoes. Following research regarding application techniques and requirements that certain types of application equipment must be used to apply aldicarb in potatoes, aldicarb's use in potatoes was reinstated in September 1995 (in the Northwest and Florida). The reinstatement of aldicarb resulted in a decline in the use of ethoprop and phorate, which had been used as replacements for aldicarb in the Northwest.

In the Northwest, aldicarb and phorate are used at-planting for control of the Colorado potato beetle and aphids. Imidacloprid was introduced in the 1990's and gained usage as an at-planting insecticide, as well, for control of the Colorado potato beetle and aphids. Because the at-planting applications do not provide full season control of aphids, foliar sprays of carbofuran, endosulfan and methamidophos are made for aphid control later in

the season. The use of foliar insecticides for aphid control increased in the Northwest in the 1990's due to increasing problems with green peach aphid, that transmits a virus to potatoes resulting in internal discoloration of the tuber. The green peach aphid problem worsened due to several factors: generally milder winter temperatures, that allowed increased populations to overwinter; and reduced tillage practices in many crops, thereby allowing higher adult aphid survival rates [221]. Another reason for increasing green peach aphid populations was the increased amounts of fungicide being sprayed to control late blight. The fungicides are toxic to beneficial fungi that help to reduce aphid numbers [222].

The introduction of imidacloprid for Colorado potato beetle control in the mid-1990's led to major reductions in insecticides that had been used for its control in Eastern states: azinphos-methyl, carbofuran, cryolite, endosulfan, methamidophos, methyl parathion, phorate and phosmet [134]. In 1997, abamectin became available for control of Colorado potato beetle and has been used in rotation with imidacloprid [220].

# 26. Raspberries

The root weevil problem in Oregon raspberry fields has grown steadily worse since the loss of chlorinated organic insecticides in the early 1980's [77]. The raspberry industry has had temporary relief from serious weevil infestations because of specific exemptions granted for carbofuran and permethrin during the 1980's and early 1990's (including 1992). Emergency exemptions for the use of bifenthrin have been granted each year during the period 1993-1999. Bifenthrin provides 99% control of the root weevil.

## 27. Sorghum

In the early 1990's, sorghum growers used granular carbofuran to protect seedling sorghum plants from chinch bug. Following EPA's ban on the use of granular carbofuran, many sorghum growers switched to planting seed that had been treated with imidacloprid, that translocates to the plant and provides early season chinch bug control.

The cost of the seed treatment is less than an at-planting time insecticide. The seed treatment also provides season long greenbug control [203]. (Note: Seed treatments are not included in the NCFAP database.) Greenbug infestations occur annually in the Great Plains sorghum growing areas of Texas and Kansas. In the early 1990's, a popular treatment for greenbug control was foliar applications of ethyl parathion, that is very inexpensive. However, EPA placed restrictions on how ethyl parathion could be applied on sorghum: (1) prior written consent must be obtained from neighboring landowners before ethyl parathion can be applied within 100 feet of an adjacent property; (2) use only in closed transfer systems; (3) do not apply in winds greater than 10 miles per hour. These restrictions discouraged ethyl parathion's use [204].

Growers have increased their use of the more expensive foliar alternative spray for green bug control, chlorpyrifos.

# 28. Soybeans

In most years, insecticides are rarely used by the vast majority of U.S. soybean growers. Most insect pests in the Midwest are attacked by natural enemies or biological control agents, that usually help keep pest populations well below the economic injury level. However, substantial soybean acreage in the Southeastern and Delta states is sprayed annually with insecticides. Worm pests migrate into Southern states from the tropics and mild winters allow for overwintering of other insect species.

In the 1990's, a significant portion of soybean growers in the South increased planting of early maturing soybean cultivars. The advantage of early planting/early maturing varieties is the avoidance of drought that occurs later in the season [234]. The advantage to insect control with earlier maturing varieties is that they are less likely to have problems with defoliating caterpillars, such as soybean looper and velvetbean caterpillar. Early maturing varieties are more likely to be unattractive or no longer susceptible during the time defoliating caterpillar populations develop damaging infestations [235]. Thus, there has been a decline in the use of the insecticides used to manage worm pests, such as

the pyrethroids permethrin and tralomethrin. On the other hand, the early planted varieties are more prone to infestations from bean leaf beetles and stink bugs, which both overwinter in the South. As they emerge from their overwintering sites, they migrate into the early planted soybeans. There are fewer problems in late planted soybeans because these fields are not planted when the beetles and stink bugs are emerging [236]. A major factor in the severity of infestations of bean leaf beetle and stink bugs is the severity of winter weather. 1997 was a year of heavy infestations due to the mild winter of 1996-97 [237]. In Delta states, including Louisiana, there was an increase in the use of insecticides targeted against cereal bean leaf beetle (thiodicarb and lambdacyhalothrin) and against stink bugs (methyl parathion) [237].

Diflubenzuron is used in Georgia and Florida on 70 to 80% of the soybean acreage. Diflubenzuron is a unique product. It acts as an insect growth regulator (providing residual control of velvetbean caterpillars and loopers); it has fungicidal properties and also acts as a yield enhancement product [239] [240].

#### 29. Strawberries

In 1996, EPA reached an agreement with the registrant of propargite, under which the company voluntarily cancelled uses of the pesticide in strawberries and nine other crops. Propargite had been used to control two spotted spider mites in California strawberry fields. The California Strawberry Commission requested and was granted an emergency registration for the use of the miticide hexythiazox in 1997 and 1998 as a replacement for propargite. In addition, the use of abamectin for spider mite control increased. The use of fenpropathrin and bifenthrin has been targeted for lygus bug control and resulted in reductions in the use of methomyl and diazinon.

# 30. Sugarbeets

Following the cancellation of the use of granular carbofuran for sugarbeets, Nebraska sugarbeet growers substituted terbufos for carbofuran. Both active ingredients control

root maggots and wireworms. Carbofuran had been used more widely because of crop safety [291].

Sugarbeet acreage treated with chlorpyrifos in North Dakota declined significantly from a high in 1992 (40%) to 7% in 1997. Chlorpyrifos is used primarily for control of adult root maggot flies. Although fly populations were as high in 1997 as they were in 1992, there was less of a threat to sugarbeets in 1997 due to increased rainfall [349]. Due to drought conditions in 1992, sugarbeet plants developed more slowly and were susceptible to larval damage for a longer period of time. The performance of soil applied insecticides is reduced in drought conditions since moisture is required to distribute this type of insecticide on the field [350].

# 31. Sugarcane

The registration of tebufenozide for sugarcane borer control resulted the displacement of azinphos-methyl, which had been implicated in fish-kill incidents in Louisiana [24].

## 32. *Sunflowers*

A major shift in insecticide usage by sunflower growers occurred, largely as a result of changes in the occurrence of economic insect pests in the mid-1990's [20]. Pyrethroids (esfenvalerate and lambdacyhalothrin) have been very effective in controlling foliage-feeding insects, which have been most prevalent. The organophosphate insecticides ethyl parathion, methyl parathion and malathion have declined in use because they are more effective on head-feeding insects, which were significantly less of a problem in the mid-1990's [20] [60].

## 33. Sweet Corn

Minnesota sweet corn growers began using the newly-registered insecticide lambdacyhalothrin in the 1990's and decreased their use of methomyl. Methomyl has

some limited ovicidal activity and has a short period of residual activity.

Lambdacyhalothrin has more ovicidal activity and a longer insect control residual [241].

Beginning in the mid-1990's, there was a notable reduction in armyworm infestations in Florida sweet corn with insects in monitoring traps decreasing [242]. As a result, growers made fewer applications and treated fewer acres with thiodicarb and methomyl. Reductions in their use are also attributed to the introduction of lambdacyhalothrin, which is used for armyworm and also, late in the season, for corn silk fly [242]. In the 1990's the range of the silk fly increased. Lambdacyhalothrin replaced the use of methyl parathion for silk fly control [242].

# 34. Sweet Peppers

Since its appearance in 1990 in Dade County, *Thrips palmi* has migrated towards the North. In 1993, *T. palmi* caused severe damage, 77% crop loss, to pepper crops in Palm Beach County [188]. Research demonstrated that applications of abamectin, azinphosmethyl and chlorpyrifos provided control of *T. palmi* [188]. The most effective control of *T. palmi* was provided by soil applications of imidacloprid, that also controlled aphids. The increase in imidacloprid's use displaced some of the use of the aphid control insecticides dimethoate and endosulfan [189].

In California peppers, the serpentine leafminer became a major pest starting in 1992. In 1992, growers used dimethoate and oxamyl for leafminer control. Their use declined in the mid-1990's following the registration of abamectin and cyromazine, that were more effective [190]. In the early 1990's, pepper growers used mevinphos and oxydemeton-methyl for aphid control. EPA canceled mevinphos and the manufacturer of oxydemeton-methyl withdrew its registration for peppers. Pepper growers received a new registration for imidacloprid for aphid control [191]. Imidacloprid replaced the oxydemeton-methyl and mevinphos usage, and also replaced much of the use of methamidophos and endosulfan, that had been used for aphid control. The registration of

spinosad and cyfluthrin for control of worm pests of peppers replaced some usage of methomyl [190].

#### 35. Tobacco

The introduction of imidacloprid for aphid, wireworm and flea beetle control in tobacco has proven popular for both soil-applied and foliar treatments. The use of imidacloprid in tobacco has resulted in declines in the uses of acephate, aldicarb, chlorpyrifos, ethoprop and carbofuran [18].

The introduction of spinosad for control of budworms and hornworms has led to reductions in the use of methomyl [18].

### 36. Tomatoes

Whiteflies are the most serious insect pest in Florida tomato production. Whiteflies vector the destructive Gemini virus and the recently discovered tomato leaf curl virus, that has resulted in some total crop failures [205]. In 1992, the virus destroyed 90% of the tomato crop in the Dominican Republic. Florida growers gained a registration for imidacloprid in the mid 1990's, and it quickly became the most widely used insecticide for whitefly management. Imidacloprid also aids in management of aphids, thrips, armyworms and leafminers. The use of imidacloprid has displaced numerous foliar insecticide applications and resulted in reduced use of endosulfan, fenpropathrin, methamidophos and oxamyl in Florida tomatoes [205].

In the 1990's the potato aphid became an important pest in California processing tomatoes. In individual fields where aphids moved in about eight weeks before harvest, yield reductions of 10 tons per acre have occurred. Dimethoate is the least costly effective control, and its use increased in the 1990's; imidacloprid is also effective against the aphid (but more costly), and its use grew, as well [209]. One drawback of the increase in dimethoate's use for aphids is the reduction of beneficial insects that usually

keep leafminers in check [210]. Thus, in 1997, there was increased use of insecticides to control leafminers: abamectin and cyromazine are used early in the season while esfenvalerate and methomyl are used late in the season to knockdown leafminer populations [211].

#### 37. Walnuts

The use of chlorpyrifos in California walnut orchards for control of codling moth declined in the mid-1990's, following the registration of tebufenozide and phosmet. Both are effective on codling moth and are less disruptive to beneficial organisms [22] [52]. As a result, walnut growers used less methidathion to control outbreaks of secondary pests, such as aphids [54].

### 38. Watermelons

Florida watermelon growers used the organophosphate insecticide methamidophos in the early 1990's for controlling a variety of insect pests. Following its cancellation for watermelons, Florida growers increased their use of the organophosphate oxamyl.

# 39. Wheat

In Nebraska, disulfoton was used in 1992 for Russian wheat aphid control. The aphid was not a problem in Nebraska in 1997; thus disulfoton was not used [291]. In the Southeast, the introduction of lambdacyhalothrin for cereal leaf beetle led to its increase. Lambdacyhalothrin applications also provide residual control of aphids, which transmit yellow dwarf virus to wheat plants. As a result of lambdacyhalothrin's excellent aphid efficacy, growers reduced their use of disulfoton and methyl parathion [292]. In the period 1993-1997, southeastern wheat production was more reliant on varietal resistance to the Hessian fly; thus, the use of insecticides, such as phorate, declined in usage [292] [293].

In Montana, a significant number of acres of wheat were treated with carbaryl in 1997 because of widespread problems with grasshoppers in that year [319].

TABLE 9: NATIONAL PESTICIDE USE BY ACTIVE INGREDIENT PESTICIDE TYPE: INSECTICIDES

	LBS AI A	% CHANGE	
ACTIVE INGREDIENT	1992	1997	
ABAMECTIN	8,642	14,932	+67
ACEPHATE	3,389,865	2,462,354	-27
ALDICARB	4,022,468	4,277,552	+6
AMITRAZ	79,473	137,097	+73
AZADIRACHTIN	70,170	556	-
AZINPHOS-METHYL	2,548,867	2,091,014	-18
BIFENTHRIN	116,716	110,246	-5
BT	-, -	-, -	-
BUPROFEZIN		20,598	-
CARBARYL	4,570,414	4,857,542	+6
CARBOFURAN	5,101,406	3,398,067	-33
CHLORETHOXYFOS		252,792	-
CHLORPYRIFOS	14,764,535	13,463,879	-9
CLOFENTEZINE	1,537	21,467	+1300
CRYOLITE	4,053,299	2,560,365	-37
CYFLUTHRIN	124,360	177,782	+43
CYPERMETHRIN	228,082	187,991	-18
CYROMAZINE	16,997	14,297	-18
DELTAMETHRIN		27,045	-
DIAZINON	1,265,739	918,087	-27
DICOFOL	1,391,691	786,805	-45
DICROTOPHOS	666,136	359,726	-46
DIFLUBENZURON	16,470	57,112	+256
DIMETHOATE	2,619,437	1,896,947	-28
DISULFOTON	1,806,527	1,196,066	-34
ENDOSULFAN	1,796,726	1,601,195	-11
ESFENVALERATE	331,522	228,885	-31
ETHION	990,706	504,535	-49
ETHOPROP	1,449,743	1,010,807	-30
ETHYL PARATHION	2,318,251	529,379	-77 -40
FENAMIPHOS	614,937	726,675	+18 -36
FENBUTATIN OXIDE FENPROPATHRIN	414,195	265,275 31,839	-30 -49
FENVALERATE	63,368 66,281	31,039	-49 -100
FONOFOS	3,233,797	417,372	-100 -87
FORMETANATE HCL	290,467	134,527	-54
HEXYTHIAZOX	290,407	12,802	-54
IMIDACLOPRID		272,207	-
LAMBDACYHALOTHRIN	205,329	321,284	+57
LINDANE	61,188	39,366	-36
MALATHION	3,377,678	5,809,943	+72
METALDEHYDE	47,587	53,977	+12
METHAMIDOPHOS	1,088,479	965,584	-11
METHIDATHION	372,953	314,091	-16
METHOMYL	2,754,907	1,997,489	-27
METHOXYCHLOR	88,906	77,957	-12
METHYL PARATHION	5,961,740	5,918,849	-1

TABLE 9: NATIONAL PESTICIDE USE BY ACTIVE INGREDIENT PESTICIDE TYPE: INSECTICIDES (CONT.)

	<u>LB</u>	S AI APPLIED PER YEAR	% CHANGE
ACTIVE INGREDIENT	1992	1997	
MEVINPHOS	283,887		-100
NALED	230,244	605,456	+163
OIL	51,104,310	102,336,882	+100
OXAMYL	945,861	938,838	-1
OXYDEMETON-METHYL	241,288	154,227	-36
OXYTHIOQUINOX	149,657	35,231	-77
PERMETHRIN	1,068,598	1,066,056	-1
PHORATE	4,452,622	3,218,465	-28
PHOSMET	941,175	1,333,468	+42
PROFENOFOS	2,062,744	879,776	-57
PROPARGITE	3,628,217	2,538,969	-30
PYRIDABEN		17,719	-
PYRIPROXYFEN		13,284	-
SPINOSAD		117,315	-
SULPROFOS	852,352	308,039	-64
TEBUFENOZIDE		104,413	-
TEBUPIRIMPHOS		272,177	-
TEFLUTHRIN	238,429	576,865	+142
TERBUFOS	8,690,363	6,515,603	-25
THIODICARB	1,705,528	821,267	-52
TRALOMETHRIN	60,105	23,767	-60
TRICHLORFON	13,974		-100
TRIMETHACARB	156,800		-100
INSECTICIDES TOTAL	149,147,575	182,402,176	+22

Active Ingredient Total (1000 LB AI/YR)  Active Ingredient Total Major Crop Changes  Abamectin +7 Citrus +2 Apples +1 Cotton +1 Potato	
Active Ingredient Total Major Crop Changes	
<u> </u>	_
Abameetin ±7 Citrus ±2 Apples ±1 Cotton ±1 Detects	
TADAMEDIN TA CINA TA ADDICO TA CUNUITA FUNDIL	es +1
Acephate -928 Tobacco -698 Lettuce -60 Cotton -70 Celery	
	its -414
Tobacco -99	
Amitraz +58 Cotton +116 Pears -58	
Azadirachtin +1 Lettuce +1	
Azinphos-Methyl -457 Sugarcane -182 Peaches -3 Cotton -447 Potato	es -5
Bifenthrin -7 Cotton -80 Corn +80 Strawberries +1	
Bt –	
Buprofezin +21 Cotton +20	
Carbaryl +287 Citrus +170 Wheat +1012 Peaches -94 Grape	s -92
	on +189
Sugarbeets -57 Sorghum -336	
Chlorethoxyfos +253 Corn +252	
	les +295
Alfalfa -293 Almonds +62 Cotton +284 Walnu	ts -44
Citrus +226 Tobacco -279 Grapes +75	
Clofentezine +21 Almonds +4 Apples +13 Peaches +1	
Cryolite -1493 Potatoes -501 Grapes -1021	
Cyfluthrin +54 Alfalfa +14 Citrus +26 Corn +14 Pears	-2
Cypermethrin -40 Cotton -38	
Cyromazine -3 Tomatoes +3 Celery -2	
Deltamethrin +27 Cotton +27	
Diazinon -347 Almonds-41 Citrus -40 Corn -47 Tobac	co -54
Cranberries +68 Celery -4 Hazelnuts -3	
Dicofol -604 Pecans +44 Citrus -247 Cotton -436	
Dicrotophos -306 Cotton -306	
	ans +9
Dimethoate -722 Tomatoes +40 Citrus -126 Cotton -244 Corn - Disulfoton -610 Broccoli -7 Wheat -310 Corn -184 Pecan	
	s -o cans -84
Endosulfan -195 Tomatoes -83 Apples -21 Grapes -97 Per Cauliflower -33 Celery -3	Jans -04
Esfenvalerate -102 Sunflowers +37 Cotton -112 Peaches +1 Almon	qс т3
Artichokes -1	us +3
Ethion -487 Citrus -454 Onions -12 Pecans -7	
Ethoprop -438 Potatoes -125 Tobacco -256	
Ethyl Parathion -1789 Sunflowers -447 Cotton -214 Sorghum -310	
Fenamiphos +111 Tobacco +123 Grapes +22 Cotton -102	
Fenbutatin Oxide -148 Citrus -132 Pecans -48 Apples -4	
Fenpropathrin -31 Peanuts +8 Cotton -32 Strawberries +2	
Tomatoes -3	
Fenvalerate -66 Cotton -26 Corn -18 Potatoes -5	
Fonofos -2816 Potatoes -35 Peanuts -266 Corn -2295	
Formetanate HCl -155 Citrus -127 Apples -40 Pears -4	
	ears +1
Imidacloprid +272 Potatoes +50 Lettuce +25 Apples +19 Cottor	
	bage +1
Grapes +8	<u> </u>
Lambdacyhalothrin +116 Sweet Corn +15 Wheat +18 Corn +42 Cottor	ı <b>-13</b>
Soybeans +12 Sunflowers +8 Cabbage +2	
Lindane -22 Squash -3 Pecans -17	

TABLE 10: Differ	ences in	Insecticide Use Amounts: 1992 and 1997 (Cont.)		
		(1000 LB AI/YR)		
Active Ingredient	Total	Major Crop Changes		
Malathion	+2433	Sunflowers -30 Cotton +2803		
Metaldehyde	+6	Strawberries +2 Citrus -3 Artichokes +5		
Methamidophos	-123	Watermelons -42 Cotton -104 Celery -17 Tomatoes -73		
		Potatoes +104 Cabbage -16		
Methidathion	-58	Safflower-17 Cotton -9 Citrus -7 Walnuts -9 Artichokes -2		
Methomyl	-758	Sweet Corn -93 Cotton -158 Apples -19 Grapes -45		
		Cauliflower -60 Tomatoes +8 Alfalfa +38 Cabbage -39		
Methoxychlor	-11	Squash -5 Grapes -3		
Methyl Parathion	-43	Sunflowers -135 Peaches +55 Cotton -226 Wheat -107		
		Apples +239 Potatoes -45 Corn +214 Soybeans +162		
Mevinphos	-284	Broccoli -25 Lettuce -122 Cauliflower -13 Celery -14		
		Green Peas -7 Cabbage -10		
Naled	+375	Cauliflower +10 Cotton +402 Celery -2 Grapes -75		
Oil	+51233	Pistachios +1055 Citrus +48846 Peaches +1666		
Oxamyl	-6	Apples -5 Onions +17 Cotton -12 Celery +24		
		Tomatoes -28 Watermelons +3		
Oxydemeton-Methyl	-87	Sugarbeets -6 Cotton -64 Cabbage +2 Onions -3		
0 (1)	445	Broccoli -12 Mint -15		
Oxythioquinox	-115	Citrus -67 Apples -22 Pears -25		
Permethrin	-3	Almonds +20 Corn +252 Cotton -43 Onions -20		
Phorate	-1235	Alfalfa -113 Cabbage -5 Apples -5 Peanuts +117 Wheat -138 Cotton +226 Potatoes -282		
Phosmet	+392	Blueberries +20 Walnuts +155 Pecans +116		
Filosifiet	+392	Potatoes -52		
Profenofos	-1182			
Propargite	-1090	Strawberries -25 Cotton -162 Peanuts -109 Peaches -42		
		Apples -278		
Pyridaben	+18	Apples +16 Pears +2		
Pyriproxyfen	+13	Cotton +12 Pears +2		
Spinosad	+117	Broccoli +4 Lettuce +9 Cotton +93 Celery +1		
Sulprofoc	-544	Cauliflower +2 Tobacco +3 Cotton -544		
Sulprofos Tebufenozide				
rebuteriozide	+104	Sugarcane +16 Apples +27 Walnuts +4 Cotton +47 Broccoli +1		
Tebupirimphos	+272	Corn +272		
Tefluthrin	+339	Sweet Corn +2 Corn +337		
Terbufos	-2175	Sugarbeets +165 Corn -2345		
Thiodicarb	-884	Sweet Corn -156 Cotton -737 Lettuce +28 Broccoli +15		
		Cauliflower +6 Celery +20		
Tralomethrin	-36	Soybeans -7 Cotton -30 Lettuce +1		
Trichlorfon	-14	Other Hay -7		
Trimethacarb	-157	Corn -157		
Total	+33255			

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TABLE 11: Insecticide Use Patterns by	Crop and State(	Selected Records)
	% Acres	s Treated
	<u>1992</u>	<u>1997</u>
I Alfalfa		
a. <u>California</u>		
Carbofuran	34	19
Chlorpyrifos	31	36
Cyfluthrin	-	10
Methomyl	11	23
Permethrin	18	14
II Almonds		
a. <u>California</u> *		
Bt	4	24
Chlorpyrifos	31	26
Diazinon	24	10
Esfenvalerate	2	13
Methidathion	16	11
Permethrin	6	18
* Acreage increased by 38%		
III Apples		
a. New York		
Abamectin	-	16
Clofentezine	-	16
Dicofol	11	3
Fenbutatin Oxide	10	4
Formetanate HCI	15	5
Hexythiazox	-	27
Imidacloprid	-	36
Methomyl	40	25
Oxamyl	31	16
Oxythioquinox	16	-
Permethrin	25	6
Phosphamidon	23	-
Propargite	57	-
Pyridaben	-	27
Tebufenozide	-	42
b. North Carolina		
Abamectin	-	8
Clofentezine	-	15
Hexythiazox	-	10
Propargite	19	-
Pyridaben	-	27
c. Washington		
Abamectin	-	26
Chlorpyrifos	65	91

TABLE 11:	<b>Insecticide Use Patterns by Crop and State</b>
	(Selected Records) (Cont.)

	% Acres Treated	
	<u>1992</u>	<u>1997</u>
Clofentezine	-	18
Endosulfan	33	22
Formetanate HCI	6	12
Imidacloprid	-	65
Methyl Parathion	28	33
Oxamyl	21	30
Oxythioquinox	19	-
Phosphamidon	72	-
Propargite	7	-
Pyridaben	-	20
IV Artichokes		
a. <u>California</u>		
Diflubenzuron	-	58
Esfenvalerate	90	70
Methidathion	90	58
V Blueberries		
a. <u>Maine</u>		
Azinphos-Methyl	50	36
Phosmet	-	12
VI Broccoli		
a. <u>California</u>		
Disulfoton	11	5
Imidacloprid	-	23
Mevinphos	27	-
Oxydemeton-Methyl	67	44
Permethrin	22	13
Spinosad	-	20
Tebufenozide	-	5
Thiodicarb	-	8
Tralomethrin	-	2
VII Cabbage		
a. <u>New York</u>	4.5	
Chlorpyrifos	18	35
Imidacloprid	-	3
Lambdacyhalothrin	-	89
Methamidophos	9	3
Methomyl	7	-
Mevinphos	6	-
Oxydemeton-Methyl	2	23
Permethrin	53	15
Spinosad	-	20

TABLE 11: Insecticide Use Patterns by Crop and State (Selected Records) (Cont.)		
	% Acres	Treated
	<u>1992</u>	<u>1997</u>
VIII Cauliflower		
a. <u>California</u>		
Bt	3	35
Endosulfan	58	2
Imidacloprid	-	38
Methomyl	38	17
Mevinphos	23	-
Naled	3	9
Spinosad	-	18
Thiodicarb	-	10
IX Celery		
a. <u>California</u>		
Abamectin	17	46
Azadirachtin	-	7
Bt	35	53
Cyromazine	-	26
Diazinon	16	4
Endosulfan	9	· -
Mevinphos	31	-
Naled	8	-
Oxamyl	54	89
Spinosad	-	31
Thiodicarb	-	63
h Elorido		
b. <u>Florida</u> Acephate	_	100
Cyromazine*	94	100
Methamidophos	84	-
* Rate reduced by 33%	04	
·		
X Citrus		
a. <u>California</u>	•	_
Carbaryl*	2	5
Chlorpyrifos**	43	49
Cyfluthrin	3	51
Dimethoate Formetanate HCI	34 47	6 5
Methidathion**	47 8	5 5
* Rate up 50%	O	5
** Rate up 40%		
·		
b. <u>Florida</u>		
Abamectin	34	42
Aldicarb	17	7

<b>TABLE 11: Insecticide Use Patterns by Crop and State</b>	
(Selected Records) (Cont.)	

	% Acres Treated	
	<u>1992</u>	<u>1997</u>
Diazinon	4	-
Dicofol	22	1
Diflubenzuron	-	4
Ethion	44	18
Fenbutatin Oxide	39	8
Formetanate HCI	1	-
Methidathion	2	_
Oil*	- 53	89
Oxythioquinox	22	4
* Rate increased by 45%	80	27
-	00	<b>~</b> 1
XI Corn		
a. <u>Illinois</u>		
Carbofuran	1	-
Chlorethoxyfos	-	2
Chlorpyrifos	11	8
Cyfluthrin	-	2
Fonofos	4	-
Lambdacyhalothrin	-	3
Permethrin	2	9
Tebupirimphos	-	2
Tefluthrin	1	7
Terbufos	6	5
b. <u>Kansas</u>		
Bifenthrin	7	20
Dimethoate	1	-
Disulfoton	5	-
Methyl Parathion	7	10
Propargite	5	-
XII Cotton		
a. Arizona		
	69	96
Acephate*	09	96 12
Buprofezin Dicofol	30	2
	30 16	۷
Ethyl Parathion		- 18
Fenpropathrin Fenvalerate	39 7	ΙŎ
	7	-
Imidacloprid	- 25	20
Methamidophos	25	3
Methomyl	29	6
Permethrin	23	-
Propargite	19	2
Pyriproxyfen	-	51

TABLE 11:	<b>Insecticide Use Patterns by Crop and State</b>
	(Selected Records) (Cont.)

	% Acres Treated	
	1992	<u>1997</u>
Sulprofos	5	-
* Rate reduced by 40%		
b. <u>California</u>		
Abamectin	25	40
Aldicarb	10	29
Amitraz	-	12
Bifenthrin	66	7
Buprofezin	-	1
Chlorpyrifos	13	40
Dicofol	48	22
Diflubenzuron	-	3
Dimethoate	33	11
Imidacloprid	-	41
Methidathion Naled	2 4	30
Oxydemeton-Methyl*	6	5
Propargite	11	8
Pyriproxyfen	-	5
* Rate reduced by 33%	-	3
c. Mississippi Acephate Aldicarb Azinphos-Methyl Bifenthrin Carbofuran Cypermethrin* Deltamethrin	18 16 25 15 - 21	39 49 4 - 11 19 5
Dicrotophos	35	12
Esfenvalerate	33	10
Fenamiphos	1	-
Imidacloprid	-	9
Lambdacyhalothrin**	45	38
Malathion	8	34
Methomyl	26	6
Methyl Parathion***	79	73
Oxydemeton-Methyl	2	-
Oxamyl	21	3
Permethrin	5	-
Phorate	1	6
Profenofos	49	11
Spinosad	-	23
Sulprofos	23	11

TABLE 11: Insecticide Use Patterns by Crop and State (Selected Records) (Cont.)		
	% Acres	Treated
	1992	1997
Tebufenozide Thiodicarb Tralomethrin * Rate reduced by 25% ** Rate reduced by 50% *** Rate reduced by 33%	38 18	11 4 4
XIII Cranberries a. Massachusetts Chlorpyrifos* Diazinon* Ethyl Parathion * Rate doubled	70 80 100	87 77 -
XIV Grapes a. California Carbaryl* Chlorpyrifos Cryolite* Endosulfan Imidacloprid Methomyl Naled * Rate reduced by 50%	9 - 71 12 - 14 12	3 6 78 1 48 11
XV Green Peas a. Washington Dimethoate Mevinphos	25 26	54 -
XVI Hazelnuts a. Oregon Azinphos-Methyl Carbaryl Chlorpyrifos Diazinon Endosulfan Esfenvalerate* Oxydemeton-Methyl Permethrin * Rate reduced by 50%	17 4 39 6 10 58 3 18	4 - 33 - 1 92 - 1
XVII Hops a. Oregon Abamectin Bifenthrin	49 -	100 10

TABLE 11: Insecticide Use Patterns by Crop and State
(Selected Records) (Cont.)

	% Acres Treated	
	<u>1992</u>	<u>1997</u>
Chlorpyrifos	61	-
Diazinon	100	25
Dicofol	25	-
Imidacloprid	-	100
Propargite	100	10
b. <u>Washington</u>		
Hexythiazox	-	62
XVIII Lettuce		
a. <u>California</u>		
Abamectin	14	20
Acephate	75	51
Azadirachtin	-	9
Bt	9	47
Cyromazine	-	7
Diazinon	36	52
Endosulfan	3	14
Imidacloprid	-	85
Methomyl*	38	76
Mevinphos	51	-
Spinosad Thiodicarb	-	22 23
Tralomethrin	<u>-</u>	13
* Rate declined by 50%	_	13
XIX Mint		
a. <u>Oregon</u>		
Acephate	70	24
Chlorpyrifos	30	27
Fonofos	38	24
Oxamyl	60	45
Oxydemeton-Methyl	2	-
XX Onions		
a. <u>Idaho</u>		
Chlorpyrifos	8	78
Ethion	55	-
b. <u>Oregon</u>		
Cypermethrin	68	7
Lambdacyhalothrin	40	91
Oxamyl	-	16
Oxydemeton-Methyl	16	-
Permethrin	30	11

TABLE 11:	Insecticide Use Patterns by Crop and State	
	(Selected Records) (Cont.)	

(delected Necords) (dont.)	0/ 1000	a Tractad
-		s Treated
	<u>1992</u>	<u>1997</u>
XXI Peaches		
a. <u>California</u>		
Azinphos-Methyl	36	2
Bt	9	50
Carbaryl	25	5
Clofentezine	-	11
Esfenvalerate	22	39
Fenbutatin Oxide	37	28
Methidathion	36	18
Methyl Parathion	7	25
Propargite	33	-
b. <u>Georgia</u>		00
Esfenvalerate	-	20
Methyl Parathion	17	94
Oil	9	70
XXII Peanuts		
a. <u>Georgia</u>		
Aldicarb	57	40
Chlorpyrifos	45	25
Fenpropathrin	-	2
Phorate	10	40
Propargite	10	5
XXIII Pears		
a. Oregon		
Abamectin	91	75
Amitraz	88	73 7
Cyfluthrin	53	-
Dicofol	2	_
Endosulfan	52	4
Esfenvalerate	41	24
Fenbutatin Oxide	12	3
Fenoxycarb	-	54
Formetanate HCI	7	2
Hexythiazox	-	14
Imidacloprid	<u>-</u>	9
Oxamyl	5	2
Oxythioquinox	55	10
Pyridaben	-	19
Pyriproxyfen	-	65
т упртолутоп		

TABLE 11:	<b>Insecticide Use Patterns by Crop and State</b>
	(Selected Records) (Cont.)

, , , , , , , , , , , , , , , , , , , ,	% Acres Treated	
-	1992	<u>1997</u>
	1332	<u>1331</u>
XXIV Pecans		
a. <u>Georgia</u>		
Chlorpyrifos	45	65
Dicofol	6	17
Disulfoton	13	6
Endosulfan	47	20
Ethion	6	-
Fenbutatin Oxide	45	5
Phosmet	-	25
XXV Potatoes		
a. <u>Idaho</u>		
Aldicarb	-	11
Carbofuran	2	17
Endosulfan	4	13
Ethoprop	19	10
Imidacloprid	-	8
Methamidophos	5	26
Phorate	45	41
b. <u>Michigan</u>		
Abamectin	-	25
Azinphos-Methyl	49	12
Carbofuran	17	10
Cryolite	11	-
Endosulfan	47	-
Imidacloprid	<u>-</u>	78
Methamidophos	35	24
Methyl Parathion	27	-
Phorate	16	12
Phosmet	52	7
XXVI Raspberries		
a. <u>Oregon</u>		
Bifenthrin	-	22
Permethrin	15	-
XXVII Sorghum		
a. <u>Kansas</u>		
<u>Carbofuran</u>	7	-
Chlorpyrifos	1	5
Ethyl Parathion	15	-
XXVIII Soybeans		
a. <u>Georgia</u>		
Diflubenzuron	-	70

TABLE 11: Insecticide Use Patterns by Crop and State
(Selected Records) (Cont.)

	% Acres Treated	
	<u>1992</u>	<u>1997</u>
h Lauisiana		
b. <u>Louisiana</u>	_	4
Lambdacyhalothrin Methyl Parathion	9	26
Permethrin	5	1
Thiodicarb	7	12
Tralomethrin	6	2
XXIX Strawberries		
a. <u>California</u>		
Abamectin*	70	67
Bifenthrin	-	17
Diazinon	13	8
Fenpropathrin	-	17
Hexythiazox	-	13
Methomyl	29	12
Propargite	40	-
* Rate increased by 33%		
XXX Sugarbeets		
a. <u>Nebraska</u>		
Carbofuran	28	1
Terbufos	13	40
b. <u>North Dakota</u>		
Chlorpyrifos	40	7
XXXI Sugarcane		
a. <u>Louisiana</u>		
Azinphos-Methyl	46	2
Tebufenozide	-	38
VVVII Cunflowers		
XXXII Sunflowers a. <u>North Dakota</u>		
Esfenvalerate	10	41
Ethyl Parathion	9	1
Lambdacyhalothrin	-	15
Malathion	2	-
Methyl Parathion	6	1
XXXIII Sweet Corn		
a. <u>Florida</u>		
Lambdacyhalothrin	-	74
Methomyl*	97	79
Methyl Parathion	6	-
Thiodicarb	70	55
* Rate reduced by 50%		

TABLE 11: Insecticide Use Patterns by Crop and State
(Selected Records) (Cont.)

(00000000000000000000000000000000000000	% Acres Treated	
	1992	1997
	1002	<u>1007</u>
b. <u>Minnesota</u> Lambdacyhalothrin Methomyl	- 15	35 6
XXXIV Sweet Peppers		
a. California Abamectin Cyfluthrin Cyromazine Dimethoate Endosulfan Imidacloprid Methamidophos Methomyl Mevinphos Oxamyl Oxydemeton-Methyl	- - 32 11 - 14 35 15 30 6	15 17 13 16 2 31 5 22 - 19 2
Spinosad	-	20
b. Florida Abamectin Azinphos- Methyl Chlorpyrifos Dimethoate Endosulfan Imidacloprid	- - - 17 18 -	11 12 17 6 9 41
XXXV Tobacco a. North Carolina Acephate* Aldicarb Carbofuran Chlorpyrifos Ethoprop Imidacloprid Methomyl** Spinosad * Rate reduced by 60% ** Rate reduced by 50%	100 22 2 62 19 - 14	87 6 - 25 6 35 11 13
XXXVI Tomatoes a. <u>California</u> Abamectin Cyromazine Dimethoate	- - 10	4 3 58

TABLE 11: Insecticide Use Patterns by Crop and State
(Selected Records) (Cont.)

	% Acres	s Treated
	<u>1992</u>	<u>1997</u>
Esfenvalerate Imidacloprid Methomyl	39 - 26	82 17 74
b. Florida Endosulfan Fenpropathrin Imidacloprid Methamidophos Oxamyl	67 30 - 64 21	23 4 81 26 12
XXXVII Walnuts a. California Chlorpyrifos Methidathion Phosmet Tebufenozide	59 10 -	35 7 17 7
XXXVIII Watermelons a. Florida Methamidophos Oxamyl	12 -	2 7
XXXIX Wheat a. Mississippi Phorate	20	-
b. <u>Montana</u> Carbaryl	-	12
c. <u>Nebraska</u> Disulfoton	5	-
d. <u>South Carolina</u> Disulfoton Lambdacyhalothrin Methyl Parathion	7 - 5	3 10 1

## VI. Other Pesticides

## A. Introduction

The category of "other pesticides" consists of active ingredients that do not clearly or exclusively fit into the category of insecticides, fungicides or herbicides. "Other pesticides" include active ingredients used for soil fumigation, crop desiccation, crop defoliation, crop thinning, sprout inhibition or crop growth regulation.

# B. <u>Crop Analysis</u>

# 1. Apples

Many apple varieties have the ability to set heavy crops most years. This trait is not totally desirable due to the negative effects a heavy fruit set has on annual production and fruit quality. Chemical thinning improves size, color and quality of fruit [177]. There are four chemicals available for thinning apples. Carbaryl was introduced as an insecticide in 1958. Shortly after its introduction, it was discovered to have thinning properties. It is used regularly as a thinner. (All of carbaryl's usage is included in the "insecticide" category.) The three apple thinning chemicals classified in the "other" category are benzyladenine (Accel), NAA and NAD. Accel was introduced as a thinner in 1994. Research has shown that Accel has the widest window of activity of all the available thinners. In addition to being a reliable thinner, Accel also has been shown to improve fruit size in some cultivars beyond what other thinners accomplish [178].

Accel has been used in Eastern states as a replacement for some of the NAA and NAD usage. Some reduction in use of thinning chemicals, such as NAA, occurred in Michigan in 1997 because it was a cold year, and the state only produced 60% of a crop [296].

In Washington State apples, there was a decrease in the use of cytokinins and gibberellic acid in the 1990's – a combination of these active ingredients is used on red delicious apples to improve their shape. As the number of red delicious apple trees declined in Washington, the use of these growth regulators also declined. A reduction in fruit thinning chemicals also was recorded in Washington in the 1990's (NAA, NAD). This reduction is partially due to the discovery that the use of the foliar fertilizer, ATS, also causes fruit thinning [297]. Research has demonstrated that the foliar fertilizer applications are as effective as the chemical thinners [298]. In 1997, apple growers gained the registration for a new growth regulator, butenoic acid (Retain). Applications of butenoic acid inhibit fruit abscission and delay fruit maturity. Fruit are held on the tree without a loss in firmness. This has the effect of lengthening the harvest season without worrying about fruit drop [299]. The use of butenoic acid has filled many of the needs that formerly were met with applications of daminozide.

## 2. *Carrots*

In the 1980's, California carrot growers primarily used the fumigant 1,3-D for nematode control. In the early 1990's, the use of 1,3-D was suspended in California. Carrot growers switched to the use of metam sodium and were granted an emergency exemption to use methyl bromide. The use of methyl bromide was allowed since metam sodium does not work well when temperatures go below 55° F. Following 1,3-D's reinstatement in the mid-1990's, the emergency registrations for methyl bromide were ended, and 1,3-D reclaimed that use.

## 3. *Citrus*

Gibberellic acid is applied to citrus to delay senescence, the overripening of fruit. It also is used on navel oranges after oil treatments to prevent rind breakdown (waterspotting). Gibberellic acid assumed new importance when USDA canceled the citrus marketing order in 1993 [156]. With the marketing order, prices were more steady throughout the year. A grower could pick sooner and get an acceptable price. Without the marketing

order, a glut of harvested fruit in January and February forces down prices. Gibberellic acid is applied to the oranges on the tree when they are approaching maturity, but are still green. The material causes a substantial delay in the rind aging of navels, prolonging ontree storage life. This enables growers to postpone harvest and extend the sales period for oranges to when the market is more advantageous, even into April or May [156].

## 4. Cotton

In harvested cotton, dried leaf material results in trash discounts and green leaf tissue results in off colors. A new product was introduced (Finish), that contains a new active ingredient (cyclanilide) in combination with ethephon. Research demonstrated that the combination provided both boll opening and defoliation [184].

Use of ethephon, a boll opener, and cyclanilide increased, especially in the Southeast where early harvests help avoid crop loss to inclement, late-season weather (i.e., hurricanes) [39]. Increased ethephon use is also attributed to increased competition and availability and decreased costs upon expiration of its patent in the mid-1990's [39].

Ethephon's use increased in Texas, where it facilitates earlier once-over harvesting instead of waiting for all the bolls to open without treatment [183].

Herbicide tolerance and the rotation of cotton with crops such as tomatoes and peppers that are in the same family as nightshade have made weed control in the San Joaquin Valley of California difficult. Hairy and black nightshade are not controlled with available herbicides, and hand hoeing costs approach \$150 per acre in some fields in addition to the cost of cultivation. Research with the use of metam sodium in California cotton demonstrated that 100% control of nightshade is achieved with its application [97].

In the early 1990's, arsenic acid was used on 11% of Texas cotton acreage as a desiccant [182]. At the end of the 1993 growing season, further use of arsenic acid was

prohibited. Growers increased their use of paraquat, which is a weaker desiccant than arsenic acid. In order to improve desiccation, Texas growers also increased their use of the defoliants tribufos and thidiazuron, whose use prior to paraquat's removes most of the leaves and conditions the crop for more complete desiccation with the paraquat treatment [50].

The use of the defoliants thidiazuron, tribufos and dimethipin also increased in the 1990's throughout the cotton producing belt due to changes in the classification system for cotton fiber evaluation, which placed greater emphasis on harvesting cotton free of trash and color pigmentation. The industry adopted high volume instrumentation (HVI) to measure non-lint materials in harvested cotton [37]. Growers increased their use of the defoliants to remove cotton plant leaves from the harvested cotton. Sodium chlorate's use as a defoliant declined since it is less effective than the other defoliants [4].

In California, cacodylic acid (an organic form of arsenic acid) is used as a desiccant. In reaction to concerns regarding high arsenic content of lint exported to European markets, California growers reduced their use of cacodylic acid in the 1990's [51]. Instead of making two cacodylic acid applications, growers substituted a sequence of one cacodylic acid application followed by a paraquat application.

The increasing use of defoliants and boll openers in Texas cotton reflects attempts to manage the crop better, improve yields and harvesting efficiency, and improve quality [183] [185].

A significant increase in the use of mepiquat chloride occurred in Texas. Mepiquat chloride acts as a plant growth regulator; its application shortens the plant, reduces excessive growth and hastens maturity, thereby allowing harvest to occur 3 to 10 days earlier [186]. The use of mepiquat chloride results in a more uniform crop and makes it easier to condition the crop with harvest aids [183].

# 5. *Grapes*

The percentage of all grape acreage in California that was treated with gibberellic acid declined from 1992 to 1997. Gibberellic acid is applied to seedless varieties of table and raisin grapes to thin berries and increase berry size. Its reduced use is linked, most likely, to a shift in the varieties planted in the 1990's [259]. The percentage of acreage that was planted to seeded varieties, such as Red Globe, increased significantly. Additionally, breeding programs are producing more varieties of seedless grapes with berry characteristics that eliminate the need for gibberellic acid applications [259]. For example, research has demonstrated no value for gibberellic acid applications to the cultivar Crimson seedless [260].

# 6. Hot Peppers

The use of 1,3-D for control of nematodes increased in New Mexico hot peppers.

Research demonstrated that if a nematicide is not used in the sandy soils of New Mexico, significant economic losses can be expected [348].

## 7. Onions

Maleic hydrazide applications to onions help to prevent sprouting. Onion growers increased the use of maleic hydrazide in the 1990's to control sprouting so that the marketing period for onions could be lengthened.

## 8. Peanuts

The decline in 1,3-D's use is due to a smaller percent of acres being treated in the Southeast (5% in 1992 to 1% in 1997). 1,3-D declined in use due to its expense and the lower price growers are receiving for peanuts [171]. 1,3-D is difficult to apply and has not been tested with reduced tillage, which is increasing in use.

## 9. Potatoes

An added effect of the late blight epidemic has been an increase in the use of chemicals that desiccate potato foliage prior to harvest [104]. Prior to 1995, not all potato vines were desiccated prior to harvest. Vine desiccation is effective in preventing the late season development and spread of the disease. By assuring that all vines are totally dead through desiccation, growers can reduce the potential of tuber infections in potatoes that are to be stored. Significant increases occurred in the use of the vine desiccants sulfuric acid and diquat (classified as an herbicide).

Metam sodium usage in Idaho potatoes has proved increasingly popular due to its effectiveness in controlling nematodes, weeds and diseases [154]. Metam sodium was used previously only through sprinkler irrigation systems; now it is available for ground spray, also, and so its market has expanded to growers who do not use sprinklers [154].

An increase in the use of maleic hydrazide in potatoes occurred in the 1990's due to the increased use of potatoes in the processing market. Processors desire a potato without sprouts and of a uniform size. Uniformity in size helps to reduce waste byproducts from the processing of potatoes into french fries. Maleic hydrazide controls sprouting and promotes uniformity.

## 10. Soybeans

In recent years Group IV soybean acreage has increased throughout the South. Group IV soybean allows growers to plant early and to take advantage of moisture that is usually available when plants are in the stages from bloom to pod fill. They also allow producers to harvest as early as August, thereby avoiding fall rains that normally delay harvest when later maturing cultivars are planted (Groups V and VI). Late season weed flushes do not reduce yields, but often create problems at harvest. Optimal yields are obtained with an application of a burndown herbicide, such as paraquat, in combination with a

desiccant, such as sodium chlorate. The desiccant helps to reduce soybean moisture content [31].

Elevated use of sodium chlorate in the Southeastern U.S. is tied to the increased planting of early-maturing varieties. Weeds are usually controlled with herbicides applied at planting. Some, however, do re-emerge, albeit stunted by the herbicides. By the time these weeds emerge, the early-maturing soybeans are at a much later development stage and thus can outcompete the weeds [35]. However, when the soybean plants reach maturity and begin to desiccate, the canopy opens up, allowing weeds below to benefit. At this point, controlling weeds for harvest may be necessary [36]. Research shows that sodium chlorate mixed with paraquat can control weeds for harvest [36]. Thus, in the mid-1990's there was increasing use of sodium chlorate in Southeastern soybean acreage.

# 11. Sugarbeets

The decrease in 1,3-D's poundage is due largely to a reduction in the percent acres treated in Nebraska and Wyoming (from 13-23% to 4%). Rhizomania disease of sugarbeets first was reported in Nebraska and Wyoming in the early 1990's. Sugarbeet growers increased their use of 1,3-D to control the disease [175]. 1,3-D also was used to control nematodes. 1,3-D's use dropped off for two reasons [175]: (1) by 1997, good disease-resistant sugarbeet varieties were available, so treatment was not needed, and (2) erratic nematode control efficacy of 1,3-D has discouraged growers from continuing to use it.

## 12. Tobacco

Maleic hydrazide (MH) has been used widely for sucker control in tobacco because it is effective, relatively inexpensive and easy to apply. Maleic hydrazide acts systemically. Several countries in the European Community, the major importers of U.S. leaf tobacco, have adopted an 80 ppm MH tolerance for tobacco products [108]. Research demonstrated that a lower rate of MH could be used if it were combined with a contact

sucker control chemical, such as flumetralin [109]. In 1995, the flumetralin label was changed to allow for a tank mix of flumetralin with a half rate of maleic hydrazide. Thus, the percentage of acreage treated with flumetralin has increased while the rate of maleic hydrazide application has decreased. The total volume of maleic hydrazide has not declined in tobacco because more acreage is being treated.

The decline in methyl bromide usage in tobacco is due to a difference in production of tobacco seedlings. In 1992, in North Carolina, some methyl bromide was used in seed beds at a rate of over 400 pounds per acre. By 1997, North Carolina had switched over to raising transplant seedlings in greenhouses where methyl bromide is not used, so the only remaining use of methyl bromide is in open fields where methyl bromide is used at about 126 pounds per acre [172].

Chloropicrin use increased in the Carolinas between 1992 and 1997. Certain soilborne diseases became more problematic in tobacco fields in the 1990's. Black shank caused its highest level of losses in 30 years because of a prevalence of wet soils and an increased planting of highly susceptible tobacco cultivars [294]. Additionally, acreage infested by bacterial wilt increased in the 1990's, and chloropicrin is the only effective control [295].

## 13. *Tomatoes*

The fumigant metam sodium is used as an herbicide primarily to control nightshades in California tomato fields. Tomato acreage treated with metam sodium increased in the mid-1990's because of the increased prevalence of nightshade [4].

TABLE 12: NATIONAL PESTICIDE USE BY ACTIVE INGREDIENT PESTICIDE TYPE: OTHER PESTICIDES

	LBS AI APPLIED PER YEAR		% CHANGE	
ACTIVE INGREDIENT	1992	1997		
1,3-D	40,083,611	34,717,237	-13	
BENZYLADENINE		518	-	
BUTENOIC ACID		1,475	-	
CACODYLIC ACID	135,915	47,571	-65	
CHLOROPICRIN	11,086,567	13,882,188	+25	
CYCLANILIDE		177,086	-	
CYTOKININS	2,970	2,518	-15	
DIMETHIPIN	212,365	282,458	+33	
ETHEPHON	2,701,284	5,407,986	+100	
FLUMETRALIN		352,742	-	
GIBBERELLIC ACID	30,636	35,964	+17	
MALEIC HYDRAZIDE	2,073,238	2,143,154	+3	
MEPIQUAT CHLORIDE	123,081	182,576	+48	
METAM SODIUM	29,095,179	60,023,092	+106	
METHYL BROMIDE	44,196,554	32,803,943	-26	
NAA	13,146	10,486	-20	
NAD	3,527	2,187	-38	
SODIUM CHLORATE	8,293,087	7,261,557	-12	
SULFURIC ACID	17,240,871	47,994,188	+178	
THIDIAZURON	325,241	326,239	0	
TRIBUFOS	3,963,864	4,918,265	+24	
OTHER PESTICIDES TOTAL	159,581,136	210,573,430	+32	

TABLE 13: Differences in Other Pesticide Use Amounts: 1992 and 1997			
		(1000 LB AI/YR)	
Active Ingredient	Total	Major Crop Changes	
1,3-D	-5366	Potatoes -2438 Peanuts -3193 Carrots +1032 Hot Peppers +945 Onions +1526 Sugarbeets -4742	
Benzyladenine	+1	Apples +1	
Butenoic Acid	+1	Apples +1	
Cacodylic Acid	-89	Cotton -89	
Chloropicrin	+2796	Tomatoes -1331 Tobacco +6184 Potatoes -1021	
Cyclanilide	+177	Cotton +177	
Cytokinins	-1	Apples -1	
Dimethipin	+70	Cotton +70	
Ethephon	+2707	Tomatoes -15 Cotton +2704 Apples +22	
Flumetralin	+352	Tobacco +352	
Gibberellic Acid	+5	Blueberries +2 Grapes -6 Cherries +2 Citrus +7	
Maleic Hydrazide	+70	Potatoes +15 Onions +54	
Mepiquat Chloride	+60	Cotton +60	
Metam Sodium	+30928	Potatoes +17857 Carrots +5237 Cotton +198	
		Tomatoes +626 Onions +2163 Peanuts +3450	
Methyl Bromide	-11393	Tobacco -4671 Carrots -1307 Watermelons -5400	
NAA	-3	Apples -4	
NAD	-1	Apples -1	
Sodium Chlorate	-1032	Soybeans +472 Cotton -1192	
Sulfuric Acid	+30754	Potatoes +30754	
Thidiazuron	+1	Cotton +1	
Tribufos	+955	Cotton +955	
Total	+50992		

TABLE 14: Other Pesticide Use Patterns by Crop and State (Selected Records)		
	% Acres Treated	
	<u>1992</u>	<u>1997</u>
I Apples a. Michigan Benzyladenine NAA* NAD * Rate declined by 40%	- 26 2	11 27 -
b. <u>Washington</u> Butenoic Acid Cytokinins Gibberellic Acid NAA NAD	58 44 56 21	5 35 35 40 16
II Carrots a. <u>California</u> 1,3-D Methyl Bromide	- 14	10 -
III Citrus a. <u>California</u> Gibberellic Acid	14	37
IV Cotton a. California Ethephon Cacodylic Acid* Metam Sodium Sodium Chlorate Thidiazuron Tribufos * Rate reduced by 80%	32 15 2 65 2 47	48 15 3 44 32 53
b. <u>Mississippi</u> Cyclanilide Ethephon Thidiazuron Tribufos	20 39 49	19 40 65 65
c. <u>North Carolina</u> Cyclanilide Dimethipin Ethephon	- 10 40	42 25 58
d. <u>Texas</u> Arsenic Acid Ethephon	11 5	- 17

TABLE 14: Other Pesticide Use Patterns by Crop and State (Selected Records) (Cont.)		
(Gelected Necords) (Gont.	% Acres Treated	
	<u>1992</u>	<u>1997</u>
Mepiquat Chloride	15	35
Sodium Chlorate	10	7
Thidiazuron	8	15
Tribufos	14	19
V Grapes		
a. <u>California</u> Gibberellic Acid	51	41
VI Hot Peppers		
a. New Mexico		0.5
1,3-D	-	95
VII Onions		
a. <u>California</u> Maleic Hydrazide	5	16
b. New York		
Maleic Hydrazide	16	36
VIII Peanuts		
a. <u>Alabama</u>	_	
1,3-D	5	1
IX Potatoes		
a. <u>Idaho</u>	0	40
Maleic Hydrazide Metam Sodium	2 10	13 30
Sulfuric Acid	7	28
	,	20
X Soybeans		
a. <u>Mississippi</u> Sodium Chlorate	_	5
		0
XI Sugarbeets		
a. <u>Nebraska</u> 1,3-D	13	4
	10	7
XII Tobacco		
a. North Carolina Chloropicrin	2	41
Flumetralin	<u>-</u>	75
Maleic Hydrazide*	77	95
Methyl Bromide	2	1
* Rate reduced by 30%		
XIII Tomatoes		
a. <u>California</u>		
Metam Sodium	20	27

# VII. Summary

A comparison of the 1992 and the 1997 NCFAP pesticide use databases reveals an aggregate increase of 93.7 million pounds of annual usage. The four previous sections of this report contain numerous explanations of why specific uses went up or down. This summary section highlights the major changes that occurred within each class of active ingredient (fungicides, herbicides, insecticides and other pesticides). The usage changes listed here are summed from changes in active ingredients listed in Tables 4, 7, 10 and 13, and they account for the bulk of the overall change in each category. Only those changes which may be attributed largely to a single factor have been included. For those changes that result from the interplay of multiple factors, or for more details regarding the changes listed here, the reader is referred back to the body of the report.

# A. <u>Fungicides (+2.2 million lbs.)</u>

- +6.0 million pounds to control new strains of potato late blight (chlorothalonil, copper, cymoxanil, dimethomorph, mancozeb, mefenoxam, metalaxyl, metiram, propamocarb, TPTH)
- +1.8 million pounds to control a worsening problem of algae in California rice (copper)
- +1.2 million pounds to control fungicide resistant sugarbeet pathogens (mancozeb, maneb, thiophanate methyl, TPTH)
- +0.4 million pounds in California due to higher rainfall and more disease pressure in: celery (chlorothalonil, DCNA); pears (triflumizole); spinach (maneb); and tomatoes (copper)
- +0.4 million pounds in tobacco to control fungicide resistant blue mold (dimethomorph, mancozeb)
- +0.4 million pounds in lettuce to control fungicide resistant downy mildew (fosetyl AL, maneb)

- +0.1 million pounds to control new fungal pests in: almonds (propiconazole); pistachios (tebuconazole); hops (myclobutanil, tebuconazole); and hazelnuts (chlorothalonil, copper, fenarimol)
- +0.1 million pounds as grape growers substituted a newly registered, less expensive fungicide with less visible residue (ziram) for an older fungicide (ferbam)
- -0.1 million pounds in soybeans due to more planting of early season varieties (thiophanate methyl)
- -0.2 million pounds in wheat due to more planting of disease resistant varieties (thiabendazole)
- -0.3 million pounds in sweet corn as a newly registered fungicide (propiconazole) substituted for an older fungicide (mancozeb)
- -0.4 million pounds in rice as a newly registered fungicide (azoxystrobin) substituted for older pesticides (propiconazole, benomyl, iprodione)
- -1.5 million pounds in peaches as newly registered fungicides (propiconazole, fenbuconazole) substituted for older products (benomyl, iprodione, thiophanate methyl, vinclozolin, triforine, captan, ferbam, sulfur)
- -3.0 million pounds in peanuts as newly registered, more cost effective fungicides (azoxystrobin, flutolanil, tebuconazole) substituted for older products (carboxin, chlorothalonil, PCNB)
- -3.7 million pounds in grapes as newly registered fungicides with lower use rates and longer residuals (triflumizole, myclobutanil, azoxystrobin) substituted for sulfur

# B. Herbicides (+7.2 million lbs.)

- +6.0 million pounds as a substitute for preplant tillage in: soybeans (2,4-D); sugarcane (glyphosate); corn (glyphosate, paraquat); and wheat (glyphosate, paraquat)
- +2.3 million pounds in corn as growers increased postemergence applications of atrazine in combination with newly registered herbicides (halosulfuron, rimsulfuron, thifensulfuron, nicosulfuron, prosulfuron, primisulfuron)
- +1.2 million pounds in soybeans to manage herbicide resistant weed species (acifluorfen, fomesafen, lactofen)

- +1.0 million pounds in apples as growers replaced older orchards with high density dwarf plantings (2,4-D, diuron, glyphosate, norflurazon, paraquat, simazine, oryzalin)
- +0.4 million pounds as substitutes for more costly hand weeding in: hot peppers (napropamide, metolachlor, sethoxydim, trifluralin); lettuce (sethoxydim, thiobencarb, imazethapyr); and sugarbeets (desmedipham, phenmedipham, ethofumesate, quizalofop, clethodim, triflusulfuron, clopyralid)
- +0.4 million pounds in canola due to a large increase in acreage planted (ethalfluralin, trifluralin, clopyralid, quizalofop, sethoxydim)
- -0.2 million pounds in alfalfa as growers substituted a newly registered herbicide (imazethapyr) for an older product (2,4-DB)
- -0.5 million pounds as substitutes for DCPA, which is no longer manufactured: broccoli (bensulide, oxyfluorfen); and onions (bromoxynil, oxyfluorfen, pendimethalin, bensulide)
- -0.5 million pounds in rice as substitutes for propanil to control resistant barnyardgrass (quinclorac, pendimethalin)
- -0.6 million pounds in cotton as growers substituted newly registered herbicides (pyrithiobac, bromoxynil, glyphosate) for older products (MSMA, DSMA)
- -0.9 million pounds in peanuts as a newly registered herbicide (imazapic) was substituted for older products (imazethapyr, paraquat, 2,4-DB, bentazon, vernolate, chlorimuron)
- -1.1 million pounds in sorghum due to a large reduction in planted acreage (atrazine)

# C. <u>Insecticides (+33.3 million lbs.)</u>

- +47.7 million pound increase in use of insecticides/miticides in Florida citrus as growers increased their use of oil as a cost saving measure and decreased their use of other products with lower application rates (aldicarb, diazinon, ethion, dicofol, formetanate HCl, fenbutatin oxide, methidathion, oxythioquinox)
- +1.8 million pounds in cotton insecticides targeted at boll weevils following the initiation of the Boll Weevil Eradication Program in parts of Mississippi, with an increase in malathion use and a decrease in the use of methyl parathion, azinphos-methyl, oxamyl and dicrotophos

- +1.0 million pound increase in carbaryl usage in wheat to control outbreaks of grasshoppers in Montana.
- +0.5 million pounds in apples due to increased insecticide resistance among codling moth and leafrollers (methyl parathion, chlorpyrifos)
- +0.4 million pounds in California citrus to control increasingly resistant populations of red scale (carbaryl, chlorpyrifos)
- +0.2 million pounds in soybeans due to more planting of early season varieties that reduce the need for late season insecticide treatments, but increase the need for early season treatments (tralomethrin, lambdacyhalothrin, methyl parathion)
- -0.1 million pounds in broccoli, cauliflower and lettuce as growers substituted the newly registered imidacloprid for the banned use of mevinphos
- -0.1 million pounds in peanuts as growers substituted the newly registered fenpropathrin for some propargite use
- -0.1 million pounds in grapes due to increased control of the western grapeleaf skeletonizer by biological control agents (carbaryl)
- -0.1 million pounds in sugarbeets due to reduced importance of adult sugarbeet root maggot flies in 1997 (chlorpyrifos)
- -0.2 million pounds in sugarcane as growers substituted the newly registered tebufenozide for azinphos-methyl
- -0.2 million pounds in grapes due to the use of the newly registered imidacloprid for leafhopper control as growers switched from older products (naled, endosulfan, methomyl)
- -0.3 million pounds in peanuts for white mold control as growers switched from chlorpyrifos to newly registered, more effective fungicides
- -0.3 million pounds in apples due to the use of newly registered products for mite control (clofentezine, hexythiazox, abamectin, pyridaben) as replacements for previously used products (propargite, fenbutatin oxide, formetanate HCl, oxythioquinox)
- -0.4 million pounds for aphid control in wheat due to reduced aphid infestation and the introduction of lambdacyhalothrin (methyl parathion, disulfoton)
- -0.6 million pounds in potato insecticide use as growers substituted the newly registered imidacloprid and abamectin for previously used active ingredients

- for Colorado potato beetle control (azinphos-methyl, cryolite, methyl parathion and phosmet)
- -0.6 million pounds in sunflowers due to decreasing damage from head-feeding insects (malathion, methyl parathion, ethyl parathion)
- -0.7 million pounds in cotton as growers substituted newly registered insecticides (imidacloprid, buprofezin, pyriproxyfen) for previously used products (fenpropathrin, acephate, methamidophos, dicofol, propargite) for control of sweet potato whitefly
- -1.0 million pounds in grapes as growers reduced cryolite applications due to residue concerns
- -1.4 million pounds in tobacco as growers substituted the newly registered imidacloprid for previously used active ingredients (acephate, aldicarb, chlorpyrifos, ethoprop, carbofuran)
- -2.2 million pounds in cotton insecticides targeted at bollworm/budworm following the introduction of Bt cotton (cypermethrin, esfenvalerate, lambdacyhalothrin, methomyl, profenofos, thiodicarb and tralomethrin)
- -5.8 million pounds in the use of soil applied insecticides in corn as growers increasingly used newly introduced active ingredients (chlorethoxyfos, tebupirimphos, tefluthrin, cyfluthrin) and reduced their use of older active ingredients (terbufos, carbofuran, fonofos, chlorpyrifos)

## D. Other Pesticides (+51.0 million lbs.)

- +30.8 million pounds in the use of sulfuric acid for potato vine desiccation, which assists in late blight control
- +6.2 million pounds in chloropicrin use in tobacco to manage increasingly problematic bacteria and other soilborne disease pathogens
- +4.0 million pounds in the use of cotton defoliants, boll openers and growth regulators to improve harvesting efficiency and quality (cyclanilide, dimethipin, ethephon, mepiquat chloride, thidiazuron, tribufos)
- +0.8 million pounds in metam sodium use in California tomatoes and cotton to replace costlier hand weeding

## VIII. Conclusions

Quantitative and descriptive analyses of pesticide use in U.S. agriculture in 1992 and 1997 illustrate the undeniable complexity of use patterns. Pesticide use patterns are driven by many biological, management and regulatory factors which continually fluctuate in relative importance from year to year. With these fluctuations come changes in both the types and amounts of pesticides applied. While gross generalizations about changes in pesticide use ignore the realities of crop production, the current analysis of observed changes in use of individual active ingredients on specific crops between 1992 and 1997 does reveal some recurring themes. Most factors that appear to account for major changes in pesticide use patterns can be grouped into nine categories: (1) weather changes, (2) pest population changes, (3) introduction of new cost effective pesticides, (4) regulatory changes, (5) economic factors, (6) changes in agronomic practices, (7) introduction of effective non-chemical controls, (8) voluntary changes to minimize environmental/residue concerns, and (9) shifts in crop acreage.

Weather changes have diverse effects on pest populations. For example, increased rainfall may benefit fungal and bacterial plant pathogens and therefore lead to an increase in fungicide use, while some insect pest populations may suffer from too much rainfall and therefore insecticide use decreases. The introduction of new pests, or new strains of pests already present, requires changes in pest management techniques, as will the development of pesticide resistance within existing pest populations. The increased efficacy of many new pesticide products as compared to older ones may mean fewer applications or less material applied per application or both, which results in decreased pounds on the ground. Regulatory changes such as cancellations or label changes will reduce use of the affected pesticides and likely increase the use of replacements. Because farmers are always struggling to produce a marketable crop while maintaining a profit margin, changes in the economics of production, such as pesticide prices, market orders and crop prices, will influence their decisions about which pesticide to use and how much. Changes in agronomic practices, such as crop residue management or cultivar

choice, may be brought about by regulation or by research, but either way they can alter pesticide usage needs. Implementation of effective non-chemical controls, such as biological control agents or genetically improved crops, can replace use of certain pesticides. Concerns about environmental effects of pesticide residues may also result in growers adjusting their management practices where feasible. Finally, even if the use of pesticides on a per acre basis does not change, if the acreage of a crop increases or decreases, overall pesticide use for that crop changes accordingly.

Of considerable interest to policymakers, regulators, legislators and the public is the extent to which public policies influence pesticide usage. A stated goal of the federal government in the 1990's was to reduce pesticide use substantially. Comparing aggregate pesticide usage estimates in NCFAP's 1992 and 1997 databases indicates that the amount of pesticide active ingredients used annually in U.S. agriculture increased by a total of 93 million pounds. However, it would be inappropriate to suggest that this indicates a failure of policies developed to reduce usage. Closer examination of the factors influencing change indicates that regulatory policies have led to reductions in pesticide use. One example is the expedited registration of new, more cost effective active ingredients. Lower application rates of many new products are needed to provide similar control benefits as compared to older products, which leads to a net reduction of pounds of pesticides used. Registration of new fungicides, herbicides and insecticides for peanuts, grapes, rice, peaches, sweet corn, cotton, alfalfa, potatoes, broccoli, cauliflower, lettuce, tobacco, corn, sugarcane and apples led to a net reduction of 17 million pounds of annual pesticide use between 1992 and 1997. Another example is the registration of genetically engineered cotton plants that contain insecticidal proteins from Bacillus thuringiensis. Their use led to an estimated annual insecticide use reduction of 2.2 million pounds.

However, other policies counteracted these reductions, and involved higher volumes of pesticides, thus negating the decreases in pesticide use. For example, expansion of the Boll Weevil Eradication Program led to an increase of 1.8 million pounds of insecticide use in cotton in the 1990's. Similarly, government programs that encourage farmers to

adopt limited tillage methods led to growers using 6.0 million additional pounds of herbicides annually in the 1990's.

One of the lessons learned from this study is that regardless of the effects of regulatory and farm policy on agricultural pesticide use, they can always be overwhelmed by other, sometimes unpredictable and uncontrollable, events, both natural and manmade. The emergence of a new virulent strain of the potato late blight fungus in the 1990's led to an annual increase of 37 million pounds of fungicides and desiccants. Depressed prices for processed oranges caused citrus growers to increase the use of a cheaper but higher use rate insecticide (oil) in lieu of synthetic chemical pesticides. This shift alone accounts for a net pesticide use increase of 48 million pounds.

Aggregate changes in pesticide use are combinations of increases and decreases, some the result of intentional manipulation, some the result of unforeseen circumstances. Add to that varying differences in pest, crop and region, and it becomes nearly impossible to generalize about trends in pesticide use. The NCFAP trends study recognizes this fact, and, by closely examining hundreds of instances of pesticide use changes, sorts out the influences of policy and regulatory changes from the effects of environmental and economic factors in an attempt to provide a better understanding of pesticide use in U.S. agriculture.

## IX. Caveats

The unit of measure used in this trends study is pounds of active ingredient. This measure has certain limitations due to several factors. First, there are certain active ingredients that are used at very high rates per acre on a very small acreage that can dominate the overall picture. Thus, a change of only a few thousand acres treated with an active ingredient used at 100 pounds per acre is equivalent to a change of millions of acres for products used typically at less than one pound per acre. Secondly, from a societal standpoint regarding risk concerns, not all active ingredients are equal. Thus, a pound of a relatively innocuous compound may not "count" as much in terms of concern as a pound of an active ingredient for which there are significant societal issues. In this report there is no weighting of poundage amounts according to any variability in risk. A final caveat is that a comparison between two years is not really a trends analysis; it is really a comparison of usage changes that occurred between the two years.

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