# THE ECONOMIC IMPACT OF THE SCHEDULED U.S. PHASEOUT OF METHYL BROMIDE


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# 1. Acknowledgements

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## 2. Introduction

Methyl bromide is a broad spectrum pesticide that is used to control nematodes, fungi, other pathogens, insects and weeds. Its primary agricultural uses include preplant fumigation of soils prior to planting; post-harvest fumigation of commodities while in storage, prior to shipment or upon inspection if warranted; and structural fumigation of processing facilities and warehouses.

Concern over the ozone-depleting properties of methyl bromide has led to announcements of phaseout schedules. The ozone layer provides protection from the harmful effects of certain wavelengths of ultraviolet (UV) light from the sun, specifically UV-B. Any significant decrease in ozone in the stratosphere would result in an increase of UV-B radiation reaching the earth surface. Increases in levels of UV-B radiation can result in the increase in skin cancers; suppress the immune system; exacerbate eye disorders and affect plants, animals and plastic materials.

The Montreal Protocol on Substances that Deplete the Ozone Layer was agreed upon in 1987 to set standards for reducing ozone-depleting substances worldwide. The Montreal Protocol limits the production and consumption of specific sets of ozone-depleting substances. One hundred sixty-seven countries, including the U.S., are now parties to the protocol.

An ozone depletion potential (ODP) index is used to gauge a substance's relative potential to deplete stratospheric ozone. The ODP represents the amount of ozone destroyed by the emission of a particular gas relative to chlorofluorocarbon-11 (CFC-11), a major ozone depletor. Substances with an ODP over 0.2 are considered class-I ozone depletors and are required to be phased out under the Montreal Protocol and the Clean Air Act.

In 1992, at the Fourth Meeting of the Parties to the Montreal Protocol in Copenhagen, an amendment to the protocol was added, listing methyl bromide as a controlled substance with an ODP of 0.7. Production and consumption of methyl bromide was to be capped in 1995 at 1991 levels, and an exemption for quarantine and preshipment uses was established [1]. Negotiations at subsequent meetings of the parties have resulted in further refinements of the regulations. At the Seventh Meeting of the Parties to the Montreal Protocol, the ODP of methyl bromide was revised from 0.7 to 0.6 [2].

When the scientific assessment of methyl bromide's ozone depletion for the Parties to the Montreal Protocol was issued in 1991, upon which the Copenhagen amendments were based, regulation of methyl bromide under the Clean Air Act was set in motion. Section 602(e) of the Clean Air Act states, "Where the ozone-depletion potential of a substance is specified in the Montreal Protocol, the ozone-depletion potential specified for that substance under this section shall be consistent with the Montreal Protocol" [3]. The Natural Resources Defense Council, Friends of the Earth and the Environmental Defense Fund filed a petition with the Environmental Protection Agency (EPA) to have methyl bromide listed as a class-I controlled substance and for production and consumption of methyl bromide to be phased out by 2000.

In December 1993, the EPA published its notice of final rulemaking, adding methyl bromide to its list of class-I substances under section 602 of the Clean Air Act. The ODP was listed as 0.7, as in the Montreal Protocol. Based on the lack of available substitutes in the near term, the longest possible period allowed for the phaseout under the Clean Air Act was adopted[1]. The EPA capped production and consumption of methyl bromide beginning on January 1, 1994, at 1991 levels and scheduled a complete phaseout by January 1, 2001, with no interim reductions. In addition, the EPA interpreted provisions of the Clean Air Act that might be understood to require labeling of produce treated with

[1] Section 602 (d) of the Clean Air Act states that "No extension under this subsection may extend the date for termination of production of any class-I substance to a date more than 7 years after January 1 of the year after the year in which the substance is added to the list of class-I substances." [3]

methyl bromide to exclude agricultural products [4]. Notably, the EPA phaseout did not allow any exemptions, which was a substantial difference between the U.S. and international phaseout schedules.

In October 1998, the U.S. Congress amended the Clean Air Act to harmonize the U.S. phaseout of methyl bromide with that under the Montreal Protocol. The Montreal Protocol schedule for reducing methyl bromide production and importation for the U.S. and other developed countries is 25% in 1999, 50% in 2001, 70% in 2003 and 100% in 2005 from a 1991 baseline. For the developing countries, there will be a freeze in 2002 at a 1995–98 baseline and a reduction of 20% in 2005 and 100% in 2015. The Montreal Protocol also allows preshipment and quarantine uses of methyl bromide and critical use exemptions after 2005.

The preshipment and quarantine exemptions mean that methyl bromide are not subject to the phaseout schedule and can still be used in the U.S. after 2005 to meet requirements of the U.S. and other countries to prevent the spread of exotic pests. Examples include imports of Chilean fruit to the U.S. in the winter months and exports of U.S. cherries and walnuts to Japan. The Parties to the Montreal Protocol have not yet agreed to a definition of “preshipment uses,” so it is unclear what other uses might be allowed, but treatment of raisins or walnuts consumed in the U.S. might not be. It is also unclear what uses might be eligible for critical use exemptions, but a lack of alternatives that are cost-effective and acceptable in terms of human health and the environment will be an important consideration.

The scheduled phaseout of methyl bromide resulted in a significant U.S. Department of Agriculture (USDA) research program to find alternatives. USDA spending for methyl bromide alternatives research increased from $7.4 million in FY1993 to $14.6 million for FY1998 [5]. In addition to USDA funding, methyl bromide alternatives projects have been funded by the EPA, state governments and commodity groups. Since 1994, an annual conference has been held for the purpose of disseminating current research on methyl bromide alternatives [6]. Proceedings are published concurrently with the conference and typically include 100+ research abstracts and posters.

The EPA has issued three volumes of case studies that describe alternatives to methyl bromide for specific uses [7]. A fourth volume is forthcoming. Compilations of information regarding methyl bromide alternatives have been issued by several groups, including the Bio-Integral Resource Center [8].

The extent to which available alternatives can serve as effective replacements to methyl bromide has been an extremely contentious issue. The USDA Agricultural Research Service issued a report analyzing the EPA case studies and concluded that most of the alternatives have not been shown to be technically and economically feasible when scaled up to commercial production levels [9]. Recent Congressional testimony from the Crop Protection Coalition, representing 35 agricultural organizations in the U.S., concluded that despite substantial investments in research, the research has not identified economically feasible effective alternatives [10].

In 1993, USDA’s National Agricultural Pesticide Impact Assessment Program (NAPIAP) issued an analysis of the economic losses to U. S. producers and consumers resulting from a ban on the agricultural uses of methyl bromide [11]. The annual losses were estimated to be $1.3 to $1.5 billion a year because of NAPIAP’s assessment that currently available alternative control practices are less effective or more expensive than methyl bromide.

The NAPIAP report was criticized for overstating likely economic consequences of the methyl bromide ban. One critique suggested that such a ban would not have the severe consequences predicted by NAPIAP [12]. The critique suggested that the NAPIAP report did not seriously consider effective nonchemical alternatives to methyl bromide. On the other hand, several grower groups thought the study underestimated impacts.

In 1997, the USDA's Economic Research Service funded the National Center for Food and Agricultural Policy (NCFAP) to conduct an aggregate economic impact analysis of the scheduled methyl bromide ban. The project was to be based on the numerous research experiments conducted since 1993 and on a thorough assessment of the practicality of alternatives – both chemical and nonchemical.

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## 3. Methodology

The primary purpose of the study is to estimate the economic impacts of the scheduled phaseout of methyl bromide for agricultural users. The economic analysis requires identification of the most cost-effective alternative. The two parameters that are used to identify cost-effectiveness are comparative yield and cost of treatment per acre. For each current use of methyl bromide, a compilation was made of available research that compares the performance of alternatives to methyl bromide. An extensive search of the published literature and conference abstracts was conducted and available literature was organized by use. In particular, experiments that included yield comparisons between alternatives and methyl bromide were the focus of the literature compilation. Experiments that only compared control efficacy and experiments that did not include a methyl bromide comparison treatment were of less utility.

The preference was for multiyear field trial data that included yield comparisons between methyl bromide and alternative treatments. However, for many crop uses of methyl bromide very few experiments were found even for a single year or trial: peppers, squash, ornamentals, nurseries, eggplant, cucumbers and watermelons. For these crops, it was necessary to assume that yield changes would be similar to crops for which experiments had been conducted, such as tomatoes and strawberries. Even in the case of tomatoes and strawberries, for which extensive experimentation has been conducted, it was not always possible to take experimental results directly as input to the economic analysis. For example, many experiments were conducted on plots that had been treated with methyl bromide for many years. While these plots might be representative of what is likely to happen in the first year following a methyl bromide ban, the results might not be representative of a long run, steady state. This steady state may not occur for a period of five to ten years following the adoption of an alternative technology. Using less effective alternatives may lead to pest buildups and pest shifts.

Most experiments were not repeated on the same plot of ground year after year. Thus, most yield change estimates could be based only partially on the experimental data and needed supplemental expert opinion to estimate the likely steady-state change in yields. In some cases, the most effective alternative from the research results is not likely to be used by growers following a methyl bromide ban. Thus, the second best alternative was selected. For California strawberries, for example, the most effective alternative was not selected because the general public would not accept its widespread use because of odor concerns. For Florida tomatoes, the most effective alternative experimentally was not selected because it has been less thoroughly researched and is dependent on favorable weather, which can increase its potential for failure.

The most cost-effective alternative also had to be registered for current use. Thus, methyl iodide, a highly efficacious alternative, is not currently considered a replacement because it is not registered for use and is unlikely to be available in the near future. Allowance was made for regional variations in the identification of the most effective alternative. For example, in Florida the most likely alternative for tomatoes currently is suspended from use in one important tomato production county. Thus, for that county, it was necessary to identify another alternative. Likewise, for California perennial crops, the most effective alternative varied depending on the individual crop and location. In addition, the most efficacious alternative was not always used in the perennial analysis because of current restrictions that limit its use.

Calculation of per-acre changes in treatment cost was more straightforward and simply required information on the rates of treatment per acre and average cost per unit of application.

For strawberries and vegetable crops, yield and cost changes were used as input into an economic model. This model has been used in a previous economic analysis of the scheduled ban on methyl bromide [1]. The model's input data on prices and shipments were updated as part of this project, and additional crops and states were added. The model was used to estimate changes in producer and consumer welfare likely to occur following a methyl bromide ban and takes into account changes in prices, location of production and imports.

For crops not included in the economic model (perennial crops and nurseries/ornamentals), short-run estimates of the aggregate economic effects of the methyl bromide ban were made considering the per-acre cost and yield changes on the acreage currently treated with methyl bromide, without taking into account any price changes. For postharvest uses, the increased cost of alternatives is calculated unless no alternative was available, in which case a diversion of products from export markets onto the domestic market was assumed, with an associated price change. In all cases, comparisons were made and differences explained between this study's economic impact estimates and those in previous studies.

This study does not include methyl bromide usage for forestry nurseries, structural purposes, treatment of exotic pest outbreaks, or imports.

Following the literature compilations, two briefing books were prepared – one for California and one for Florida. These briefing books summarized the research results and highlighted the parameters of interest for the study. Two workshops were held and attended by numerous university and USDA Agricultural Research Service researchers, as well as representatives of grower groups and related industries, who were asked to review the research compilations and to provide additional information on the cost and yield differences and constraints on the use of alternatives. The attendees at the two workshops are listed in Tables 3.1 and 3.2.

At the 1998 Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, NCFAP project staff presented preliminary results in three papers and one poster [2] [3] [4] [5]. In addition, NCFAP staff organized a symposium on preplant alternatives that included seven commodity group representatives who provided reactions to the preliminary NCFAP analysis.  The comments at the workshops and on the conference papers provided additional information that has been incorporated into the analysis.

Many experiments into alternatives and regulatory changes are likely to occur before the 2005 phaseout date.  These experiments and regulatory changes may dramatically change the likely economic impacts of the actual ban of methyl bromide.

The NCFAP study is based on what is available currently as alternatives and what is known now about the effectiveness and constraints on the use of alternatives.  Thus, the project simulates what the economic impact would be if methyl bromide were to be banned now.

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## 4. **Crop-Specific Analyses**

### A. Strawberries

#### 1. Introduction

With a value of over $900 million per year, strawberries are the fourth most valuable fruit produced in the U.S., following grapes, apples and oranges. Strawberry production accounts for nearly twice the value of pears, grapefruit and peach production combined [3]. For fruit sold in the fresh rather than processed market, strawberries are second only to apples in value [3]. Fresh strawberries account for the vast majority of production and crop value at nearly $800 million [107]. The top strawberry growing states are California and Florida, which collectively account for more than 90% of U.S. production. California alone accounts for nearly 80% of U.S. production. (See Table 4.A.1.) Strawberry production has been increasing in California and Florida in recent years, but declining in Oregon and other smaller producing states [3].

Although total U.S. strawberry acreage is nearly the same in the 1990s as it was in 1970, nearly three times as many strawberries are produced per acre [3]. More acreage in California, where per-acre yields are significantly higher (Table 4.A.1), and improved yields in other states raised the U.S. average strawberry yield from 9800 lb/acre in 1970 to 27,600 lb in 1993 [3]. In the early 1970s, Oregon had more acres of strawberries than California. Oregon grows strawberries primarily for the processed market. However, Oregon's acreage declined rapidly during the mid-1970s [3]. Increased supplies of frozen berries from Mexico, as well as expanding California production, brought low processing prices, and Oregon growers consequently planted less [3].

Strawberries are grown as an annual crop in California and Florida. First-year berries are superior to those of later years and are the most economical to harvest [17]. In California, most nursery plants are set out in October through November, though some plantings are made in July through September. Planting in Florida begins in September. Plants are replaced the following year. Strawberries are grown as a perennial crop in the Northwestern and most Eastern states. Strawberry plants can produce for four to five years before being replaced, though most are replaced after two production seasons in perennial production systems. Strawberry plants in California and Florida can produce fruit for six months or longer, rather than four weeks as in other states. Northwest strawberries are picked in June, and Florida strawberries are picked between December and March, but some berries are picked nearly every month in some areas in California. California production peaks from March through September.

The United States is the world's leading producer and consumer of strawberries. Because of increased domestic production, U.S. imports of fresh strawberries declined from 51 million lb to 31 million lb between 1970 and 1993 [3]. During the same period, U.S. imports of frozen strawberries dropped by nearly half, from 110 million to 57 million lb. At the same time, exports became more significant, climbing from 3% to 11% of supplies. U.S. consumption of fresh strawberries doubled from an average of 1.7 lb per person in 1970–72 to 3.6 lb per person in 1991-93 [3].

The focus of this chapter is fresh strawberry production, because of greater reliance of these growers on methyl bromide than those who grow strictly for the processing market.

### 2. California

Fresh strawberry production in California is located primarily along the Central and Southern Coasts with a small amount in inland areas. Strawberries are best adapted to the moderate temperatures that prevail in the coastal areas within 10 miles of the ocean [4]. About two-thirds of the total acreage is planted in the Central Coast and Santa Maria Valley, and about 30% is planted in the Oxnard Plain and South Coast production areas. The small acreage of the San Joaquin Valley makes up about 3% of the total. The average strawberry farm in the Watsonville/Santa Cruz area of the Central Coast is 73 acres, and approximately 70% of the strawberry farmers in this area grow only strawberries [5].

Specific planting and harvest seasons vary from one growing area to another. Summer plantings usually are made in mid to late summer and “winter” plantings from mid-October to early November. The principal advantages of winter planting systems are that they provide early fruit, have more even fruit production, yield higher quality fruit, and are less costly than summer planting systems. Almost all strawberries are winter plantings in Southern California, where early fruit is of primary economic importance. In Central Coast areas, winter plantings are used for day-neutral cultivars, which usually do not produce fruit of acceptable quality when grown as summer plantings [4]. Only summer plantings are grown in the San Joaquin Valley [4]. Overall, summer plantings account for 5% of total acreage and winter plantings 85%. Nine percent of total acreage is in the second year of a perennial production system [69].

All strawberry plantings are made with transplants from either high-elevation nurseries in the intermountain valleys of Northern California or low-elevation nurseries in the Sacramento and San Joaquin valleys [4]. Strawberry plants have a chilling requirement similar to that of many deciduous fruit trees [18]. If the chilling requirement is satisfied completely during the winter, normal growth cycles occur [18]. Transplants for winter plantings are grown in high-elevation nurseries where temperatures are low enough in the fall to provide the required chilling [4]. Transplants are harvested in October and planted in fruit beds immediately or after one to two weeks of cold storage [4]. Transplants used for summer plantings are grown in low-elevation nurseries and are planted in mid-April or early May. The strawberry transplants are harvested in December or January when they are as dormant as possible and held in cold storage until they are planted the following summer [4].

The strawberry production system that is followed by the majority of California producers has been described by Marsh et al. and consists of a complex sequence of operations, as follows [5]:

The soil is plowed, disked, tilled, leveled, and sprinkle irrigated. Lime or gypsum is sometimes broadcast and incorporated. The soil is then fumigated with a mixture of methyl bromide and chloropicrin and sealed with a plastic tarp. The most common method is flatbed fumigation where fumigant is applied to the entire field before beds are formed [4].

California regulation requires that tarps remain in place for five days to reduce emissions, after which time the tarps are removed and disposed of, raised beds are shaped and the drip tape irrigation system is installed. Virtually all strawberries in California are grown with drip irrigation. The strawberry plants are transplanted at least two weeks after fumigation to insure that no phytotoxic residues of the chemicals remain. Strawberry root development and plant nutrition are enhanced as long as the proper waiting period is observed [4].

Plastic mulch is then placed over the beds. Clear plastic mulch is used primarily in the Southern production region, while Central Coast growers may use clear, black, white or green plastic. A special burner is used to heat a metal cylinder that punches a hole in the plant row over each plant, and the plants are pulled through the holes. Slots for planting the transplants into the beds are opened and closed by machine, although the plants are transplanted by hand. Beds are sprinkler irrigated before and after planting. Slow-release fertilizers are often placed in the center of the beds before transplanting. Liquid fertilizers are later applied through the drip system.

Fumigants may also be applied to formed beds that are immediately covered with plastic mulch that is sealed with a layer of soil at the edges [4]. Bed fumigation lowers costs by reducing the amount of plastic and fumigant used, as only part of the field is treated and the plastic tarps applied during fumigation remain in place, instead of being removed and replaced. After a waiting period of at least three weeks, transplants are placed through holes cut in the plastic [4].

The use of clear plastic mulch allows sunlight to heat the soil, stimulating growth and fostering early yield [4]. The plastic reduces decay problems by limiting fruit contact with the soil. Preplant weed control is critical because clear and translucent plastic mulches do not control weed growth [4]. Insect and disease control measures are taken on a regular basis during the growing season, and herbicides are occasionally used [5].

Soil fumigation with methyl bromide+chloropicrin is the single most expensive pest control operation for strawberry producers. Most growers hire a custom applicator to perform fumigation. The cost to the grower is estimated at $1580 per acre [108].

*Historical Pest Control Practices*

Soil fumigation with combinations of methyl bromide and chloropicrin has been an integral part of strawberry cultivation in California since about 1960 [7]. Starting in 1950, strawberries in California were produced almost entirely from cultivars developed by the University of California and Driscoll Strawberry Associates. Although the yields of these cultivars occasionally reached 40,000 or even 60,000 lb/acre, the state average for the period from 1950 to 1960 ranged from 10,000 to 12,000 lb/acre [7]. The yield potential of the new cultivars was far from being realized. One source of strawberry yield losses was verticillium wilt, a disease caused by the fungal pathogen *Verticillium dahliae*. In the period before fumigation became a common practice, growers constantly searched for new land in order to avoid plantdiseases. Generally, land on which tomatoes had been grown within the previous ten years was disqualified. Land previously cultivated for potato or cotton production was also linked to disease problems in subsequent strawberry crops. Strawberry growers often retreated from the Coastal valleys to outlying foothill areas that usually had not been cultivated but were otherwise not as suitable for strawberry production [7].

Although *Verticillium* was identified as a pathogen of California strawberries as early as 1931, no methods were available for its control until research with chloropicrin began in the late 1950s. In a 1956 experiment, 480 lb/acre of chloropicrin was found to control verticillium wilt in strawberries and to double yields [7]. During 1957 and 1958, the idea of mixing chloropicrin and methyl bromide was tested. The first experimental results, reported in 1961, indicated that methyl bromide not only augmented the fungicidal properties of chloropicrin, but also gave excellent weed control [8]. Chloropicrin and methyl bromide are believed to act synergistically. Early experiments indicated that an application rate of 200 lb/acre of chloropicrin failed to control verticillium wilt [17]. The same was true for methyl bromide. A mixture composed of equal parts of chloropicrin and methyl bromide at 200 lb/acre of each provided nearly complete control of the disease in a wide variety of soil types [17]. The fumigant mixture required immediate covering of the fumigated soil with polyethylene film, which is not necessary after the application of chloropicrin alone [7].

Since about 1965, approximately 90% of strawberry land in California has been fumigated before each crop is planted [7]. Growers who do not fumigate are generally growing perennial plants or are producing for the processing or organic markets. Statewide average strawberry yields tripled following the adoption of fumigation. In addition, soil fumigation made available lands that previously had been avoided for strawberry cultivation. These were the rich, fertile alluvial lands with long crop histories and fungal infestations [17].

The important role of fumigating strawberries was recognized by the National Academy of Sciences in their 1989 study Alternative Agriculture [9]:

> In California the use of methyl bromide and chloropicrin soil fumigation resulted in huge increases in yield and quality for several crops. The combination is widely credited with saving the strawberry industry from high production costs and foreign competition.

Generally, the increase in strawberry yield is credited to effective control of verticillium wilt with chloropicrin [7]. Weed control has been an important benefit of fumigation with methyl bromide; the need to hand weed and cultivate strawberry fields has been reduced greatly. Effective weed control by fumigation made the practice of covering plant beds with clear polyethylene film possible, which speeds crop growth. By eliminating cultivation for weed control in the plant row, fumigation also has made possible the use of drip irrigation [7].

*Target Pests*

The major pests that methyl bromide+chloropicrin is used to control are soilborne diseases and weeds. Verticillium wilt is the most troublesome disease for strawberry growers. Verticillium wilt is a soilborne fungal disease, caused by *Verticillium dahliae*, which attacks the water-conducting tissue of the plant. Infected plants wilt, and outer leaves dry and turn brown. Infected plants often collapse during the peak of the first year's growth [19]. Eventually the entire plant wilts and dies. The fungus has been known to carry over in the soil for 25 years [18]. Verticillium wilt is controlled by preplant soil fumigation, but the soil population of fungi is only reduced and not eliminated by each treatment [22]. Preplant soil fumigation also controls other soilborne fungi and related diseases such as phytophthora root and crown rot, anthracnose, black root rot and charcoal rot.

Fumigation not only controls lethal pathogens, but also provides control of a highly variable complex of sublethal competitive soil organisms, such as *Pythium* spp. [23]. As a result there is an increased growth response:

> The full explanation of this growth response still eludes investigators, but research continues to point to elimination of certain *Pythium* spp. that may otherwise act as inducers of crop phytostasis, possibly even without being parasitic [7].

Research is currently under way to try to identify microbiological differences associated with the enhanced growth and productivity of strawberries in soils fumigated with methyl bromide+chloropicrin where the response is not due to control of major known pathogens [77]. Plants in fumigated soils normally have higher root length densities and fewer dark roots than plants in nonfumigated soils. Total amounts of fungi are usually low for several months following fumigation [77]. The research suggests that reductions in deleterious fungi and increases in beneficial soil microorganisms contribute to the enhanced growth response of strawberry to soil fumigation with methyl bromide+chloropicrin [77].

Methyl bromide is an effective herbicide, providing control of numerous weed species such as pigweeds, lambsquarters, shepherds purse, yellow oxalis, purslane, groundsel, hairy nightshade, common chickweed and spurge. Certain hard-seeded weed species are not controlled with methyl bromide fumigation: field bindweed, little mallow, burclover, sweet clovers and filaree.

Soil fumigation with methyl bromide+chloropicrin also controls certain arthropods such as root weevils, cutworms, strawberry rootworms, white grubs, garden symphylan and brown mealy bug, as well as nematode species including foliar nematode and northern root-knot nematode [4] [7]. The larvae of several soil insect pests can cause plant injury by feeding on strawberry roots. Plants wilt, the foliage turns reddish brown and the fruit becomes small and seedy. Injured plants often die [18]. Although nematode species are pathogenic to strawberries, nematodes rarely have been established in sizable populations in strawberry production areas [16] [20]. There have been occasional outbreaks in

California strawberries, but essentially nematodes have disappeared from strawberry production areas largely because of annual methyl bromide+chloropicrin fumigation [20].

*Alternative Fumigants*

Since the 1980s, University of California researchers have been experimenting with various alternative soil fumigant treatments to test for yield enhancement, disease control, growth responses and weed control in strawberry production. These research experiments have been described in regular progress reports and presentations at scientific meetings [36] [37] [38].

Recently, meta-analysis statistical techniques were used to analyze and compare results from 45 separate experiments, representing 11 production seasons and three different locations that tested the performance of alternative fumigants [35]. The treatments included in the meta-analysis are the following: methyl bromide+chloropicrin, 1,3-D+chloropicrin, chloropicrin at both high and moderate rates, metam sodium, and untreated. The analysis included the available multiyear studies that compare yields in the first, second and third years of successive use of alternative treatments. Multiyear studies permit the evaluation of treatments as pest populations build up or shift over time under continued use of a particular treatment. The results of this analysis are presented in Table 4.A.3.

The data suggest that in the untreated plots, strawberry yields were about 37% lower than in the methyl bromide+chloropicrin plots in the first year, with the loss increasing to 60% by the third year. The treatment that consistently resulted in the highest yields was a high rate of chloropicrin per acre (≥ 300 lb/acre). Yield losses in the first year following a switch from methyl bromide+chloropicrin to chloropicrin alone were small (2.2%), but in the second and third years, yield reductions increased to 9.6 and 12%. A shift to a new equilibrium soil status will not occur in a single cultivation cycle [34]. When moderate rates of chloropicrin were used alone, yield losses were at 13.3% in the first year. Since all of the studies using a moderate rate of chloropicrin alone were single-year studies, no results were available showing the yield losses over time.

Yield results from plots treated with combinations of 1,3-D+chloropicrin were similar to those in plots treated with a low rate of chloropicrin alone [35]. This would imply a lack of synergy between 1,3-D and chloropicrin, as opposed to the apparent synergy that exists when using methyl bromide+chloropicrin, where yield increases using a combination of methyl bromide and chloropicrin were greater than those resulting from using either material alone.

In general, yield differences between the plots treated with either methyl bromide+chloropicrin, chloropicrin alone or 1,3-D+chloropicrin were not found to be related to differences in the incidence of disease or nematode problems [36] [37]. Rather, the higher yields in methyl bromide+chloropicrin–treated plots were attributed to overall differences in plant growth and vigor [37]. Many strawberry plants in the metam sodium and unfumigated plots exhibited stunted growth characteristics [39].

Another chemical fumigant that has been included in several research trials is dazomet (Basamid). Strawberry yields in plots treated with dazomet were 87%, 76% and 66% for high, medium and low application rates, respectively, relative to yields from plots treated with methyl bromide+chloropicrin [10]. However, dazomet is not currently registered for use in strawberry fruit production, though it is registered for nonfood uses. No experimental use permit was available for the 1998–99 growing season [82]. However, BASF, the manufacturer of Basamid, submitted a registration package to the EPA in June 1997 [109].

Field-scale research trials have been conducted to evaluate the most promising treatments from small-scale tests under more realistic production conditions. The California Strawberry Commission, in cooperation with USDA-ARS, supported five on-farm trials in 1996–97 and nine trials in 1997–98. Trials were conducted in all major production areas, using standard grower practices. Average yields from plots treated with chloropicrin, Telone C-35, and dazomet over two years of trials relative to methyl bromide+chloropicrin were 95, 95 and 90%, respectively [82].

The results of small and large plot research to date indicate that treatments using a high rate of chloropicrin or a combination treatment of 1,3-D+chloropicrin would be the best alternatives to methyl bromide+chloropicrin. However, it is unlikely that either of these treatments would be available for use by all strawberry growers. Public concerns over the odor associated with using high rates of chloropicrin are expected to lead to limits on maximum application rates that are much lower than the rates used in most of the research trials [78] [91] [92]. Indeed, Monterey and Santa Cruz Counties have issued interim guidelines for the use of chloropicrin, limiting the rates that may be used in the buffer areas around occupied structures where methyl bromide may not be applied [110] [111]. The availability of 1,3-D is also limited to a maximum amount that may be applied within each township. Approximately half of the strawberry acreage would not be allowed to be treated with 1,3-D under the current township restrictions.

The limitations on chloropicrin and 1,3-D have led researchers to look more carefully at combinations of materials that may prove effective. One combination that has looked promising is the use of a low rate of chloropicrin with Vapam. Trials conducted in Irvine during the 1997–98 growing season compared treatments of chloropicrin+Vapam to a methyl bromide+chloropicrin standard. The chloropicrin+Vapam plots had marketable yields that were 94 to 96% of the methyl bromide+chloropicrin plots, though the yield differences were not statistically significant [78]. An analysis of the results of 10 trials showed that the combination of chloropicrin+Vapam resulted in a significant yield increase compared to treatments of either chloropicrin or Vapam alone. However, yields using chloropicrin+Vapam were significantly less than yields using methyl bromide+chloropicrin [78]. The inclusion of Vapam in a combination treatment should improve weed control over the use of other fumigants alone.

Another combination treatment that has been tested recently is the use of 1,3-D+chloropicrin with dazomet. During the 1997–98 season, trials were conducted on 96 acres to compare a combination of Basamid and Telone C-35 to the methyl bromide+chloropicrin standard. Yields, growth promotion and weed control were comparable between the treatments in three of the four plots evaluated [81]. However, the application methods used for Basamid in these trials did not conform to those stipulated in the experimental use permit for Basamid.

Recent research has also focused on application of 1,3-D through drip irrigation systems that would reduce application rates and costs [93]. A reduction in application rates would increase the number of acres that could be treated under the current township restrictions on 1,3-D. Drip application methods may also reduce emissions of 1,3-D from treated fields, which might allow easement of the township restrictions. In the 1997 trials, which included very high *Verticillium* pressure at one of the two sites, the use of 1,3-D+chloropicrin applied through the drip irrigation system produced marketable yields 48 to 87% of yields using methyl bromide+chloropicrin [49] [93]. During 1998, plots treated with drip-applied 1,3-D+chloropicrin combination produced 92 to 115% of yields from the standard use of methyl bromide+chloropicrin treatments [93].

The emulsified concentrate version of Telone C-35 is not currently registered for use, but will be marketed under the trade name InLine. InLine recently received a federal experimental use permit that will allow California strawberry growers to treat up to 800 acres during the 1999–2000 season [113].

*Herbicides*

Annual weeds are the primary weed problem in California strawberry production. These develop mainly during the rainy season or appear in the new plantings when the beds must be kept comparatively wet so the plants can become established. The weeds would take over in the absence of fumigation [29]. Weeds thrive under the clear polyethylene used in Southern production areas if fields were not fumigated, and hand labor for weed control under the plastic is extremely costly [12]. Opaque black plastic can control weed growth in the planting bed although weeds do emerge through the plant holes. However, black mulch delays fruit production, which may cause growers to miss market windows, and fruit burn is a potential problem when temperatures are above 90°F [4].

The research on alternative fumigants has focused on the problem of controlling soilborne diseases. To facilitate this comparison, the plots are hand-weeded on a regular basis in order to remove the effects of uncontrolled weed growth on strawberry yields, and data on weed control are not generally recorded. Without additional control practices, the amount of hand weeding that would be required in fields treated with fumigants that do not provide weed control equivalent to methyl bromide is expected to increase substantially. The amount of labor required for handweeding acreage treated with various fumigants is shown in Table 4.A.4.

Weed control options for strawberry growers other than hand weeding are limited. Historically, three herbicides were used in strawberry plantings in California: chloroxuron (Tenoran), diphenamid (Enide) and DCPA (Dacthal). Weed control ratings indicate that combinations of these three herbicides would control the same weed species as methyl bromide+chloropicrin [29]. DCPA has to be applied immediately after transplanting, before weeds germinate, while chloroxuron and diphenamid were used two to six weeks after planting [29]. However, none of these herbicides are available today. Chloroxuron and diphenamid were canceled voluntarily by registrants in the 1980s. And recently the manufacturer of DCPA discontinued its production in the U.S. because of concerns regarding air pollution emissions from its factory. There is interest in locating a facility outside the U.S. to restart production.

At this time, only three herbicides are available for use in strawberries: napropamide, sethoxydim and paraquat. Napropamide (Devrinol) is registered as a selective pre-emergence herbicide for use in newly transplanted strawberries [27]. To be most effective, napropamide must be applied before plastic mulch is laid over planting beds so it can leach into the upper few inches of soil [4]. Napropamide is not registered for use as a preplant incorporated treatment, however. Napropamide is currently used to control weeds that are not killed by fumigation. Napropamide does not provide control of pineappleweed, burning nettle and yellow nutsedge, all of which are controlled by methyl bromide+chloropicrin fumigation [11]. When strawberries are grown on sandy soils, maximum label rates of napropamide have caused strawberry runner inhibition and some reduction in the development of the strawberry plant [11].

Sethoxydim (Poast) is a systemic grass herbicide that can be applied to control grass weeds after they have emerged in strawberries [11]. Sethoxydim application is very safe for strawberries as it has no activity on dicotyledons [28]. The nonselective herbicide paraquat can be used in the row prior to planting strawberries and will kill emerged weeds. Paraquat can also be applied with a shielded sprayer during the growing season to control emerged weeds between rows.

Current estimates of the extent of weed control practices in California strawberries are shown in Table 4.A.2.

Many herbicides and herbicide combinations have been tested for preplant and postplant application within strawberry rows [30]. However, most herbicides have proven to be phytotoxic to strawberry plants [12]. Registration for several nonphytotoxic herbicides have not been pursued. For example, although the herbicide oxadiazon works well to control weeds in strawberries, registrations of food uses have not been pursued by the registrant [59].

Recently weed science researchers at the University of California have been asked by the California Strawberry Commission to screen new herbicides for safety and weed control efficacy in strawberries. This project will determine if any of eight new highly active herbicides (carfentrazine, cloransulam, dimethenamid, halosulfuron, imazamox, rimsulfuron, sulfentrazine and triflusulfron) could potentially be used on strawberries [55].

There are several ongoing projects through the USDA IR-4 program, which subsidizes research toward registering pesticides for minor crops. Many of these herbicides, however, are likely to be restricted to perennial strawberry production areas for application during postharvest renovation or dormant periods [56]. The concern with a registration in an annual production system is the shortened treatment interval to harvest – the herbicide would be applied when the berries are growing with a possibility of damage to the fruit. The herbicides that are in the IR-4 testing program at this time for strawberries are clopyralid, acifluorfen, oxyfluorfen, glyphosate, metolachlor and pendimethalin. Acifluorfen has a federal tolerance established for strawberries; however, the registrant has not put strawberries on the label. Both acifluorfen and clopyralid have been tested under California conditions [27].

*Insecticides*

Soil insect pests were serious problems in California strawberries before soil fumigation became a standard practice [41]. Several arthropod pest species can be problems for strawberries in California: root weevils, rootworms, white grubs, garden symphylan and ground mealybug. Adult weevils, which are nearly all females, lay their eggs around the strawberry plant. After hatching, weevil larvae work their way into the soil and feed on strawberry roots, which can destroy small rootlets completely and damage the bark and cortex of larger roots [11]. Plants that suffer this type of damage wilt because their roots no longer can provide moisture for leaves. Generally, root weevils become serious as a result of successive and intensive cropping. When the same planting is fruited over several years, insect numbers increase [33].

Before modern pesticides were developed, most strawberry insect pests were extremely difficult or impossible to control. Chlorinated hydrocarbons, such as DDT, aldrin and dieldrin were first used in the 1950s. They gave excellent, long-lasting, inexpensive control of insects such as root weevils, white grubs and strawberry rootworm [16]. However, since these chemicals were banned in the early 1970s, strawberry growers have not had a registered insecticide that will control the larvae of these pests [11]. Diazinon is registered but is not effective [11].

In California, the use of methyl bromide+chloropicrin mixtures has largely eliminated soil insect pests. There have been no significant outbreaks of these insect pests in fumigated strawberry fields in recent history [32]. As a result, no research has been conducted in California targeted at the use of alternative insecticides or other methods for control of the soil insect pest problems. If soil pests become a problem without fumigation, growers will likely use registered insecticides in season [41]. Control achieved by these applications is believed to be lower than that currently achieved, and it is probable that multiple applications would also be necessary [41].

*Biological Control*

USDA ARS researchers are undertaking strawberry experiments with several biological control products, including DiTera, a biological nematicide labeled for use on citrus, grapes, cole crops, ornamentals, and annual crops. DiTera (also known as ABG-9008) was discovered at Abbott Laboratories in 1987. DiTera is produced by the fermentation of a fungus, originally isolated from a cadaver of the soybean cyst nematode. The active ingredient is a microbial composition containing fermentation solids and solubles of the fungus [60]. DiTera kills nematodes on contact and, depending on its concentration, inhibits hatching of plant parasitic nematode eggs. The product can be incorporated into the soil, either mechanically or with water, prior to planting, at emergence, or as a postplant treatment [60].

Research is also underway utilizing plant growth promoting bacteria. Over one hundred bacterial strains that have been known to promote growth in some crop plant are being tested for their ability to increase vigor in strawberry transplants. Strains that do increase vigor will be tested for ability to induce resistance to specific diseases [42]. Strawberries may be an ideal candidate for biological control of root diseases because the plants are transplanted. This provides a ready opportunity to colonize the roots with biological control agents [14].

A recent study evaluated the potential of combining chemical fumigants with biological control agents to increase strawberry yields [73]. The biological control agents *Pseudomonas fluorescens* and *Bacillus cereus* were applied to plants grown in fumigated soil. No effect could be attributed to the application of the biological control agents. The agents did not have an effect on yield in the nonfumigated plots [73].

*<u>Crop Rotation</u>*

The simplest approach to management of soilborne disease through cultural practices is long-term rotations to nonhost crops. Under these rotations, *Verticillium dahliae* is unable to reproduce as it would in a systemically infected host such as strawberries, so infestation levels steadily decline due to attrition [43]. Published reports suggest that rotations as long as five to seven years out of a susceptible crop such as strawberries may be required to prevent significant damage to a subsequent planting of a host crop [43].

An experiment conducted in Watsonville compared various rotations on nonfumigated ground that had high populations of *Verticillium*. Strawberries were planted after either two crops of broccoli, a cover crop of rye or a previous crop of strawberries. The one-year broccoli rotation increased yields in the following strawberry crop by 24%, while yields following a year of rye increased yields by 18%, compared to a continual strawberry rotation. Researchers concluded that broccoli or rye rotations are beneficial but only partially compensate for a lack of fumigation [36]. The feasibility of rotating out of strawberries in the Watsonville area is limited by the lack of available land. An acre of prime farmland in Wastonville sells for $25,000, and rents for about $2000 per year [44]. Land rents are generally higher in the South Coast production region.

*Solarization*

Solarization techniques use clear plastic mulch to heat soil to temperatures high enough to kill soilborne pests [15]. A period of at least six weeks during the warmest part of the year is usually necessary to achieve the degree of heating throughout the root zone [4]. Solarization increases soil temperature to as high as 140°F [76]. Infestation levels of most soilborne pathogens can be reduced by solarization, though the pathogens that cause charcoal rot and black root rot are not controlled. Most soil-dwelling arthropods controlled by soil fumigation are also controlled to some extent by soil solarization [4]. Other pests may not be effectively controlled due to their ability to avoid the treatment by moving deeper into the soil or migrating from soil depths not affected by the treatment.

Solarization could be practical for fresh strawberry production in the San Joaquin Valley, which accounts for approximately 3% of total fresh strawberry production acreage and where temperatures are sufficiently hot for it to be effective [15]. Solarization also has some potential for strawberries grown in Southern California around Irvine because the crop is grown as an annual with a summer fallow period, followed by a fall planting through clear plastic mulch [14].

Two studies have been conducted to test solarization in the Southern Coastal region. In the first study, fresh strawberry yields in the solarized plots were similar to those in the plots treated with methyl bromide+chloropicrin [14]. However, the methyl bromide+chloropicrin treatment was applied through drip tubes instead of with the standard practice of shank injection, which may have lowered yields. In the second study, also conducted at Irvine, an eight-week bed solarization treatment was compared to methyl bromide+chloropicrin application on land that had not been planted to strawberries for 20 years. Yields from the solarized plots were 19% lower and required twice as much hand weeding time as the plots treated with methyl bromide+chloropicrin [40].

Despite some promising results from research for Southern California strawberry growers, solarization is generally not considered a viable option for several reasons. Growers may not have enough time for an effective solarization treatment before planting, depending on the cutoff date for the previous crop, which is often dictated by market conditions.  Weather conditions might not be conducive to an effective treatment every year, so there is an additional risk factor for growers who might choose to solarize in the Southern Coastal areas.  Solarization is not an option in Central Coast fields located close to the ocean where clouds, fog and wind prevent adequate soil heating [4].

*Crop Breeding*

The success of soil fumigation in controlling soilborne diseases of strawberries resulted in discontinuation of commercial breeding for verticillium wilt resistance in the 1960s [17]. Breeders concentrated instead on breeding for fruit quality characteristics [21].  Recently, researchers have returned to investigating the feasibility of using genetic resistance to disease organisms as an alternative to methyl bromide+chloropicrin fumigation [45]. Research in artificially infested soil under greenhouse conditions has revealed marked differences in levels of resistance to disease pathogens among strawberry cultivars [45]. The researchers have cautioned that the level of resistance in the tested cultivars may not be equal to the disease-countering impact of methyl bromide+chloropicrin preplant soil fumigation for commercial strawberry production in California [45].  Field research suggests that only the most resistant genotypes are likely to survive high soilborne pathogen concentrations in the production fields [22].  Even with these cultivars, the levels of stunting and mortality suggests that the economic viability of the most resistant California genotypes under field conditions with very high levels of pathogen infestation may not be possible [22].

Recent efforts to improve strawberry performance in nonfumigated soils through genetics and breeding have emphasized the need for reducing plant mortality due to lethal pathogens and obtaining enhanced tolerance to the sublethal or competitive effects of soil organisms [46]. Since the sublethal soil organisms can reduce strawberry yield by 50% or more, they will remain an obstacle to strawberry production in nonfumigated soils even if cultivars are developed with significant resistance to known lethal pathogens [46]. Research to date documents that little opportunity exists within the University of California strawberry germplasm for developing cultivars specifically adapted to the unspecified reductions in performance commonly observed for strawberries grown in nonfumigated soils [47]. Furthermore, when evaluated in California, the best strawberry genotypes obtained from other states produced, at most, 50% of the yield of modern California cultivars [47]. Nonetheless, it is expected that resistant varieties will become more valuable when less effective pesticides are used, as plants will be exposed to higher levels of disease-causing pathogens.

### *Greenhouse Production*

The Netherlands has phased out methyl bromide and developed a greenhouse strawberry production industry [15]. Plants are grown on artificial substrate on hanging shelves in greenhouses or on raised shelves outdoors. The roots and runners do not contact soil and thus soilborne diseases and pests are reduced. Planting densities in greenhouses are doubled by hanging each tightly spaced row from cables attached to winches. Alternate rows are then raised and lowered to gain access for tending or harvesting [15]. These systems have high fixed and variable costs. A greenhouse typically costs $5 million to $8 million per acre [15]. However, yields are higher than that of California's best conventional growers. Research with greenhouse growing of California strawberry cultivars is on-going at USDA's ARS Fruit Research Station in Kearneysville, West Virginia [80].

*Organic Amendments*

One strategy for controlling populations of soilborne pathogens is the use of organic soil amendments. One type of amendment that has been investigated is broccoli plant residue. Decomposition of residue derived from broccoli plants has been shown to produce volatile compounds that are toxic to a broad range of fungi [43]. Another approach is the incorporation of compost, which may control pathogens by establishing a complex food web of suppressive micro-organisms [10]. However, three years of experimentation in replicated field plots with high rates (25 tons per acre) of compost and broccoli mulch have not demonstrated reduced pathogenicity or enhanced strawberry plant performance in comparison to untreated soil [48]. The results suggest that disease suppression may occur in the early season but is not long lasting enough to prevent yield reduction [48]. A detrimental impact may be a phytotoxic effect of broccoli decomposition on strawberry plants [48]. One striking result of the research was the difference in weeding times between the fumigated and composted/mulched plots. Weeding time for the organic plots was approximately five times greater than weeding time required in the fumigated plots [10].

Four yield trials with soil treatments of shredded broccoli plants showed that while pathogenicity of soils is somewhat reduced, a single application of shredded broccoli is not sufficient to maintain roots pathogen-free into the season [72]. In these plots, yield was significantly reduced over methyl bromide+chloropicrin fumigation and usually only slightly better than untreated soil without fumigation. This result was consistent for the entire four-year period of these trials, with broccoli mulch incorporated into beds on previously fumigated soil, fallowed soil, soil cover cropped for one and two years prior to planting, and broccoli residue with and without high rates of compost. None of the conditions of these studies yielded significant disease reduction or significant yield increases to the extent necessary for commercial adoption with California strawberries [72].

In 1997–98 experiments, the use of compost resulted in strawberry yields that were 32% of the yields obtained with methyl bromide+chloropicrin [78].

*Organic Production*

The adoption of organic production practices that may incorporate several of the nonchemical pest control techniques described previously is considered a potential alternative to the use of methyl bromide+chloropicrin. Currently, less than 1% of California strawberries are organically grown. Organic growers do not use methyl bromide nor any other synthetic pesticides or fertilizers, so differences in yields are due to many factors, not only the lack of fumigation. However, organic strawberry growers do use transplants produced using methyl bromide+chloropicrin. Yields in organic production are about 65% that of conventional production but may vary widely [15]. One organic strawberry producer reported that organic yields were 70% below conventional yields of California strawberries [74]. Organic fruit generally earns a higher price, and this offsets the lower yield and higher production costs [15]. Organic strawberry prices remain higher by as much as double the retail price of conventional strawberries [71].

The lower yields obtained by organic growers have several causes. One reason is the lack of the "nonspecific yield increase" that results from fumigation with methyl bromide [15]. In addition, since organic growers do not use in-season applications of insecticides or fungicides, fruit sometimes is lost to uncontrolled foliar/fruit diseases and insect/mite pest species.

One example of a successful organic strawberry producer is Swanton Berry Farms in the Central Coast area of California where strawberries have been grown profitably without methyl bromide since 1986 [24]. Strawberries are rotated with other crops on small plots around the farm in order to avoid accumulation of diseases in the soil [26]. Strawberries are planted only once every four to five years on any one piece of land [15]. Although the farm has a history of relatively disease-free ground, strawberry yields are approximately 20% lower than industry norms for conventionally grown strawberries [26].

Swanton Berry Farms was the site of a three-year university sponsored on-farm research trial comparing organic and conventional strawberry production methods. The plots were grown as annuals during the first two years and were allowed to continue growing as perennials into year three. The conventional plots received fumigation in years one and two. Yields were significantly lower in the organic production system all three years, but the range narrowed progressively [13]. Specifically, organic yields relative to those of conventional yields were 39% lower in the first year, 30% in the second year and 28% in the third year [13]. For weed control, black plastic mulch was employed in the organic plots. Research indicated that at root depth, soil temperatures in the conventional production system exceeded those in the organic system by as much as 2°C through March [25]. Earlier development of plants in the conventional system resulted in higher fruit yields [25].

No evidence of disease outbreaks caused by pathogenic root fungi was seen in the organic production plots. *Verticillium* was practically nonexistent in the organic plot [13]. This may have been, in part, the result of the site's long cropping history of nonhost Brussels sprouts [13].

In 1998, Driscoll Strawberry Associates produced a certified organic strawberry crop [71]. A farmer in Salinas who grows for Driscoll reports using compost, blood meal, fish emulsion, trap crops and alfalfa in the row middles. The cost savings from avoiding fumigation equals the additional costs of organic fertilizers and more labor-intensive operations. During the 1998 season, he was growing eight acres of certified organic strawberries but planned to expand his acreage in the following season. The acreage he currently farms is rented from a landowner who rotates his land through cauliflower and lettuce and has no *Verticillium* and low weed pressure [112]. Producers of organic strawberries grow on relatively small plots ranging from about two to six acres.

Weed control is a major difficulty for organic growers. In the trials on the Swanton farm, a significantly higher biomass of weeds occurred in the organic plots early in the season [25]. In one year, approximately $1717 per acre was spent on handweeding the organic plots [13]. Since labor inputs were valued at $7.20 per hour, approximately 238 hours of labor per acre were required for weed control in the organic plots [13]. One Santa Cruz organic grower reported spending about $5000 per acre for hand weeding [5]. Black plastic mulches are used by organic growers to help suppress weeds. The cost of black plastic mulches used by organic growers is about 20% higher than clear plastic ($600 per acre vs. $435 per acre) [5].

### 3. Florida

Florida is the second largest strawberry-producing state, behind California, producing during winter months and ending shipment when California Central Coast production increases. Strawberries are grown in the North, Central and Southern regions of the state, though production from the Central region accounts for approximately 90% of acreage and value [89]. Since 1980, 4900 to 6000 acres have been planted annually. The value of the crop was estimated at more than $112 million for the 1995–1996 season [89].

Strawberries are grown as an annual crop in Florida using a raised bed system, as in California, with two or four rows of plants per raised bed. Planting beds are fumigated with methyl bromide+chloropicrin, most often using a formulation of 98% methyl bromide and 2% chloropicrin, approximately two weeks prior to planting transplants for the control of soilborne insects, soilborne diseases, nematodes and weeds. Fumigation is performed at the time that the planting beds are formed. The beds are immediately covered with plastic and the edges are sealed by covering them with soil. Bed fumigation is standard in Florida, in contrast to California where full field fumigation is more common. Bed fumigation allows growers to reduce the amount of fumigant used per acre, since only the beds are treated, and to reduce expenditures on plastic mulch, which remains in place for the growing season with transplants planted into the beds through the plastic. Transplants are set beginning in late September and harvest starts in late November, peaking in March and early April. Some double cropping occurs using vegetables such as pepper, eggplant, or squash, planted after the strawberry crop. However, this is not considered a usual practice [90]. The use of overhead sprinklers is common practice to establish transplants [90].

Prior to the 1960s, Florida strawberries were treated with preplant applications of organophosphate nematicides and herbicides [83]. However, these materials did not control soilborne diseases. Research with soil fumigants found that they provided superior disease and nematode control. Subsequent research indicated that among other fumigants tested, yields were highest with methyl bromide+chloropicrin fumigation under clear plastic [84]. Much of the yield difference was attributed to superior weed control in the methyl bromide+chloropicrin plots compared to plots treated with 1,3-D and herbicides [84].

Fumigation with methyl bromide+chloropicrin in a formulation of 98% methyl bromide to 2% chloropicrin has been standard since the early 1980s [88]. Previously, a 67:33% methyl bromide+chloropicrin mixture had been used. The 98:2% formulation along with black plastic mulch controls nematodes and most weeds. If soilborne diseases are a problem in a particular field, then a 67:33% mixture may be more appropriate though it is more expensive.

Over 99% of Florida's strawberry acreage is fumigated with methyl bromide [100]. Preplant soil fumigation with methyl bromide is so widely used due to the broad spectrum soilborne pest and disease control that it provides. Methyl bromide+chloropicrin is used to control black root disease (*Pythium, Ceratobasidium* spp., *Idriella lunata*); rhizoctonia bud rot and hard brown rot (*Rhizoctonia solani*); verticillium wilt (*Verticillium albo-atrum*); sting, root-knot, and leaf and stem nematodes; and weeds. The use of methyl bromide+chloropicrin has almost completely alleviated problems of the sting nematode as well as other soilborne pest and disease problems in Florida strawberry production systems [68].

Much less research has been conducted to identify alternatives to methyl bromide in Florida strawberry production systems than in California. However, more research has been initiated recently, for which results are not yet available. In a 1995 experiment at Dover, Florida, alternative fumigant treatments produced yields equivalent to those from methyl bromide–treated plots. Treatments included methyl bromide+chloropicrin (400 lb/acre), chloropicrin (350 lb/acre), Vapam (100 gal/acre), and Telone C17 (35 gal/acre) [68]. Fumigant experiments in Northwest Florida indicated that in comparison to plots treated with methyl bromide+chloropicrin (98:2) strawberry yields were 5% lower with metam sodium, 1% lower with 1,3-D, and 2% higher with dazomet treatments [86].

Currently available alternative fumigants to methyl bromide do not fully control hard seeded winter annual weeds nor nutsedges under Florida strawberry cultural conditions. Herbicides will be needed to control these weeds in an alternative production management situation [85]. At the present time no herbicides are labeled for pretransplant application under mulch for Florida strawberries. Napropamide and DCPA are labeled only for posttransplant application. Diphenamid was labeled and recommended for pretransplant use but was voluntarily withdrawn from production and use in the U.S. During the early to mid-1980s, several herbicide trials on strawberries in Florida demonstrated that chloxuron was effective and safe for use on strawberries. Chloxuron use, however, has been discontinued in the U.S. [85].

Recent experiments with 12 herbicides applied as preplant incorporated or preemergence treatments in plastic mulched strawberries indicated that strawberries were tolerant of the majority of the herbicides tested: clopyralid, metolachlor, napropamide, prodiomine, simazine, terbacil, EPTC, norflurazon, trifluralin, oxyfluorfen, and pendimethalin [85]. Vigor of strawberry plants was lower with oryzalin. Simazine, oxyfluorfen, and high terbacil rates produced excellent season-long control of the two major weeds that emerged—Carolina Geranium and cut-leaf evening primrose [85].

Several nonchemical alternatives have also been tested for Florida strawberry production systems.  Hot water can be injected into the soil and incorporated with rototilling equipment.  The use of water heated to 230°F resulted in yields below those of untreated plots [68].  The failure of the hot water treatment to produce equivalent yield response to that of the standard methyl bromide+chloropicrin treatment suggests the importance of other, more difficult to control, soilborne pests in determining strawberry yield [86].  The water was applied at the equivalent of 42,373 gal/acre[68].

Several off-season management practices have been tested for control of nematodes.  A 1995 experiment assessed the value of cover crops and clean fallow as summer, off-season management practices for controlling sting nematode [68].  Soil population numbers of the sting nematode increased three-fold in sorghum and sudangrass plots but declined to low, near undetectable levels in plots maintained in a clean fallow or planted to velvetbean [68].

Solarization has also been tested.  Strawberry acreage in Florida is generally out of production during the hot months of July and August, the most desirable time for conducting solarization treatments [87].  A disadvantage to solarization during this period is the heavy seasonal rainfall.  Studies conducted in 1987 in strawberry acreage compared four treatments: a sorghum cover crop, either alone or with fumigation, and solarization, either alone or with fumigation.  Except for the sorghum treatment alone the other three treatments produced similar fruit yields [87].  A 1995 experiment evaluated soil solarization as a strawberry fruit production strategy at a site with a 25-year history of soil fumigation [88].  Results of the study showed few significant differences among trials.  Researchers hypothesize that the lack of significant differences among results of the treatments may have been the site's history of soil fumigation  [88].

Some Florida strawberry growers are experimenting with organic production methods in 1999, which might incorporate some of the above nonchemical practices [102]. Currently, the supply of organic strawberries to U.S. markets during the winter months is extremely limited. In addition to not fumigating with methyl bromide, these growers will not be able to use other synthetic pesticides or fertilizers. Disease control is expected to pose a great challenge under these conditions.

4. Other States

Strawberry growers in states other than California and Florida use methyl bromide on a much smaller percentage of their annual acreage. (See Table 4.A.5.) Perennial production systems in these states are more predominant, where the plants are left in the ground for two or more years. Eastern strawberry growers have been reluctant to fumigate, in general, because of the initial high cost and the uncertainty of a reliable return on investment [98].

Increasingly, strawberry growers in North Carolina are adopting an annual, raised-bed, plasticulture system, similar to that used in California and Florida [94]. Methyl bromide is estimated to be used on approximately one-third of North Carolina's strawberry acreage. (See Table 4.A.5.). Three trials were established in 1997 to evaluate alternative treatments in the plasticulture strawberry production system in North Carolina [96]. In the first year of a three-year study, there was no significant difference in yield between any treatment at one site. To some extent, this may have resulted from the choice of testing location, where strawberries had not been grown for over 20 years [96]. At another location, the plots treated with Vapam and dazomet had higher yields than the methyl bromide plots [96]. At this site, strawberries had been grown in the same plots for the previous two to four years. In a 1998 on-farm study in North Carolina, the use of compost resulted in yields of strawberries equivalent to the use of methyl bromide [97].

A two-year experiment in Alabama compared strawberry yields with methyl bromide with metam sodium and soil solarization treatments. Metam sodium treatments resulted in strawberry yields equal to 127% and 92% of the methyl bromide plots in the two years while solarization for two months resulted in yields equivalent to 88% and 95% of the methyl bromide yields [95].

No research into methyl bromide alternatives was located for other strawberry production areas of the U.S.

5. Strawberry Nurseries

California is the largest producer of strawberry nursery plants in the world, growing about 80% of strawberry transplants in the U.S. and exporting approximately 30% to international markets [53]. In other producing areas in the U.S. and abroad, many nurseries are reliant on plant material from California, which they will use in their own runner production or high-elevation nurseries. In 1996, the value of nursery plants produced was estimated at over $17 million [53].

The strawberry plant is a perennial that reproduces both sexually from seed and vegetatively by sending out stems called runners along which new plants grow [4]. Until it develops its own root system, the new plant receives water and nutrients through the vascular system of the runner [4]. Eventually, the new plant begins the process of runner and new plant formation. When allowed to multiply, as in nurseries, a single plant can produce 100 or more new plants in a single season [4]. A rule of thumb is that one nursery plant ultimately will produce 30 plants destined for fruiting fields [53]. Approximately 500 million runner plants are produced in these nurseries every year [51].

Several different strawberry pathogens can be transmitted in infected transplants to production fields. These include viruses, mycoplasmas, foliar and root-knot nematodes, and various fungi that cause plant diseases. In addition, weed seeds and vegetative reproductive structures of perennial weeds can be spread on contaminated transplants. Using certified transplants is an important means of preventing weeds, diseases and nematodes from being introduced into fruit production fields [4].

The production system for strawberry nursery plants in California is complex, consisting of at least four separate stages. At the first stage, mother plants grown in artificial soil in a hot greenhouse environment produce virus-free runner tips that are harvested and grown out into small plants under sterile conditions. This material is checked by the state to ensure that it is free of viruses and pathogens. The next stage is the foundation nursery, where the daughter plants from the first stage are planted out into a field at a low elevation in the Central Valley. The long, hot growing season allows these plants to produce hundreds of thousands of runner plants. At this stage, the state continues to sample for viruses and diseases [63].

After the foundation stage, there is a third stage where the plants are increased once again at a low-elevation nursery. From this third stage on, there is no more virus checking of the nursery plants by the state. Some nurseries may choose to increase the plants one or more additional times at a low-elevation nursery before moving plants onto the next stage of nursery plant production. For plants destined for fall planting, the last stage takes place at high-elevation nurseries located in the northern part of the state and in southern Oregon. Nursery plants for summer plantings are supplied directly by the low-elevation nurseries. Conducting the last stage of nursery production at a high elevation subjects the plants to shorter day length and cooler temperatures, which contribute to increased plant vigor, consistent production patterns and higher quality fruit [63]. When the plants are harvested from the high elevations in the fall and planted into growing areas in Central and Southern California, they experience extended daylight and warm temperatures, which promotes plant growth and early production.

The quality of California-grown strawberry nursery plants is ensured through three certification programs run by the California Department of Food and Agriculture. General cleanliness standards are enforced for all nursery crops in California through annual inspections of production fields [104]. In addition, nursery crops destined for on-farm use must participate in a registration and certification program designed specifically to prevent the spread of nematodes into production fields. The nematode registration and certification program outlines acceptable treatments to meet certification standards. For field-grown nursery crops, preplant fumigation with either methyl bromide or 1,3-D will satisfy the requirements. Alternatively, fields may be sampled for nematodes at the time of harvest, although this practice is considered extremely risky because the crop must be destroyed if nematodes are found [103] [105].

Finally, a certification program specifically for strawberry nursery plant production is in place. Index testing for viruses and nematode sampling at various stages of the production process, as described previously, ensures the cleanliness of strawberry nursery plants [106]. Methyl bromide is currently used at all but the first stage of strawberry nursery plant production in California in order to meet the requirements of the certification programs.

Alternative fumigants have been tested for use in the California strawberry nurseries. In 1993, researchers compared the efficacy of methyl bromide+chloropicrin, chloropicrin alone, and nonfumigation preplant treatments to plants grown in a high-elevation nursery in ground not previously cultivated to strawberry plants [51]. Compared to methyl bromide+chloropicrin, use of chloropicrin and nonfumigation resulted in significant reductions in nursery runner productivity and runner plant size. Furthermore, when transplants from these three nursery fumigation treatments were grown in a fruiting field in Southern California, there was a significant effect of nursery treatment on fruit production, with the methyl bromide+chloropicrin nursery treatment producing the greatest yield [64]. Throughout the study, there were no visual symptoms of root or crown disease on plants in any treatment, suggesting that differences among fumigation regimes resulted from competition with sublethal soil organisms, rather than specific, lethal pathogens [66].

Subsequently, research conducted from 1994 through 1996 compared the three preplant soil fumigation regimes (methyl bromide+chloropicrin, chloropicrin alone and nonfumigation) in both low-elevation and high-elevation nurseries. For all of these trials, strawberry transplants were produced in soil that had never previously been planted to strawberries. In these trials, runner plants produced with various fumigation regimes at the low elevation in year one were transplanted into high-elevation fumigation regimes during year two, and the runner plants produced at high elevation were then transplanted to fruit production fields in Southern California in the third year. The objective of these multiyear studies was to determine the extent of nursery soil treatment "carryover" when a methyl bromide alternative was used throughout the entire strawberry plant propagation cycle. Results indicate that the most recent treatment has the greatest effect on fruit production. The choice of treatment in the fruiting field has a greater influence on yields than the treatment used in the high-elevation nursery, which, in turn, has a greater effect than treatments at the low-elevation nursery. An important finding was that the fumigation regime that is used at the low-elevation nursery stage can have a significant effect on fruit production two years later [66].

The alternative to methyl bromide+chloropicrin that produced the highest yields was 300 lb/acre of chloropicrin. The use of plants grown in nurseries treated with chloropicrin is expected to result in decreases in fruiting field yields of approximately 2.5% per propagation level. The relatively low vapor pressure of chloropicrin in the wet, cold conditions at the high-elevation nurseries may result in phytotoxicity at these rates unless significant time lapses before planting [51]. At lower rates of chloropicrin, runner yield and size are significantly greater than in fields with no treatment but not as high as with methyl bromide+chloropicrin.

As in the fruit production fields, weed control is anticipated to be problematic in the strawberry nurseries when using alternative fumigants. In nurseries, plastic mulch is not used. Weed control relies on preplant soil fumigation and hand weeding after planting to remove weeds that invade fields before the plant canopy closes over [4]. Runners take up space between the mother plants so growers cannot cultivate between the rows to control weeds [63]. Research in Canadian nurseries in Nova Scotia indicated that applications of 1,3-D+chloropicrin gave about 85% control of a range of broadleaf and grassy weeds, while the addition of metam sodium gave 85 to 98% overall weed control [64]. The Canadian researchers investigated the use of the preplant incorporated herbicide, trifluralin and the postemergence herbicides DCPA and fluazifop and found that minimal phytotoxic effects occurred to the nursery plants [64].

Methyl bromide was used also to eliminate strawberry seeds that may have survived in the soil from the previous nursery plantings. It is possible that a seed from a previous planting may survive and grow in a strawberry nursery, if no methyl bromide is used as an herbicide [63]. The possibility of off-type contamination, which cannot be detected visually, causes concerns about the quality of the nursery crop.

Beyond alternative fumigants, the production of strawberry plants in sterile soilless media is under investigation. Containerized “plug plants” are a new development by a few eastern growers, where strawberry runner plants are set into transplant trays and grown out in artificial potting mix similar to vegetable transplants [72]. They are planted by hand as are conventional plants but receive less wounding and shock at planting than conventional bare root transplants. As a result, they initiate growth faster and achieve higher yields than conventional bare root transplants [72]. In trials with University of California cultivars on the West Coast, plug plants also consistently perform very well in nonfumigated soil. Plug plants grown properly and planted into nonfumigated soil achieve yields comparable to conventional bare root plants grown in methyl bromide–fumigated soil [72].

Experimentation has been undertaken with strawberry plug plants transplanted into sterile soilless potting media for the last six weeks of growth. The plug plants were more vigorous and in the field yielded 38% more in nonfumigated soil than did traditional transplants [65]. In fields fumigated with methyl bromide+chloropicrin, the plugs and traditional transplants yielded equivalently.

Another approach to producing nursery plants free of pathogens is the use of hot-water dips. Research in northern California nurseries shows that foliar nematodes, anthracnose and common leaf spot or tan spot can be controlled by dipping bare root strawberry plants in hot water [4]. This technique is used for nursery plants between propagation stages but must not be used for transplants destined for fruit production fields because plant vigor is substantially reduced by the hot-water treatment [4]. Nursery plants go into shock, and a number do not recover [62]. Hot-water dips of strawberry stock is not an approved treatment for certification under the California nematode registration and certification program.

Experiments with incorporation of cover crops in a strawberry nursery have been undertaken to evaluate the potential effects on managing verticillium wilt [43]. Incorporation of a summer-irrigated sudan grass crop, a summer-irrigated mustard crop, a winter canola crop and a rye crop all failed to effect any measurable reduction on the soil populations of *Verticillium dahliae* [43]. Under the mustard cover crop treatment, an increase in populations of *Verticillium dahliae* was observed [52].

The importance of using nursery fumigation is widely recognized. Currently, all certified organic strawberry farmers use strawberry transplants grown in methyl bromide–fumigated nursery plots [66].

About 70 to 80% of the strawberry transplants used in Florida strawberry production come from nurseries in Canada. Because of the rationing of methyl bromide in Canada, some nurseries are already switching away from methyl bromide and using chloropicrin alone.  Because of this, the growers are seeing an increase in soilborne diseases [101]. Soilborne diseases have not been a major problem for Florida strawberry growers, but now with contaminated transplants, they are becoming more of a problem [101].

Washington state nursery growers obtain plant material for the perennial varieties that they propagate from in-state or Canadian sources and are also subject to a state certification program.  Certification may be achieved through fumigation with several materials, although methyl bromide is the preferred treatment [70].

## 6. Previous Studies

USDA's NAPIAP has conducted two assessments of the potential impact on strawberry production following a loss of methyl bromide [57] [2].  University of Florida researchers estimated the impact of the methyl bromide ban on Florida strawberry growers [117].  In addition, two studies have been conducted by researchers at the University of California [54] [114] [115].

In a 1993 study [57], NAPIAP collected expert opinions from Extension Service specialists who profiled likely replacements for methyl bromide and estimated changes in production that would be expected from the substitution.  In California, the replacements for methyl bromide were listed as metam sodium on 10% of the acreage at a cost of $700 per acre and chloropicrin on 90% of the acreage at $1,200 per acre.  The overall per-acre change in control cost of the substitutes in comparison with methyl bromide was estimated at an addition $50 per acre.  The change in California strawberry production without methyl bromide was estimated at –14%.  For Florida, the 1993 NAPIAP study estimated that 65% of the acreage would be treated with Vorlex at a cost of $397 per acre, while 25% of the acreage would be treated with metam sodium at a cost of $235 per acre. The overall change in Florida strawberry production costs without methyl bromide was estimated at an additional $125 per acre with an associated production change of –59%.

In a 1997 commodity assessment of pesticide use in strawberry production, NAPIAP again collected expert opinions from Extension Service specialists who profiled likely replacements for methyl bromide and estimated changes in production resulting from the substitution [2]. The substitution scenarios from the 1997 NAPIAP report are listed in Table 4.A.6 by state. The estimates of impacts on yield of the substitutes are listed in Table 4.A.7. As can be seen, the 1997 NAPIAP assessment estimated that 1,3-D+chloropicrin and metam sodium would be used on 95% and 10% of California's strawberry acreage, respectively. In Florida, the estimate was that 1,3-D+chloropicrin and metam sodium would be used on 70% and 30% of the strawberry acreage, respectively. California specialists also estimated increased usage of several insecticides following the ban on methyl bromide. The alternative treatments were estimated to reduce strawberry production by 8% in California and 20% in Florida.

The 1997 NAPIAP report also presented analyses of substituting alternatives for methyl bromide in states that produce perennial strawberries (Ohio, Oregon, etc.). The substitutions and yield impacts for these states also are presented in Tables 4.A.6 and 4.A.7.

Researchers at the University of Florida conducted a study of the impact of a ban on methyl bromide on the vegetable industry. Both California and Florida strawberry production was considered, with both areas incurring yield losses after the ban. Strawberry growers were assumed to use Telone C-17 + napropamide as an alternative to methyl bromide, at similar costs to the methyl bromide system. Growers were assumed to experience a 25 or 27% yield loss in Florida and California, respectively. Total FOB revenue losses for Florida and California producers were estimated at $72 million and $59 million [116].

In a 1994 study conducted by the University of California, a combination of metam sodium with chloropicrin was estimated to be the best alternative to methyl bromide+chloropicrin for strawberry production [54]. The cost of this treatment was calculated to be $520 more per acre with a yield decrease of 20% because of the reduced spectrum of control provided by metam sodium. At the time of the 1994 study, 1,3-D had been suspended for use in California and, as a result, was not considered as a possible replacement. 1,3-D is now permitted for use in California under restrictive conditions. In the most recent analysis conducted by the University of California for strawberries, 1,3-D+chloropicrin is now considered the best alternative at no increased cost but with yield reductions in the 3 to 8% range [58].

The analysis in the 1994 UC report was extended in a later study conducted by one of the authors of the current report. In that study, California, Florida and Mexico production areas are included in the analysis. Growers in California were assumed to switch to metam sodium at an additional cost of $520 per acre and sustain a 20% yield loss. Florida strawberry growers were assumed to switch to Telone C-17 at an additional cost of $468 per acre and suffer yield losses of 25%. Overall, U.S. strawberry producers were estimated to suffer $313 million in reduced revenues [115].

## 7. Yield and Cost Changes Under a Methyl Bromide Ban

California strawberry growers were assumed to use methyl bromide in combination with chloropicrin in a 67% methyl bromide and 33% chloropicrin mix. Most growers hire a firm that applies the mixture to the entire field using 200 lb of methyl bromide per acre at a cost of $1250 per acre. The California Strawberry Commission estimates that 95% of strawberry acreage is fumigated each year [30]. California strawberry producers are assumed to switch to a low rate of chloropicrin and Vapam. This will cost an additional $97.50 per acre. In addition to alternative fumigants, growers are likely to face increased weeding costs due to the less effective weed control associated with Vapam. It is estimated that weeding costs will increase by $600 in the Central Coast area and $500 in the South Coast regions. Thus the postban increase in costs equals $697.50 for Central Coast and $597.50 for South Coast.

Florida growers use methyl bromide in combination with chloropicrin in a 98% methyl bromide and 2% chloropicrin mix. They apply the mixture to the beds only using 200 lb of methyl bromide at a cost of $230 per acre. These growers are assumed to use Telone C-17 at 17.5 gal/acre at a cost of $227.50. In addition, they are assumed to use the herbicide Napropamide at 3 lb/acre at a cost of $51.23. This herbicide is not expected to be as effective against weeds as methyl bromide. Therefore, a cost of $400 per acre for hand weeding over the course of the season is included. The increase in costs will be $448.73 per acre. These costs do not include increased costs that are anticipated due to the more stringent worker safety requirements for Telone. Nor do they include the costs of running a broadcast spreader or spray boom and disc to distribute and incorporate the herbicide.

There has been a substantial amount of research into alternatives to methyl bromide for California strawberry producers. Results suggest that growers might expect a yield loss of approximately 4% in the strawberry field using chloropicrin and vapam compared to methyl bromide in the first year [42]. In addition, the loss of methyl bromide for production of strawberry nursery stock will have carryover effects through the transplant vigor in the growing fields. Estimates are that a 7.5% reduction in yield in the strawberry field may be expected from using alternatives in the nurseries to grow the transplants. Taking the effects of alternatives in both the nurseries and strawberry fields together, as well as how they may change in the second and third year, a yield loss of 21.5% has been assumed for California strawberry growers.

There is less research into alternatives for strawberry growers in Florida. Florida workshop participants suggested a range of yield losses between 15 and 30%. Here a yield loss of 21.5% is assumed.

| TABLE 4.A.1: Strawberry Production by State (1996) | | | | | |
|---|---|---|---|---|---|
| | | | Total | Value | |
| | Acres | Yield | Production | | |
| State | Harvested | (lb/A) | (1,000 lb/yr) | $/100 lb | Total ($1,000) |
| Arkansas | 170 | 2,100 | 400 | 75 | 300 |
| California | 25,200 | 54,000 | 1,360,800 | 43 | 584,860 |
| Florida | 6,000 | 26,000 | 156,000 | 72 | 112,632 |
| Louisiana | 850 | 7,500 | 6,400 | 61 | 3,904 |
| Michigan | 1,500 | 4,000 | 6,000 | 75 | 4,512 |
| New Jersey | 450 | 3,500 | 1,600 | 69 | 1,101 |
| New York | 2,100 | 3,900 | 8,200 | 120 | 9,840 |
| North Carolina | 2,300 | 7,000 | 16,100 | 67 | 10,787 |
| Ohio | 1,000 | 3,600 | 3,600 | 89 | 3,204 |
| Oregon | 5,200 | 9,200 | 47,800 | 48 | 22,835 |
| Pennsylvania | 1,300 | 4,300 | 5,600 | 97 | 5,432 |
| Washington | 1,300 | 8,100 | 10,500 | 63 | 6,605 |
| Wisconsin | 1,100 | 4,000 | 4,400 | 98 | 4,312 |
| **Total** | **48,470** | | **1,627,400** | | **770,324** |

Source: [1]

| TABLE 4.A.2: Weed Control Practices inCalifornia Strawberries | |
|---|---|
| | **% Acres Treated** |
| Napropamide | 3 |
| Paraquat | 3 |
| Cultivation | 60 |
| Handweeding | 100 |
| Methyl bromide/chloropicrin | 91 |

Source: [2]

**TABLE 4.A.3: Meta Analysis Results of Yield Comparisons**
**Methyl Bromide/Chloropicrin (MBC) and Alternatives**

| | # of Studies | Yield Relative to MBC |
|---|---|---|
| Chloropicrin | | |
| overall | 34 | 91 |
| high rate | 23 | 94 |
| moderate rate | 11 | 87 |
| first cycle (high rate) | 12 | 98 |
| second cycle (high rate) | 7 | 90 |
| third cycle (high rate) | 4 | 88 |
| 1,3-D + Chloropicrin[a] | 10 | 87 |
| Metam Sodium[a] | 8 | 77 |
| Untreated | | |
| overall | 45 | 51 |
| first cycle | 17 | 63 |
| second cycle | 19 | 50 |
| third cycle | 9 | 40 |

[a] Results for subsequent cropping cycles not available for 1,3-D + Chloropicrin and Metam Sodium.

Source: [35]

**TABLE 4.A.4: Weed Control Requirements for Soil Fumigation Treatments**

| Treatment | Labor (hours/acre) |
|---|---|
| Methyl Bromide/Chloropicrin | 109 |
| Chloropicrin | 157 |
| Metam Sodium | 159 |
| Basamid | 173 |

Source: [40]

**TABLE 4.A.5: Methyl Bromide Use in Strawberries by State**

| State | % Acres Treated | Acres Treated | lb/acre | lb/yr (1,000) |
|---|---|---|---|---|
| California | 91 | 22,932 | 318 | 7,292 |
| Florida | 99 | 5,940 | 294 | 1,746 |
| Michigan | 10 | 150 | 300 | 45 |
| New York | 5 | 105 | 300 | 31 |
| North Carolina | 32 | 736 | 281 | 207 |
| Ohio | 55 | 550 | 315 | 173 |
| Oregon | 10 | 520 | 300 | 156 |
| Pennsylvania | 10 | 130 | 312 | 41 |
| Washington | 5 | 65 | 316 | 21 |
| Wisconsin | 15 | 165 | 325 | 54 |
| | | **31,293** | | **9,766** |

Source: [2]

**Table 4.A.6: Methyl Bromide+Chloropicrin (MBC) Substitution Scenario (NAPIAP-2)**

| State | Alternative | % Use on MBC Acreage[1] |
|---|---|---|
| California | 1,3-D+Chloropicrin | 95 |
| | Metam Sodium | 10 |
| | Carbaryl | 5 |
| | Chlorpyrifos | 5 |
| | Propargite | 50 |
| Florida | 1,3-D+Chloropicrin | 70 |
| | Metam Sodium | 30 |
| Michigan | 1,3-D | 100 |
| North Carolina | Metam Sodium | 100 |
| New York | 1,3-D | 50 |
| | Rotation | 50 |
| Ohio | Metam Sodium | 80 |
| | Hand Hoeing | 100 |
| | Crop Rotation | 100 |
| | Resistant Varieties | 100 |
| Oregon | 1,3-D | 75 |
| | Fenamiphos | 10 |
| | Hand Weeding | 90 |
| Pennsylvania | Metam Sodium | 50 |
| | Crop Rotation | 50 |
| Washington | 1,3-D | 50 |
| | Metam Sodium | 50 |
| | Hand Weeding | 100 |
| Wisconsin | 1,3-D | 50 |
| | Soil Solarization | 5 |
| | Rotation | 20 |
| | None | 25 |

[1] Percentage of growers using various treatments may add to more than 100 due to the use of a combination of alternatives on acreage previously treated with methyl bromide+chloropicrin.

Source: [2]

**Table 4.A.7: Methyl Bromide+Chloropicrin (MBC) Substitution Scenario: Average Yield Impacts (NAPIAP-2)**

| State | Yield Impacts on MBC Treated Acres(%) |
|---|---|
| California | -8 |
| Florida | -20 |
| Michigan | 0 |
| North Carolina | -20 |
| New York | -10 |
| Ohio | -20 |
| Oregon | -15 |
| Pennsylvania | -25 |
| Washington | -40 |
| Wisconsin | -15 |

Source: [2]

Note: If 1,3-D and chloropicrin are not available in California as alternatives to MBC, the yield impact is estimated at –24% in absence of a major pathogen such as verticillium wilt and at –50% in the presence of a major pathogen [2].

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## B. Tomatoes

### 1. Introduction

Florida is the largest grower of fresh market tomatoes, growing over one third of the U.S. total fresh market tomato crop [90]. California is the next largest producer of fresh market tomatoes, growing approximately 30% of the U.S. total. Several other states account for the balance of production, with Georgia, South Carolina and Virginia among the larger producers [90]. Nearly all Florida tomato acreage is fumigated with methyl bromide, while in California, only growers in the South Coast area use methyl bromide to any great extent, generally every second or third year [62] [91] [92] [93]. Growers in southeastern states, such as Georgia, North Carolina and South Carolina, are also reliant upon methyl bromide fumigation as part of their production system [62].

This chapter reviews the development of the current tomato production system, of which methyl bromide fumigation is a component. A discussion of the pests that methyl bromide is used to control follows. A review of research into alternatives is then provided. Due to the heavy reliance of Florida producers on methyl bromide and abundance of research both into the development of the current system and recently into alternatives to methyl bromide, this section is focused on Florida production systems. Research performed in other states is then reviewed.

### 2. Florida

Tomato production in Florida is concentrated in several areas of the state: in the panhandle area west of Tallahassee, in northern areas near Oxford and in the Suwannee

Valley, in the southwest near Immokalee, in the Palmetto-Ruskin area south of Tampa, and along the east coast near Palm Beach and in Dade County. The southwest and Palmetto-Ruskin areas account for the majority of acreage and production [105]. In most areas of the state, it is possible to plant and harvest two crops each year, during the fall and spring. Most fields are left out of production during the summer months, though production lasts into June in the Quincy area of Western Florida.

Planting of the fall crop begins in the northern production regions in mid-July and is usually completed by early August. Transplanting starts in mid-August for areas in the southern Peninsula. Dade County growers begin to plant in the second half of September. Quincy area growers begin harvest in late September. Southwest and Southeast growers begin harvesting in late October and early November. Dade County growers begin picking in early December. Planting for the spring crop in Dade County is completed by early January. Southwest growers finish planting by late February. Palmetto-Ruskin and East coat regions finish by mid-March and most Quincy growers are done by early April [105].

Production practices vary considerably among the major production areas, although almost all of the state's tomato crop is grown on polyethylene-mulched raised beds, using staked culture and drip or seep irrigation. Irrigation systems vary from one region to another. In Dade County, drip irrigation is becoming more common. In the Palmetto-Ruskin and East Coast areas, most tomatoes are irrigated using subsurface or drip irrigation. In Western Florida almost all crops are grown with drip irrigation [37]. Twenty-five percent of Florida’s tomato acreage is under drip irrigation [62].

### *Historical Pest Control Practices*

Before 1950, vegetable production in Florida can best be described as nomadic [20]. One to four successive crops were produced on rented land after expensive clearing operations or long pasture rotations to avoid a complex of soilborne pests and disease problems popularly called “old land disease” [20] [63]. As urban growth increased, land suitable for tomato production became more difficult to locate and expensive to acquire and develop. During the late 1940s and early 1950s, various soil fumigants became available for testing and use that could control nematode and disease problems that developed in continuously cultivated fields [20] [99]. Ethylene dibromide and dichloropropene fumigants were among the first to be tested and used during the 1940s [99] [100]. Early tests showed that fumigation could double yields, although there was some observed growth retardation when the fumigant had not completely dissipated from soil [100]. Metam sodium became available in the mid-1950s for testing and by 1959 was being recommended to growers for field use [101]. In the late 1950s, nonfumigant nematicide chemicals also became available for field testing [20].

Fumigation with methyl bromide+chloropicrin formulations, among other fumigants, was adopted as part of a system of raised-bed production with in-the-row fumigation, followed by application of polyethylene mulch, the use of synthetic fertilizers and maintenance of a high water table [36] [63]. This system was modified over time to include disease-resistant cultivars and containerized transplants [36]. In-the-row application allowed growers to use less fumigant, which reduced costs and permitted growers to fumigate each time a field was prepared. This was found to be more beneficial than less-frequent full field, i.e., broadcast, fumigation [63] [100]. The use of polyethylene film improved the efficacy and feasibility of broad spectrum fumigants on large acreage [63]

Landmark research on the benefits of the systems approach to soil disinfestation has been attributed to the work of Geraldson, et al. [64]. They showed that nematode populations were controlled six weeks longer when polyethylene films were used than without. They also showed that the use of a high water table restricted tomato root growth to the treated area, further preventing disease attack. Polyethylene films also controlled many weeds, which eliminated the necessity to cultivate close to the crop row, a practice that often led to the mixing of treated and untreated soil [63] [64]. Overman and Jones found that the benefits of polyethylene mulch were due to protection of plants from moisture and nutrient stress, from competition by weeds, and from the root pruning associated with cultivation, which all contributed to increased tolerance of the plants to root-knot nematode infection [65]. Crops develop faster from transplants so direct seeding is used rarely for tomatoes in Florida. Nearly all tomatoes are transplanted using containerized transplants [37].

By the 1977–78 crop year, the systems approach had been adopted widely for tomato production throughout Florida. At that time, 81% of tomato fields were mulched, and 64% of tomato fields were fumigated. Of the tomato acreage that was fumigated, 43% of the acreage was fumigated with methyl bromide/chloropicrin, while 30% was fumigated with a formulation of 1,2-dichloropropane, 1,3-dichloropropene and methyl isothiocyanate (DD-MENCS, trade name Vorlex). Containerized transplants were used on approximately 70%, and seep irrigation was used on 83% of the fields. It was estimated that on over 20% of the fields, the system was used intact [36].

The result of these technological improvements has been a dramatic increase in yields since 1960. Florida tomato yields have doubled since the early 1960s, from 178 cwt/acre on average from 1960 to 1965, to 350 cwt/acre in the 1990s [73]. Figures 4.B.1 and 4.B.2 show trends in Florida fresh-tomato production and yields. This production system effectively solved the "old land" problems in repeatedly cultivated fields. Growers can use the same fields for tomatoes each year, taking advantage of their financial investment in drainage and irrigation systems [36]. Growers have also increasingly become owners of the land on which they farm [30].

The use of methyl bromide and other fumigants was also a critical factor in the development of several high-value multiple cropping systems, leaving plastic mulches and drip irrigation systems in place for subsequent crops that benefit from the pest control provided by fumigation of preceeding crops. Although several different crops may be part of a multicrop system, it is most common for a short-season cucurbit crop such as cucumbers, squash or melons to follow a high-value, long-season crop like tomatoes. The profitability of the first crops, usually tomatoes, peppers or strawberries, is therefore tied to the continuation of these systems, which spreads the costs of field preparation and inputs across two or more crops.

Currently, methyl bromide is used on approximately 94% of the acreage planted to tomatoes each year in Florida [66]. The formulation that is most commonly used is 98% methyl bromide and 2% chloropicrin, though formulations with higher proportions of chloropicrin may be used where diseases are more prevalent. The use of a 98:2% formulation provides effective control of nutsedge, the primary weed of concern to Florida vegetable growers [6]. In addition, the higher price of chloropicrin compared to methyl bromide affects grower decisions as to which formulation to use. For soil fumigation purposes, methyl bromide is injected 20–30 cm deep as a liquid. It rapidly volatizes into a gas, permeating open soil pore spaces [20]. In Florida vegetable production, methyl bromide is applied at the same time that several other operations are performed, including bed formation, fertilizer application and full-bed plastic mulch application.

The tomato production system in Florida is one of high inputs and costs. Per acre production costs were estimated at between $10,218 and $11,973 per acre for the 1995–96 season, including harvest costs [71]. The cost of methyl bromide alone accounts for about $500 of these costs [70]. The adoption of a high-input system has been worthwhile because Florida produces for the winter market when high prices prevail.

Tomatoes are a suitable host for a wide range of plant pathogenic fungi, bacteria, viruses, nematodes and many insect species. These pest problems may become especially acute under Florida growing conditions due to the lack of an annual freeze that would provide some natural pest control. A combination of pest stressors on plant growth may interact such that the combined effects of the pest complex are greater than the added effects of each pest. Nematode parasitism frequently increases plant susceptibility and potential yield losses to plant pathogenic fungi and bacteria [6].

_Nematodes_

Plant parasitic nematodes are microscopic roundworms that live in the soil and attack the roots of tomato plants [37]. Foliar symptoms of nematode-infected roots generally involve stunting, premature wilting and leaf yellowing. Under heavy nematode infestation, crop seedlings or transplants may fail to develop, maintaining a stunted condition, or die, causing poor or patchy stand development [37].

The primary nematode parasites of tomato in Florida include the root-knot nematode (*Meloidogyne* spp.) and the sting nematode (*Belonolaimus longicaudatus*), either of which can cause extensive root damage and yield loss [34]. On sandy soils, awl nematode (*Dolichodorus* spp.) and stubby root nematode (*Trichodorus* spp.) can affect tomato plants. On the heavier soils of southeastern Florida, the reniform nematode (*Rotylenchulus* spp.) is common and is known to damage tomatoes [33].

Root-knot nematodes are known to induce the development of large tumorous galls on the roots of tomato plants. These galls reduce the size of the tomato plant's root system and reduce the plant's ability to transport water and nutrients effectively through the root systems to plant leaves [35]. Tomato yield losses often are increased significantly as a result of the interaction between nematodes and other pests. Parasitism by the root-knot nematode has been shown to enhance tomato plants' susceptibility to verticillium and fusarium wilt diseases [34].

Nematodes can survive fumigation in some cases. The presence of large, undecayed roots prior to treatment can shelter endoparasitic nematodes from lethal gas [34]. Excellent control of root-knot nematode-infected roots has been obtained with methyl bromide, which penetrates root tissue more readily than other fumigants [34].

Because of the extensive use of broad-spectrum fumigant nematicides in Florida, nematode-induced tomato crop loss currently is less than 1% of total production [35]. Plant damage, when it occurs, generally occurs in areas where fumigants are not applied. These areas often are ends of rows where fumigant delivery is discontinued prematurely or in areas where exhausted fumigant cylinders are changed [33].

*Diseases*

In Florida, there are four major soilborne diseases of tomato: bacterial wilt caused by the bacterium *Pseudomonas solanacearum*, southern blight caused by the fungus *Sclerotium rolfsii*, fusarium wilt caused by the fungus *Fusarium oxysporum* f. sp. *lycopersici*, and fusarium crown and root rot caused by the fungus *Fusarium oxysporum* f.sp. *radicis-lycopersici*. Soilborne diseases remain a major limiting constraint for the production of fresh market tomatoes in Florida [18]. Even with the use of methyl bromide as a preplant fumigant, epidemics of bacterial wilt, fusarium wilt, fusarium crown and root rot and southern blight have occurred in commercial production fields [18]. Several other pathogens may be present in tomato production fields, including *Rhizoctonia solani*, *Sclerotinia sclerotiorum*, *Phytophthora infestans*, *Phytophthora parasitica*, and *Verticillium albo-atrum* [37].

Bacterial wilt is endemic to Florida and can persist indefinitely in infested fields by surviving in the root systems of a wide range of host plants including native weeds and rotational crops. Another characteristic of this bacterium that makes it especially difficult to control is its explosive reproductive potential, often causing epidemics on newly planted land. Populations can increase by several orders of magnitude in a period of several days [18]. Bacterial wilt is distinguished from fusarium and verticillium wilts by the rapid wilt, lack of foliage yellowing, and hollowness of stems. Stems cut from plants with bacterial wilt exude a gray-brown, flowing material from the cut. The bacteria enters the plant from various types of wounds to the roots [37].

Southern blight attacks mature plants just below the soil surface, completely girdling the stem and causing rapid wilting and death. The mycelium grows over the diseased areas and the soil surface forming a mat with tan, mustard-seed-sized sclerotia. Fruit near the ground are often attacked. The use of staked cultural practices to keep fruit off the ground reduces spread of this disease [37].

Three races of the fungus that causes fusarium wilt exist in Florida. The fungus can survive and persist indefinitely in most fields. When fungus spores germinate adjacent to tomato roots, the fungus penetrates the epidermis on hairs of the plants' root systems. The fungus grows and eventually reaches the vascular tissue. Lower leaves eventually turn yellow and die. In fields, the affected leaves may dry up before wilting is detected [9].

*Fusarium oxysporum* f. sp. *lycopersici* race 1 has been observed in Florida since the beginning of commercial tomato production. Race 2 was discovered in Florida in 1961 [102], and race 3 in the early 1980s [18]. A rotation of five or more years will reduce significantly, but not eliminate, the pathogen from the soil, rendering this option impractical for Florida producers. Before resistant varieties were developed, fusarium wilt nearly destroyed tomato production in parts of Florida. Individual crop losses associated with race 2 were as high as 70% in Florida fields in the 1970s.

Fusarium crown and root rot was first detected in Florida in 1974 [1]. The disease has been reported from all major production areas of the state but is particularly severe in the acidic, sandy soils in Florida's southern production regions. The fungus invades susceptible plants through wounds and through natural openings created by newly emerging roots. Infected plants may be stunted, and as they begin to bear fruit heavily, their lower leaves turn yellow and wilt. Infected plants may wilt totally and die or persist in a weakened state producing inferior fruit. The taproot of infected plants often rots entirely. The fungal spores have thick walls that enable them to survive for long periods in the soil. Masses of spores form in great abundance in necrotic tissue and spread on air currents, readily reinfesting soil sterilized by fumigants [1].

Fumigation with methyl bromide+chloropicrin formulations have been the most commonly used preplant practice for control of fusarium crown and root rot in Florida tomatoes [2]. Application of methyl bromide+chloropicrin significantly reduces the incidence and severity of the disease [2]. Crown rot severity varies widely by site and season and is favored by cool temperatures [3]. Methyl bromide+chloropicrin mixtures have proven to be the most effective preplant treatment for reducing fusarium crown rot. However, fusarium crown and root rot incidence is still very high. (See Table 4.B.3).

Verticillium wilt is caused by the fungus *Verticillium albo-atrum.* The disease starts with wilting of the lower leaves. Eventually leaves develop yellow areas along the margins and die. The disease does not rapidly kill the plant but results in reduced yields. The interior of the stem, near the base of the plant, will reveal a tan discoloration of the vascular tissue, which does not extend up the stem as far as fusarium wilt does. Also the stem cavity does not become hollow as in bacterial wilt [37]. Mixtures of methyl bromide and chloropicrin (98:2% and 67:33%) have given excellent control of verticillium wilt [4].

*Weeds*

Many weed species flourish year-round in Florida's semi-tropical climate. Millions of buried weed seeds are present in every acre of soil. Some weed seeds may be dormant for 40 to 50 years before germinating. Weeds compete with tomato plants for space, nutrients and light and, if uncontrolled, result in significantly lower crop yields. Prior to the introduction of methyl bromide, weeds were controlled in Florida tomato fields with repeated cultivations, hand weeding and herbicide applications. Methyl bromide applications combined with plastic mulch have provided almost complete control of weeds within the row of tomato plants, reducing weed control efforts to those directed at weeds between the rows. It is estimated that 100% of Florida's tomato acreage is cultivated for weed control purposes [62].

Methyl bromide kills germinating weeds. The plastic mulch usually smothers weeds that germinate later in the season. An exception is the nutsedge species. Nutsedge species are endemic throughout Florida tomato production fields. Nutsedge is a concern in the plastic mulch system because its sharp pointed shoot tips readily penetrate the plastic film [14]. This characteristic enables nutsedge to emerge through the plastic and compete with the crop. Nutsedge is considered the most troublesome weed in vegetable production in Florida.

*Alternative Fumigants*

Initial research into alternatives to methyl bromide focused on substitute fumigants alone and in combination, such as 1,3-D, chloropicrin, metam sodium and dazomet. However, it was discovered quickly that none of the alternative fumigants provided weed control equal to methyl bromide, and weeds, nutsedge species in particular, emerged as the most difficult aspect of any alternative program [10].

Early research into methyl bromide alternatives demonstrated that simply substituting alternative fumigants for methyl bromide would not produce equivalent yields because of a lack of control of nutsedge. For example, 1994 experiments with treatments of chloropicrin, metam sodium, 1,3-D+chloropicrin and dazomet resulted in tomato yields that were 45 to 55% lower than yields in methyl bromide+chloropicrin treatments [7]. The addition of the herbicide pebulate to the 1,3-D+chloropicrin treatment resulted in tomato yields that were 1 to 16% higher than the methyl bromide+chloropicrin yields [7]. Subsequent experiments have demonstrated that combinations of pebulate with chloropicrin, 1,3-D+chloropicrin, and dazomet produced tomato yields equal to those obtained with methyl bromide+chloropicrin [48] [49].

Experiments on commercial farms during 1996, 1997 and 1998 indicated that 1,3-D+chloropicrin plus pebulate produced similar yields to that of methyl bromide in most cases [44] [51]. A recent experiment with combinations of pebulate plus 1,3-D+chloropicrin formulation consisting of 35% chloropicrin used at 36 gal/acre resulted in a marketable tomato yield equivalent to methyl bromide+chloropicrin [52]. In this experiment the use of a combination of pebulate plus 1,3-D+chloropicrin consisting of 17% chloropicrin resulted in tomato yield that was 8% lower than the methyl bromide treatments [52].

With regard to controlling root-knot nematodes, research indicated that 1,3-D combinations with chloropicrin are only slightly less effective than methyl bromide [50]. Early development of bacterial wilt is greatly reduced by combinations of methyl bromide and chloropicrin and all tested alternative fumigants [8]. However, with the presence of bacterial wilt, methyl bromide was the only treatment to perform consistently among all plots. The next best treatment, 1,3-D + 35% chloropicrin, was only 91 to 93% as effective [39]. (See Table 4.B.1.) Recent experiments with fumigant alternatives indicated that mixtures of methyl bromide and chloropicrin reduce the incidence of fusarium wilt from 61% in untreated plots to zero. Other treatments reduce incidence to 3 to 30% [7]. (See Table 4.B.2.)

In general, the majority of the research into methyl bromide alternatives were conducted under conditions of relatively low disease severity [22]. In studies where populations of nematodes and fungi were high and not adequately controlled, relative yields with chloropicrin plus pebulate and with 1,3-D+chloropicrin plus pebulate were as low as 60% of those provided with the methyl bromide treatments [45]. In addition, most studies indicated a greater incidence and population level of root-knot nematodes at final tomato harvest after 1,3-D+chloropicrin treatment, suggesting the potential for greater resurgence in root-knot nematodes and increased damage if the field is double cropped [51].

Methyl iodide has also been investigated as a potential alternative. In 1995, methyl iodide broadcast application treatments at several rates were compared with an untreated control. Nutsedge tubers were buried in each plot and weed control was observed. Nematode densities were also assessed. Although yields were significantly increased by all but the lowest methyl iodide application rate, high at-harvest nematode densities led to speculation that double crops would be at risk of suffering injury [103]. Results are presented in Tables 4.B.6 and 4.B.7. Two studies have been conducted in Dade County to assess the effects of methyl iodide on tomato yields compared to methyl bromide treatment. In those studies, yields relative to methyl bromide ranged between 70 and 85%. Combinations of methyl iodide with chloropicrin achieved higher yields, between 99 and 102% relative to methyl bromide treatments [83] [88].

*Herbicides*

Because of the importance of achieving weed control in the crop rows, researchers have investigated herbicides that may be either incorporated into the planting beds prior to the application of plastic mulch or applied postemergence over the growing crop. Research has involved looking into both currently-registered and unregistered herbicides.

Research in 1994–95 demonstrated that of the currently-registered herbicides, pebulate provided the most effective control of nutsedge [11]. Trifluralin provided no control of purple nutsedge. Lactofen performed erratically with good nutsedge control one season and none the next. Metolachlor provided good nutsedge control; however, it was injurious to tomato plants [11]. Napropamide applications provided erratic control [10].

Applications of pebulate (4 lb/acre) in the bed followed by applications of Telone C-17 (35 gal/acre) has provided nutsedge control similar to methyl bromide, and yields have been about the same [10]. Typical research results have indicated that treatments that include pebulate significantly reduce the incidence of nutsedge [13].

Research with pebulate has involved experiments to determine the best way to incorporate the herbicide into the soil. It has been demonstrated that pebulate must be incorporated thoroughly in the soil to the depth of the bed to provide good weed control [15]. Tomato plants were quite stunted in an experiment in which pebulate was incorporated with bedding disks [15]. Bedding disks tend to fold soil into a bed rather than provide thorough mixing. It is believed that this resulted in a concentrated layer of pebulate through which the tomato roots were attempting to grow, which restricted root growth until enough herbicide had degraded to stop impeding root development [15]. Incorporation of pebulate with rototillers or field cultivators did not result in tomato plant stunting.

Some experiments with pebulate demonstrate a resurgence in nutsedge infestations later in the growing season [12]. High temperatures may reduce the effective residual life of pebulate in the soil, allowing nutsedge populations to rebound [12].

Recently, the herbicide rimsulfuron was labeled for use between the rows in Florida tomato plant production fields. Rimsulfuron provides good control of broadleaves and some grasses. Experiments have been conducted using rimsulfuron in the row of the tomato plants for nutsedge control. Rimsulfuron does not control nutsedge if applied prior to weed emergence. Applications of rimsulfuron to emerged nutsedge at the rate of 2 oz/acre provided good control [16]. However, the labeled rate for postemergence rimsulfuron applications in other crops is 0.5 oz/acre. Experiments have been conducted in Florida with rimsulfuron applications up to 8 oz/acre with no phytotoxic effects on tomato plants. Other unregistered herbicides that have been the subject of experimentation in Florida tomatoes include sulfentrazine and halosulfuron. Both of these herbicides provide postemergence nutsedge control without phytotoxic effects on tomato plants. The use of a postemergence herbicide would be feasible since tomato plants have been shown to withstand several weeks of competition from emerged nutsedge plants without incurring yield losses [16].

*Solarization*

Soil solarization is a procedure that uses transparent film to trap solar energy in the soil. When extended over a six- to eight-week period, heat generated in the soil by the trapped solar energy can lead to the suppression of several key soilborne pests found in Florida [25]. Early trials of solarization in Florida were performed in the early 1980s by laying transparent film over the entire area to be treated [43] [26] [104]. However, several problems with this procedure were discovered including the cost of plastic, which would be removed after treatment and field preparation, and pooling of water after rains. These problems were addressed with further development of the system, using plastic over only the beds that would then remain in place as mulch during the growing season [60].

Optimal soil temperatures for soil solarization are achieved in the summer months. In North Florida the best period of time for application of soil solarization is between May 15 and September 15. Solarization can be incorporated into commercial production practices with minimal disruption to field procedures. Raised beds are prepared and covered using standard production practices, except that clear, low-density polyethylene plastic is used instead of white or colored films. The only additional requirement is that the film must be painted white before planting to cool the soil [25]. Soil temperatures achieved in solarization treatments range from 134ºF at the surface to 101ºF at a depth of 10 in. Mixed populations of yellow and purple nutsedge have been controlled in North Florida by solarizing raised beds prior to planting. Tubers germinate producing vegetative shoots that are burned back by the high temperatures at the soil's surface. Eventually, as the process repeats itself, the depleted food reserves in the tubers leave them unable to compete when the crop is planted. Less success has been obtained with fungal and bacterial pathogens. Lack of direct suppression may be the result of the higher thermal tolerances of fungi and bacteria [25].

Solarization experiments in South Florida did not prevent high populations of root-knot nematodes from occurring in the winter tomato crop [26]. The existence of frequent cloud cover (rainfall on 60% of days during solarization) may have resulted in fluctuations to lower temperatures or in a shorter duration of maximum temperatures, thereby enhancing pest survival [26].

Large-scale soil solarization field demonstration/validation plots were evaluated in 1995 and 1996 for fall production of tomatoes in Northern Florida. On one farm, soil solarization out-yielded methyl bromide test treatment plots by 122 boxes per acre [27]. On two other farms, methyl bromide out-yielded soil solarization plots, but by less than 100 boxes per acre. Weed suppression in solarization plots was comparable to that in plots treated with methyl bromide in all locations, except when purslane and Texas panicum were present, in which case soil solarization failed to produce adequate control [27]. The experiments demonstrated that soil solarization alone does not produce effective control of plant parasitic nematodes. Control of root-knot nematodes is inadequate when soil solarization is applied without any additional spot treatments in fields with high densities of root-knot nematodes [60]. In those cases, additional treatments with alternative fumigants may be necessary. In addition, in some cases plants were stunted visibly in the solarized areas early in the season because of heat stress.

However, in a study where precipitation occurred on 30 to 64% of the solarization days, marketable yields of fresh market tomatoes in plots receiving soil solarization were similar to or greater than yields in plots receiving methyl bromide [28].

The application of soil solarization in Florida is limited to fall production systems [60]. Recent trials were conducted where solarization was performed during the cool season. While soil temperatures were increased by the treatment, lethal temperatures were not achieved for several weeds that are commonly controlled by summer solarization treatments [89]. Approximately 40% of Florida tomatoes are planted in the fall [105].

*Organic Amendments*

Organic amendments and mulches can improve crop performance and yield. Reductions in population densities of plant-parasitic nematodes in response to application of organic amendments have been reported in many studies [21]. Practical use depends on a large and readily available supply of these materials. Yard and lawn maintenance in the urban environment generates large amounts of organic waste materials, mainly sticks, leaves, branches, grass clippings, and wood chips. The volume of material poses problems for urban landfills, and the composting and recycling of these biodegradable organic products are encouraged by urban municipalities for financial and environmental reasons [21].

Field research conducted in Florida and in other parts of the world has also shown that composts can be suppressive to soilborne pathogenic fungi and plant-parasitic nematodes. Suppression of soilborne pathogens by incorporation of composted amendments is reportedly based on enhanced microbial activity and increased numbers of antagonists generated by decomposition of the amendment in soil. Weed suppression has also been demonstrated with some types of composted materials through content and production of organic acids with phytotoxic properties [22].

A study during spring 1997 was conducted to determine the influence of increasing application rate of a municipal solid composted waste (composted yard wastes fortified with municipal sludge from the West Palm Beach Authority) on the ability of tomato plants to tolerate root infection by the southern root-knot nematode (*Meloidogyne incognita*). This single study showed that in a sandy soil, poor in organic matter content (less than 2%), tomato yields increased dramatically with soil amendment application rate in both the nematode-free and infested microplots. The impact of the root-knot nematode on tomato yield was effectively constant, although there was a tendency for crop losses to decrease with soil amendment application rate. Based on this single study, it would appear that application of the soil amendment did not enhance the ability of the tomato plant to tolerate root infection by *M. incognita*. Much of the previous and ongoing research in Florida also seems to indicate that the major effects of soil amendments to crop yields appear to be less related to nematode or soil pathogen control than to enhanced plant nutrition and nutrient and water availability [22].

Experiments with composted organic amendments on the incidence of bacterial wilt of tomato indicated a reduction in incidence but concluded that the levels of reduction will be variable and depend on site-specific soil properties [19]. Composts have been applied experimentally at a rate of 268 mt/ha [21].

*Resistant Varieties*

The development of tomato varieties with resistance to major soilborne pests of tomato has been pursued by researchers as a potential alternative to methyl bromide. Resistant varieties are already common used to limit the impact of some diseases. It is estimated that 100% of Florida's tomato acreage is planted with cultivars that have resistance to fusarium and verticillium wilt [62].

Use of nematode-resistant tomato varieties has not been extensively evaluated in Florida. In tomato, a single dominant gene (subsequently referred to as the Mi gene) has been widely used in plant breeding efforts and variety development that confers resistance to all of the economically important species of root-knot nematode found in Florida. In a resistant tomato variety, nematodes fail to develop and reproduce normally within root tissues, allowing plants to grow and produce fruit even though nematode infection of roots occurs. Commercially resistant fresh market varieties, climatically and horticulturally adapted for Florida, have only recently become available in the Peto Seed tomato variety Sanibel [22].

Unfortunately, in previous research with nematode-resistant tomato varieties, the resistance has often failed as a result of the heat instability or apparent temperature sensitivity of the resistant Mi gene. For example, previous research has demonstrated threshold soil temperatures and incremental reductions in nematode resistance with each degree above 78°F, such that at 91°F tomato plants are fully susceptible. This would suggest that in Florida, use of these varieties may have to be restricted to spring plantings when cooler soil temperatures prevail. Even with spring plantings, it may also be necessary to consider eliminating the use of black plastic mulch in favor of other colored or highly reflective mulches, which may pose other problems to Florida tomato growers [22].

In addition to problems of heat instability, the continual or repeated planting of resistant tomato varieties will almost certainly select for virulent races of *Meloidogyne* spp. capable of overcoming the resistance. Therefore, the duration and/or utility of the resistance may be limited. In previous studies with resistant tomatoes, resistance-breaking nematode races have been shown to develop within 5 to 12 planting cycles. Since new races of the nematode can develop so rapidly, a system of integrated control usually mandates the rotation of resistant and nonresistant varieties to slow the selection process for new virulent races.

During fall 1996 and spring 1997, two field microplot experiments were performed to study the influence of increasing soil population levels of the southern root-knot nematode on fruit yield of susceptible (Agriset 761) and nematode resistant (Sanibel) tomato varieties. The results of the fall study showed that for both varieties, tomato yields decreased with initial soil population level of *M. incognita*. However, Sanibel was damaged less and was significantly more tolerant of root infection by *M. incognita* than Agriset 761, particularly at the highest soil population levels. Although root gall severity was typically high and generally increased with initial inoculum levels for both varieties, the galling response of Sanibel was always less than that of the susceptible Agriset 761. No differences in tomato yield or root gall severity were observed between either variety or soil population level of *M. incognita* during the spring 1997 experiment [22].

The results of these preliminary experiments have demonstrated that even with a resistant variety, some consideration of initial soil population level of *M. incognita* must be observed to minimize tomato yield losses. Use of a resistant tomato variety should also not be considered in itself a stand-alone, direct replacement strategy for the benefits of methyl bromide soil fumigation. Given Sanibel tomato yield reductions of 40% at the highest inoculum level, combined efforts to manage soil populations to low levels prior to planting must still be considered, particularly if tomatoes are planted as a fall crop [22].

In Florida, the development of genetic resistance to bacterial wilt began in 1898 and is still in progress [18]. Resistance is mediated by at least six quantitative trait loci, which are located on five different chromosomes of the tomato plant. Multiple-resistance genes coupled with variability in expression of symptoms in the field have hampered breeding efforts [18]. A cultivar with moderate resistance has been developed but was found to have undesirable horticultural characteristics. Work continues to develop an acceptable resistant cultivar. Calcium nutrition and soil temperature have been shown to affect disease incidence [18].

Resistance to southern blight has been identified in breeding lines but has not been incorporated into cultivars with horticulturally acceptable characteristics [18]. Most of the tomato cultivars presently used in the Florida industry have resistance to races 1 and 2 of *Fusarium oxysporum* f. sp. *lycopersici* [18]. Hybrid cultivars are available that have resistance to all three races and have been evaluated by growers in Florida [18]. Resistance to fusarium crown and root rot is conferred by a single dominant gene and already has been incorporated into a commercially available cultivar [18]. Work is in progress to develop additional resistant cultivars, and these should be available by 2001 [18].

*Biological Control*

Experiments using biological control agents to reduce soilborne diseases of tomatoes in Florida have met with limited success [29] [30]. Experiments have evaluated the effectiveness of root colonizing biocontrol microflora that have been added to greenhouse-produced seedlings that were transplanted to the fields. Root colonizing biocontrol agents may not prevent disease development in the field because of lag periods between planting and disease development, failure of biocontrol microflora to colonize roots and compete with other soilborne microflora, and cultural factors that may intervene to suppress the development of biocontrol agents or enhance development of the pathogen [29].

Four tomato tests with biocontrols were evaluated between 1992 and 1995 in commercial plantings in Florida. These tests involve five biocontrol agent treatments, alone and in combination. Seedlings were planted in plastic mulch raised beds of soil fumigated with methyl bromide+chloropicrin [29]. The effectiveness of the biocontrol agents was evaluated in terms of the reduction of disease incidence in comparison to the control plots that received only the methyl bromide+chloropicrin treatments.

Over all tests, *Trichoderma* reduced crown rot, with a calculated mean reduction in disease severity of 42% and a calculated reduction of disease incidence of 39%, compared to the control. *Bacillus subtilis* reduced disease severity a mean of 31%, almost as effective as *Trichoderma.* In the only test in which both these biocontrol agents were combined with *Gliocladium*, disease incidence was reduced 43%. All biocontrol agents used in these tests reduced disease severity and incidence numerically but not statistically compared to the control, i.e., the reduction could have been due to chance [29].

Inclusion of biocontrol agents in planting mixes, as was done in this study, exposes these agents to a minimal level of competition from other microflora. The planting mix environment was a favorable one for the high level of root colonization achieved by most of the biological control agents [29].

Research was conducted for a number of years with a rust organism for control of yellow and purple nutsedge, but it has not proved to be commercially successful in Florida. The rust organism is adversely affected by the fungicides commonly applied to vegetable crops, and environmental conditions for its development are rather strict. Typically the temperature and humidity at which the organism thrives occur during the summer months when Florida crops are finished and establishment of the organism in a commercial field has been difficult. The control tends to be achieved slowly. A natural strain of rust has been observed on nutsedge in Florida, and although it does seem to kill the foliage, the effect is often short-lived and new plants become established soon after [30].

*Hot Water*

Florida studies have been conducted to evaluate the effectiveness of soil applications of hot water for nematode control. Water from a nurse tank is pumped to a 4 million BTU heat exchanger mounted on a flatbed pulled by a tractor, heated to a temperature of 230ºF and sprayed on top of and injected into the soil [31] [32]. The soil is then rototilled to increase the uniformity of soil temperature. The plant beds are formed, fertilized and tarped following conventional practices. The amount of water required to raise soil temperature ranges from 20,000 to 100,000 gal/acre and is dependent upon soil type and soil temperature (warm fall soils or cool spring soils). The experimental system used a 1700 gal nurse tank to supply the water, which required frequent stops to refill.

The currently available experimental system can treat 1 acre a day. A commercial unit is planned that could treat 10 acres a day. The current one-pass bed fertilizer, fumigant and tarp system can treat 40–50 acres a day. Research at a Florida tomato plot indicated that root-knot nematode populations were reduced to zero with hot-water treatment [31]. However, no crop yield data were collected. The concern exists that lack of pest control in soil horizons below the incorporation depth will allow subsequent pest recolonization and only delay pest impacts on crop growth [32].

While the water volume appears large, it should be noted that most crops will be irrigated immediately after planting with water volumes in the lower portion of the range utilized with a hot-water treatment [31]. Assuming that planting takes place within a few days after treatment, the hot-water treatment alleviates the need for irrigating prior to planting [31].

Rainfall immediately after a hot-water soil treatment reduces maximum temperature development and increases the rate of heat loss, thereby reducing cumulative exposure of nematodes to elevated soil temperatures [32]. The system uses 400–700 gal of diesel fuel per acre. Hot-water units tend to be quite large and can get stuck in the field if the soil becomes too wet [30].

*Crop Rotation*

Crop rotation is an important means of controlling nematode damage to susceptible crops grown in the Southeast. Recently, several different tropical crops have been introduced into rotation sequences in the Southeast for suppression of root-knot nematodes. Crops such as velvetbean, castor, American joint vetch and sesame have shown potential for this purpose in greenhouses and field trials [23]. There is a concern, unfortunately, that some rotations, while effective against root-knot nematodes, may increase populations of other nematodes [23].

For control of fusarium wilt, a rotation of five or more years will reduce significantly (but not eliminate) the pathogen from the soil. By contrast, a crop rotation of two years will effectively eradicate crown rot because the fungus does not survive in soil more than one or two years [18].

*Strip Tillage*

Recently, researchers have begun to experiment with methods of managing growth of bahiagrass sod and fertilizer application in a strip till production system. Five separate experiments have been conducted since 1995. Highest yields were obtained with a 24-in. strip of killed sod and postplant suppression of sod growth with either Poast or Gramoxone. Yields of 83 to 135% of average commercial yields obtained with conventional systems were observed [108].

*Natural Chemicals*

Many volatile compounds (known as essential oils) from aromatic plants, spices and herbs possess pesticidal properties. Dazitol is a liquid spray product whose active ingredients are essential oils of mustard and oleoresin of capsicum from chili peppers [55].

Dazitol moves downward through the soil. Research has shown that it is necessary to inject it near the soil surface so that it would be effective as a pre-emergent herbicide [57]. Dazitol is applied at a rate of 200 to 300 lb/acre [55]. Dazitol has been applied by chisel and spray systems. In all areas, plastic tarping has been used.

In an experiment at Manley Farms in Naples, Florida, an evaluation of the effectiveness of Dazitol against various pests was made by comparing the plants in the Dazitol-treated plots (about 4 acres) with the plants in methyl bromide–treated plots (about 40 acres) [56]. In this study, Dazitol was found to be more effective than methyl bromide in controlling various pests of tomatoes. Plants in the Dazitol-treated plots were taller and had more biomass than the plants in methyl bromide-treated plots [56]. Mean numbers of fruits per tomato plant were significantly higher when tomatoes were planted in the Dazitol-treated plots than when planted in the methyl bromide-treated plots [56]. Disease incidence (*Alternaria*, *Rhizoctonia*, and *Fusarium* spp.) was significantly lower than in the methyl bromide–treated plots [56].

Research with soil populations of *Fusarium* and other soilborne pathogens demonstrated that use of the Dazitol may affect a wide range of soil fungi and may create a biological vacuum [58]. Soil populations of *Fusarium* were lowest (99.9% reduction) 3 to 7 days after the soil was treated with aqueous emulsions of the formulated pepper extract. However, populations of *Fusarium* increased over time with these treatments. One explanation may be that the extract breaks down rapidly in soil [58].

A test comparing Dazitol to methyl bromide for nematode control found that the pepper product at the standard field rate was not quite as effective as methyl bromide right after treatment. But at transplant time, 12 days after application, the plot treated with Dazitol was free of nematodes while a few had migrated back into the methyl bromide-treated soil [57]. At the Gonzales Farm near Belle Glade, Dazitol resulted in a mortality rate of 100% for root-knot nematodes at five days posttreatment [57].

Researchers at the University of Florida tested several natural chemicals for their potential as a methyl bromide replacement during the spring of 1998. Yields relative to methyl bromide-treated plots are presented in Figure 4.B.4.

*Greenhouse Production*

Greenhouse vegetable production systems have been developed that do not rely on methyl bromide. These systems are costly to establish, with high initial investments in the structure and equipment necessary for the operation. There are several different types of systems, including hydroponic or nutrient film technique systems, rockwool, bag culture, and peat trough culture. Greenhouse-grown tomatoes are often marketed as a specialty product, and growers may need the price premium to cover the higher production costs [94].

Greenhouse production of tomatoes has increased in recent years. Industry experts have estimated that greenhouse tomatoes comprise 5 to 10% of U.S. tomato consumption. Many large greenhouse tomato firms are planning on increasing acreage considerably in the next five years. Large U.S. operations are currently located in Colorado, New Mexico, Arizona and Texas. Other major growers are located in Ontario, Canada, and in Baja, Sinaloa and Guadelajara, Mexico [95] [96].

The costs of constructing and operating a greenhouse tomato production system in Florida have been analyzed and are presented below in Table 4.B.4. The greenhouse assumed in this analysis is an aluminum frame structure that is available in kit form. Break-even prices at differing yield levels are given in Table 4.B.5[98].

*Organic Production*

In March 1998, an environmental group obtained organically grown Florida fresh tomatoes and distributed them to members of Congress to demonstrate that growing tomatoes without methyl bromide was possible in Florida [24]. No information has been released concerning the yields and production costs of organic tomato production in Florida.

An organic system for tomato production in Florida would likely incorporate several of the alternatives discussed above, including crop rotation, resistant varieties, organic amendments, solarization, plant extract products and/or greenhouse production.

### 3. Other States

There is very little research into methyl bromide alternatives for states other than Florida. Production practices in these states are similar to the system in Florida. Growers in these states face many of the same pest problems as Florida growers, including nematodes, diseases and weeds, and will benefit from the extensive research program undertaken to identify alternatives for Florida tomato production systems.

In a 1993 experiment in Charleston, South Carolina, metam sodium treatments were compared to methyl bromide treatments for control of southern stem blight and effects on yields. All treatments resulted in similar yields, as shown in Table 4.B.8 [76]. Also in Charleston, two years of trials using solarization during the summer months were evaluated for control of nutsedge, nematodes, and Southern blight on a following year's spring tomato crop. Although nutsedge and nematode levels were somewhat reduced the following spring, no beneficial effect on tomato yield was found [77]. (See Table 4.B.9.)

Research trials were conducted in North Carolina over the years 1988–90 to assess the effects of solarization used in combination with the biological control agent *Gliocladium virens* on sclerotia of *Sclerotium rolfsii* and the incidence of Southern blight on tomato. *G. virens* significantly reduced numbers of sclerotia in all three years, while solarization alone reduced the number of sclerotia in only one year. Plant dry weights were doubled four weeks after solarization compared to untreated controls, but fruit yield of tomato planted the season after solarization was not affected by either solarization or the presence of *G. virens* [78].

Trials of soil solarization have also been performed in Georgia for fresh market tomato production. In 1994, trials combined various sorts of plastics with either no treatment, cabbage residues, metam sodium or methyl bromide+chloropicrin. Clear solarization films were painted white at the end of the solarization period to terminate treatment [28]. Results of these trials are presented in Table 4.B.10. Large-scale field plot studies were conducted on two farms in Decatur County, Georgia, in 1996. In these tests, solarization was applied alone and in combination with 1,3-D, or 1,3-D+chloropicrin. Solarization treatments were conducted using clear, low-density polyethylene plastic over raised beds and were terminated by painting film white [79]. Results are presented in Table 4.B.11.

## 4. Current Status of Alternatives

A literature review produced 26 articles that summarized research with methyl bromide alternatives in experiments with Florida tomatoes. Each test included a methyl bromide+chloropicrin treatment for comparison, and all the experiments measured yield differences between individual alternatives and the methyl bromide+chloropicrin standard. The articles included experiments conducted at different locations and during different seasons and years. These articles included 185 treatments that were compared with the methyl bromide+chloropicrin standard in the separate experiments. Forty-three treatments were of metam sodium as a stand-alone alternative; 24 treatments utilized the combination of Telone C-17 plus pebulate. Table 4.B.12 summarizes the yield results of the 185 treatments in comparison to the methyl bromide+chloropicrin standard. As can be seen in the 43 tests with stand-alone metam sodium, tomato yield averaged 78% of the methyl bromide+chloropicrin standard. The 185 individual treatments are listed in Table 4.B.13.

Average yields greater than the methyl bromide+chloropicrin standard were produced in tests that included methyl iodide plus chloropicrin (100.5%). The methyl iodide treatments are not considered further since the active ingredient is not registered. (See chapter on Alternative Specific Analyses.)

Solarization is not considered as a primary replacement for methyl bromide. The soil would have to be solarized during the summer, meaning that solarization would only be practical for the fall-planted crop (40% of Florida production) and not the winter-planted crop. The effectiveness of solarization in Florida in the summer most likely would be greatly reduced because of cloud cover and rain [30]. Grower acceptance is viewed as a major obstacle to solarization [30]. Nematode control has been poor with solarization [30].

A recent survey of Florida tomato growers indicated that 18% would try soil solarization as a way of managing pests without methyl bromide while 70% of surveyed growers listed Telone and chloropicrin (Telone C-17) as an alternative they would utilize [61]. Sixty percent of growers indicated they would try metam sodium while 55% would rotate crops and 30% would apply chloropicrin as a stand-alone treatment [61].

Based on trials conducted to date, researchers and extension specialists indicate that the most likely treatment tomato growers will choose to adopt when methyl bromide is no longer available will be a combination of Telone C-17 and pebulate. The average of 24 experimental comparisons indicated yield losses of approximately 5% using this combination compared to methyl bromide–treated plots. (See Table 4.B.12.) Field-scale trials during the 1996–97 and 1997–98 growing seasons found that the combination of Telone C-17 + pebulate provided similar yields to methyl bromide, although there was a delay in crop maturity of up to a week, which for some growers may be a period when they could receive high prices.

Researchers urge caution when interpreting these results, however, because research trials have taken place in plots that have been fumigated with methyl bromide for many years and consequently have low disease and weed pressures. There are no results available on yields from areas treated with alternatives for successive years. However, a long-term cropping system study is currently under way, in which building up pest levels in the test area is a focus. This has been accomplished by infesting seedling tomato plants with fusarium wilt and root-knot nematodes, transplanting them and allowing them to mature during the 1997–98 season. Plants were then disked under and more inoculated transplants were planted in the spring. Nutsedge tubers have also been introduced into the site. In the fall of 1998, the test plots were planted with a crop of tomato. Several fumigants are being tested [108].

Several caveats are necessary for an appropriate assessment of the viability of Telone C-17 + pebulate as a potential alternative to methyl bromide. First, personal protective equipment is required for 1,3-D applicators. Besides the expense of this equipment, the hot, humid conditions are such that wearing this type of equipment is expected to be a burden that workers will oppose. This issue is described further in Chapter 5 of this report.

At present, 1,3-D products are suspended for use in areas of South Florida that do not possess an impermeable soil layer [22]. The next best alternative that has been tested that does not include 1,3-D is a combination of metam sodium+chloropicrin+pebulate, which in a recent experiment produced tomato yields 9% lower than the methyl bromide+chloropicrin treatment [53]. Experiments with metam sodium demonstrate a lack of consistency in controlling fungi and nematodes with associated inconsistent tomato yields [54].

It should be noted that available alternatives for tomato production have been found to result in greater incidence of root-knot nematodes at final harvest than in methyl bromide–treated plots, even when yields were found to be similar. The viability of a second crop planted into the same field following these treatments has been doubted by researchers, although this has not been confirmed through research. Alternatives research designed to assess the impact of alternatives on second crops is under way as part of the long-term cropping systems study described previously [108].

5. <u>Trade Conflicts</u>

Florida tomato growers face other circumstances that may affect the future viability of current operations. Competition from Mexican producers is an important issue for the Florida tomato industry and has led to trade disputes in recent years. Figure 4.B.3 shows tomato imports from Mexico since the late 1970s, demonstrating a substantial increase since 1993 [73]. U.S. imports of fresh Mexican tomatoes increased 52% from 1993 to

1996, the first three years of the North American Free Trade Agreement (NAFTA). Tariffs are being phased out under NAFTA. The tariff-rate quotas, levels of imports above which higher tariff rates take effect, which were introduced with NAFTA, are also being phased out. While the changes in terms of trade under NAFTA contribute to a favorable position for Mexican imports into the U.S., only a 5 to 9% increase in imports would be expected from the tariff changes alone. Tariffs on Mexican tomato imports were already very small at the time NAFTA was implemented. Much of the change in imports must be attributed to other factors such as the peso devaluation, good weather in Mexico and poor weather in Florida, and technical change in Mexico [67].

On March 25, 1995, the Florida Tomato Exchange, an agricultural marketing cooperative that handles over 90% of the fresh tomatoes sold in Florida, filed a petition with the International Trade Commission (ITC) seeking relief from increased tomato imports. The ITC made a negative determination in the provisional relief phase of the investigation because Florida winter tomatoes could not be considered a separate industry on the basis of seasonality [67] [69]. The petition was subsequently withdrawn and the investigation terminated without a final determination [69]. In March of 1996, Florida growers were among parties who filed a second petition with the ITC for economic relief against import surges of fresh tomatoes and bell peppers. In July of that year, the ITC found that imports were not a substantial cause or threat of serious injury to the U.S. industries [68].

Another petition was filed in April 1996 with the U.S. Department of Commerce (DOC) charging Mexico with dumping tomatoes on the U.S. market at below fair market value prices and materially injuring the domestic industry [69]. The DOC reached a preliminary decision that dumping had in fact occurred, finding that Mexican producers were in fact selling tomatoes at less than fair market value in the U.S. market. On October 28, 1996, the DOC announced a negotiated plan with approximately 85% of Mexican producers/exporters to settle the dispute, and on November 1, 1996, the antidumping investigation was suspended. The negotiated plan established a reference price, or minimum price, of $0.2068/lb for Mexican fresh market tomatoes imported by signatories to the agreement into the U.S. [67] [70]. The reference price was revised in the summer of 1998 to $0.1720/lb for imports between July 1 and October 22 and $0.2108/lb for imports from October 23 through June 30 to account for seasonal price differences [97].

To prevent a reduction in the reference price, the Florida Tomato Growers Exchange has reached an agreed-upon floor price of $5 per 25-lb carton. Under the Capper-Volstead Act of 1922, farmers have the right to form cooperatives that are largely exempt from U.S. antitrust statutes [67].

Other issues facing Florida vegetable growers in general include urban encroachment, environmental restrictions related to Everglades restoration and water management, and uncertain labor availability. In Palm Beach County, developers have been buying parcels in an agricultural reserve with the anticipation that restrictions on development will eventually be lifted. Labor disputes have drawn the attention of national labor organizations, as workers in the Immokalee area demand higher wages. As part of the Everglades restoration efforts, South Florida’s system of canals has been modified, which has led to increases in flooding of agricultural areas near Homestead [72].

## 6. Previous Studies

The impact of a methyl bromide ban on fresh tomato production has been estimated in two reports prepared by NAPIAP[62][74], a report by researchers at the University of Florida (UF)[75], and two reports by researchers at the University of California [109] [110] [111].

In the 1993 NAPIAP report, descriptions of the assumptions used to calculate impacts were given for the five states considered in that study. For California fresh tomato producers, 10% of the acreage was assumed to be taken out of tomato production and planted to a rotation crop. Eighty percent of Florida fresh tomato acreage was expected to be treated with Vorlex, with the remaining 20% taken out of production completely due to increased production costs. In Georgia and North Carolina, half of the tomato growers were assumed to use metam sodium and 10% of the acres was expected to be treated with Vorlex. In South Carolina, 20% of the acres was assumed to be treated with chloropicrin, 25% was expected to be treated with Vorlex and 30% was expected to be treated with metam sodium [74].

The economic analysis provided in the 1993 NAPIAP report estimated impacts assuming that in the short run production losses would not be compensated for by increased imports. In that case, net revenues were expected to increase due to an increase in prices. However, assuming that over time imports would make up 70% of the domestic production loss in the long run, prices were assumed to decline to 7% over pre-ban prices, and U.S. producers were found to suffer losses [74]. (See Table 4.B.14.)

In a 1998 commodity assessment of pesticide uses in tomato production, NAPIAP collected expert opinions from Extension Service specialists who profiled likely replacements for methyl bromide and estimated changes in production resulting from the substitution [62]. The substitution scenarios from the 1998 NAPIAP report are listed in Table 4.B.15 by state. Although released in 1998, the NAPIAP assessment is based on data collected following the 1993 crop year. Thus, the substitution scenarios reflect the understanding in 1993 of the potential of alternatives to replace methyl bromide. The 1998 report acknowledges that since the time the data were collected, a number of studies indicate that there may be viable methyl bromide alternatives [62]. The 1998 report specifically notes that for Florida, the combination of 1,3-D, chloropicrin and pebulate resulted in yields nearly equivalent to those from methyl bromide–treated plots [62]. Nevertheless, the 1998 report’s estimate of the Florida tomato yield change following a methyl bromide ban is –40%, largely because of the assumption that pebulate would not be a viable alternative because of labeling restrictions and that weed control with the alternative fumigants would be poor [62].

Researchers at the University of Florida constructed a model of fresh fruit and vegetable production in Florida to assess the impact of a methyl bromide ban on the state's agricultural sector. Fresh tomato production was modeled along with several other annual crops, including consideration of double cropping practices where a tomato crop may be followed by a second crop of cucumber, squash or melon planted into the plastic-covered beds. The UF model included the major Florida production regions, with the exception of North Florida, and Mexico as a competitive production region that could increase imports in response to increased postban prices in U.S. markets. Yield losses were assumed to be 20% in all production regions except Palm Beach, where a 40% yield loss was expected. Growers in all regions were expected to switch to a combination of Telone C-17 and pebulate, except in Dade County where growers were assumed to use metam sodium and pebulate. Revenue losses for tomato producers were estimated at over $400 million [75].

Researchers at the University of California have also studied the impact of the ban on methyl bromide. The first study considers the impact of the ban on California producers only. The first study was released in 1994 and considered impacts on fresh tomato producers in five regions: Sacramento Valley, San Joaquin Valley, Central Coast, Southern Coast and the Southern Valleys. Metam sodium was considered the best available alternative at the time, as 1,3-D was then suspended in California. Per acre costs were assumed to increase $520 and yields to decrease by 20%. Southern Coast growers were expected to suffer the greatest impact, at $2.6 million of a total $3.0 million for the state [109] [110].

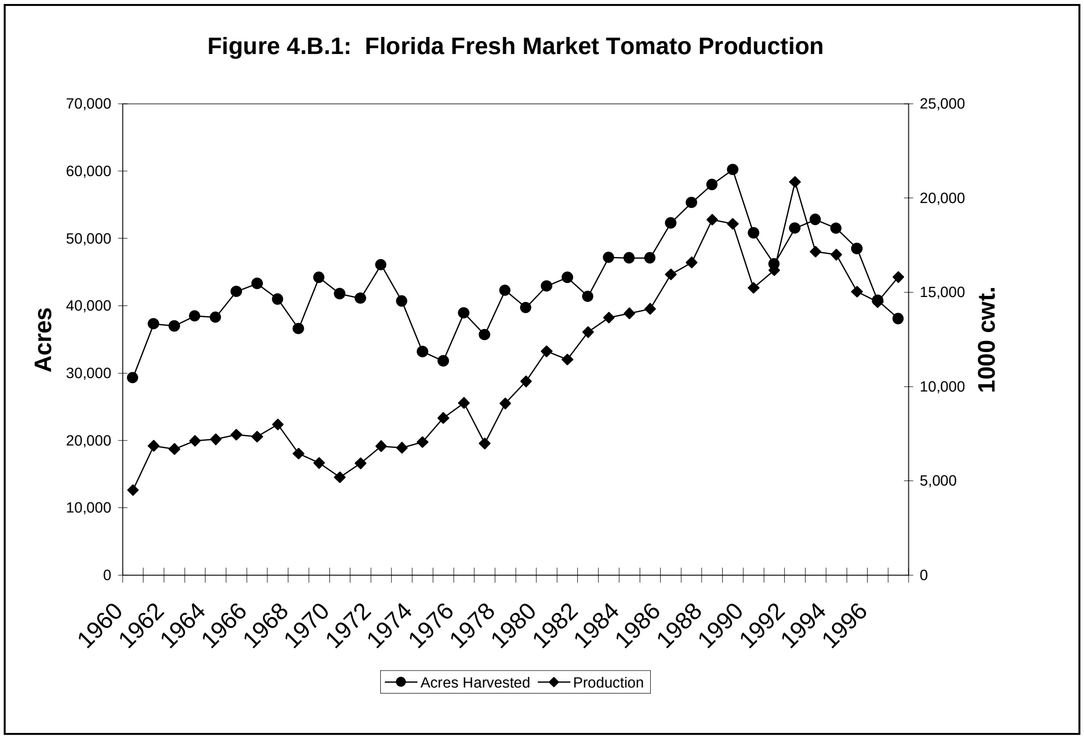
The previous study was extended in a later study to consider the impacts on Florida producers as well as California growers. In addition to the five California production regions, four Florida regions were included in a model of the national impact of the ban. Imports from Mexico were also considered in the model. California growers were assumed to use Vapam, as in the previous study, and Florida growers were assumed to use Telone C-17 as an alternative, with cost changes from a savings of $359/acre to an increase of $416/acre. Double-crop systems were included in the model, where crops such as cucumbers followed tomatoes. Yield losses for Florida tomato growers were estimated to be between 20 and 40% in different production areas. Mexican producers were not assumed to switch away from methyl bromide since they would still be able to use it after the U.S. ban. Regional impacts for different areas within the U.S. were not given. The total U.S. producer impact was estimated as a loss of $65 million [111].

## 7. Yield and Cost Changes Under a Methyl Bromide Ban

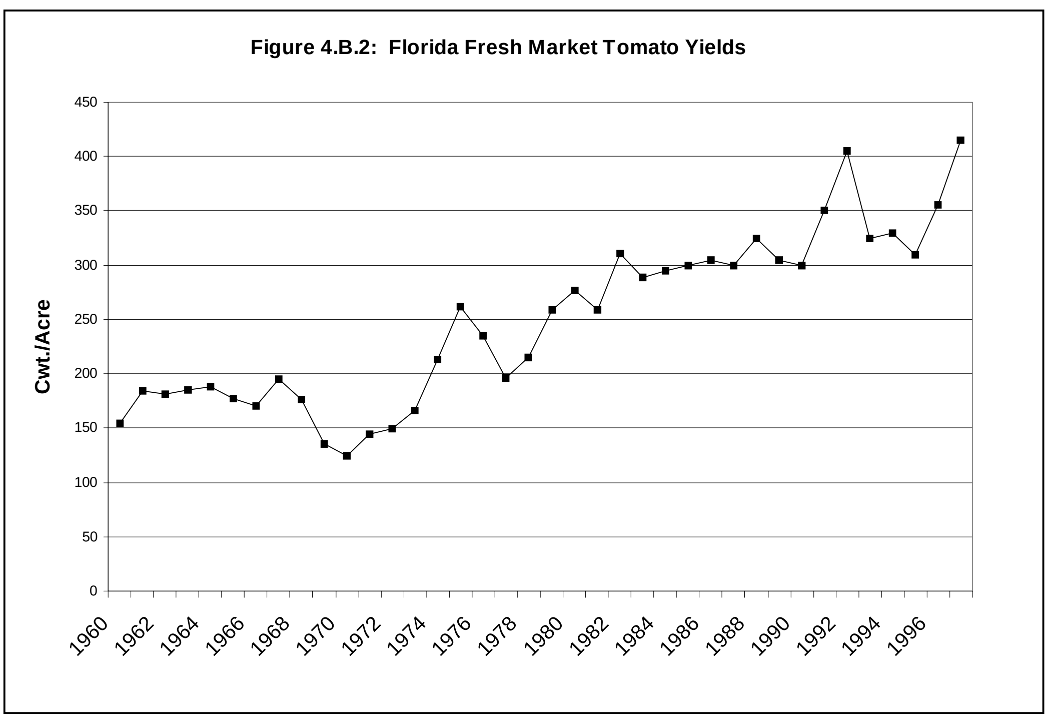
Florida tomato growers fumigate their beds with a mixture of 98% methyl bromide and 2% chloropicrin at a rate of 200 lb/acre for a cost of $230 per acre. Florida growers, outside of Dade County, are assumed to switch to using Telone C-17 at 17.5 gal/acre, which costs $227.50 per acre. Dade County growers, who are restricted from using Telone, will use Vapam instead of Telone, at 37.5 gal/acre, which will cost $153.75. In addition, growers will use the herbicide pebulate at 2 lb/acre, which costs approximately $15.86. The postban change in costs is $13.36 per acre. These costs do not include increased costs that are anticipated due to the more stringent worker safety requirements for Telone. Nor do they include the costs of running a spray boom and disc to distribute and incorporate the herbicide. South Carolina tomato growers are assumed to use Telone C-17 and pebulate as Florida growers and experience postban change in costs of $13.36 per acre.

Although all the tomato growers in Florida are assumed to fumigate their fields with methyl bromide before planting, not all tomato growers in California do so. All growers in the South Coast region were assumed to fumigate as they double or triple crop, keeping the land in production all year round. Tomato growers in other regions of California (San Joaquin, Imperial Valley, and Central Coast) are assumed not to use methyl bromide as an annual practice. Southern California tomato growers are assumed to switch to use Telone applied on the full fields with a comparable cost to methyl bromide/chloropicrin. No change in costs is expected following the ban. Tomato growers in other areas of California use methyl bromide only as a spot treatment rather than as a common production practice. Postban change in cost is also assumed to be zero.

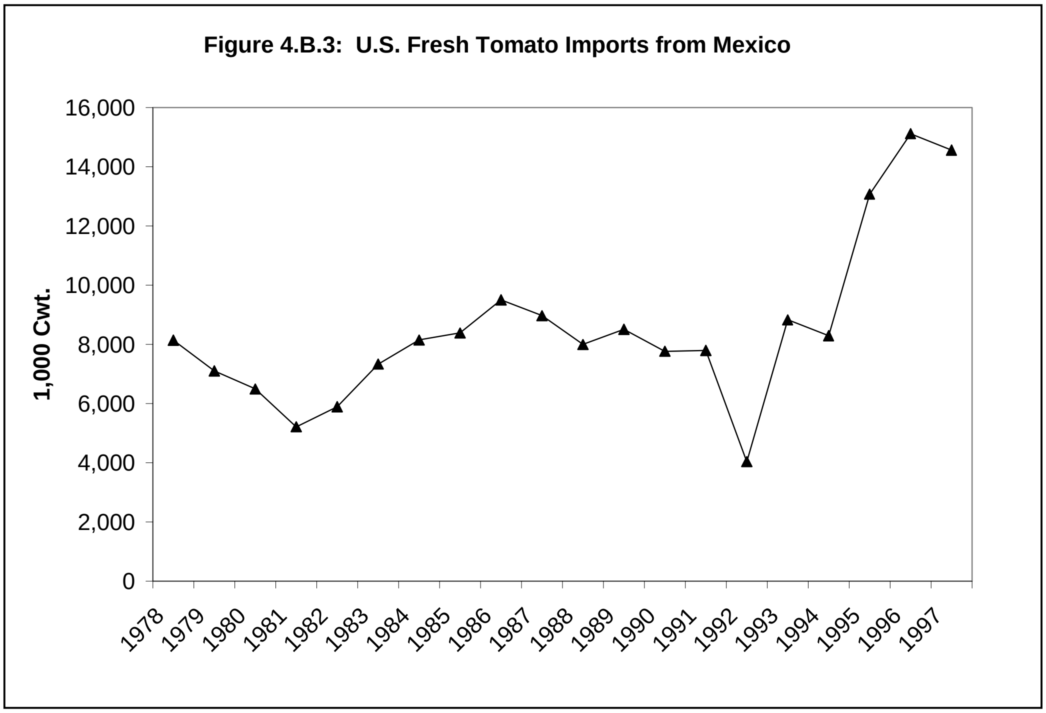
Many research projects have been conducted to identify alternatives for Florida tomato growers. As discussed earlier, the average yield loss for Florida tomatoes using Telone C-17+pebulate from research trials was 5%. In this model, a yield loss of 10% is assumed to account for anticipated pest buildup over time. Dade County growers are assumed to experience yield losses of 17.5% due to less effective control with Vapam. South Carolina growers are assumed to experience a yield loss of 10%. South Coast California tomato growers are assumed to experience a 10% yield decrease relative to methyl bromide–treated acreage.



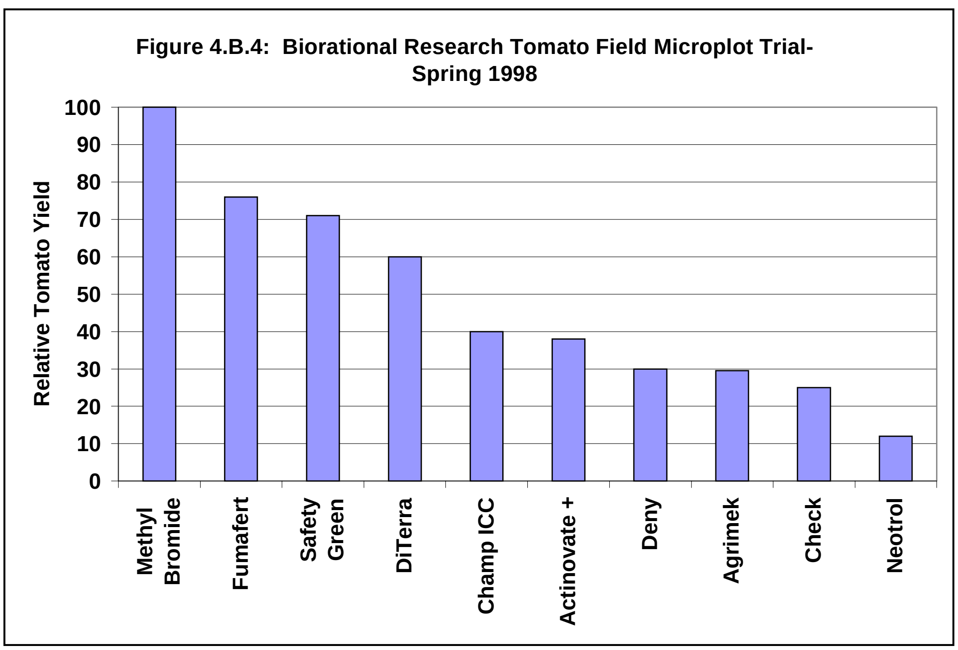

Source: [73]




Source: [73]




Source: [73]




Source: [108]

**TABLE 4.B.1: Effect of Fumigants on Development of Bacterial Wilt (*Pseudomonas solanacearum*) of Tomato**

| Fumigant | Rate/A | | Incidence of Bacterial Wilt (%) 3 April | 19 April | 10 May | 15 June |
|---|---|---|---|---|---|---|
| None | --- | | 8 | 53 | 76 | 92 |
| MBC 67-33 | 350 | lb. | 0 | 7 | 23 | 48 |
| Chloropicrin | 350 | lb. | 0 | 5 | 10 | 26 |
| Metam-sodium | 100 | gal. | 0 | 0 | 2 | 20 |
| Dazomet | 400 | lb. | 0 | 2 | 13 | 37 |
| Telone C-17 | 35 | gal. | 0 | 10 | 22 | 44 |

Source: [8]

**TABLE 4.B.2: Effect of Fumigant Treatment on Fusarium Wilt**

| Fumigant | Broadcast Rate/A | Fusarium Wilt % Infected |
|---|---|---|
| None | 0 | 61 |
| Methyl Bromide/Chloropicrin (98/2) | 400 lb. | 0 |
| Methyl Bromide/Chloropicrin (67/33) | 350 lb. | 0 |
| Chloropicrin | 350 lb. | 7 |
| Vapam (pre-bed) | 100 gal. | 13 |
| Vapam (drip inject) | 100 gal. | 30 |
| Telone C-17 | 35 gal. | 12 |
| Basamid (rototill) | 400 lb. | 4 |
| Enzone +<br>Enzone (drip inject) | 200 gal<br>20 gal.-2x | 14 |
| Telone C-17 +<br>Tillam | 35 gal.<br>4 lb. ai | 3 |
| Telone C-17 +<br>Tillam | 21.4 gal.<br>4 lb. ai | 8 |
| Vapam +<br>Tillam (pre-bed) | 100 gal.<br>4 lb. ai | 4 |

Source: [7]

**TABLE 4.B.3: Effect of Fumigant Treatment on Fusarium Crown Rot**

| Fumigant | Rate/A | Incidence (%) Immok. | Incidence (%) Bradenton |
|---|---|---|---|
| None | 0 | 100 | 58 |
| Methyl Bromide/ Chloropicrin (98/2) | 400 lb. | 73 | 28 |
| Methyl Bromide/ Chloropicrin (67/33) | 350 lb. | 85 | 16 |
| Chloropicrin | 350 lb. | 79 | 24 |
| Vapam (pre-bed) | 100 gal. | 75 | 16 |
| Vapam (drip inject) | 100 gal. | 92 | 17 |
| Telone C-17 | 35 gal. | 73 | 24 |
| Basamid (rototill) | 400 lb. | 88 | 36 |
| Enzone + Enzone (drip inject) | 200 gal 20 gal.-2x | 98 | 45 |
| Telone C-17 + Tillam | 35 gal. 4 lb. ai | --- | 34 |
| Telone C-17 + Tillam | 21.4 gal. 4 lb. ai | --- | 36 |
| Vapam + Tillam (pre-bed) | 100 gal. 4 lb. ai | --- | 32 |

Source: [7]

**Table 4.B.4. Greenhouse Tomato Production Annual Enterprise Budget**

| Item | Cost |
|---|---:|
| **Variable Costs:** | |
| Seed | $47.00 |
| Starter cubes | 15.00 |
| Transplant cubes | 99.00 |
| Utilities | 2,200.00 |
| Fertilizer | 400.00 |
| Pesticide | 100.00 |
| Miscellaneous production items | 130.00 |
| Repair and maintenance | 150.00 |
| Labor | 3,200.00 |
| Hauling, packing, and marketing | 4,070.00 |
| Interest on operating costs | 416.44 |
| **Total Variable Costs** | **$10,827.44** |
| **Fixed Costs:** | |
| Insurance | $100.00 |
| Taxes | 100.00 |
| House[1,2] | 3,038.50 |
| Durables[1,3] | 1,627.40 |
| **Total Fixed Costs** | **$4,865.90** |
| **Total Cost** | **$15,693.34** |

[1] Fixed costs for house and durables equal depreciation plus 10% of average investment over life of item.
[2] Total capital costs for greenhouse of $26,350, including construction costs and costs of irrigation and generator systems.
[3] Total capital costs for other durable goods of $4226, includes cool cell pump, rockwool blocks, shade system, etc.
Source: [97]

**Table 4.B.5. Breakeven Prices for Greenhouse Tomato Production at Nine Yield Levels**

| | **Yield (pounds/plant)** | | |
|---|---|---|---|
| | **17** | **22** | **27** |
| **Plants/house** | **$/pound** | | |
| 850 | 1.001 | 0.821 | 0.707 |
| 925 | 0.937 | 0.771 | 0.667 |
| 975 | 0.899 | 0.742 | 0.660 |

Source: [97]

**Table 4.B.6. Methyl Iodide Trial Results for Florida Fresh Market Tomato, Spring 1995 Experiment 1**

| | | | | M. incognita per 100 cc soil | | | |
|---|---|---|---|---|---|---|---|
| **Treatment** | **Plot Rate (ml)** | **Tomato Yield (g)** | **Nutsedge Germ. (%)** | **Pre** | **Mid** | **Final** | **Root Gall** |
| Check | | 1125.4 [a] | 80.0 | 266 [a] | 21 [a] | 769 [a] | 7.3 [a] |
| Methyl iodide | 0.36 | 2350.0 [ab] | 17.8 | 997 [a] | 0 [b] | 175 [ab] | 5.3 [a] |
| Methyl iodide | 0.72 | 2658.6 [a] | 2.2 | 1021 [a] | 1 [b] | 205 [ab] | 5.6 [a] |
| Methyl iodide | 1.43 | 2460.5 [a] | 0.0 | 678 [a] | 3 [b] | 65 [b] | 4.5 [a] |
| Methyl iodide | 2.87 | 3125.1 [a] | 0.0 | 822 [a] | 0 [b] | 228 [ab] | 5.4 [a] |
| Methyl iodide | 4.29 | 2738.8 [a] | 0.0 | 1339 [a] | 0 [b] | 244 [ab] | 4.4 [a] |

Note: Yields, nematode counts and root gall ratings followed by same letter are not significantly different (P=0.05). Nematode counts taken preplant (Pre), midseason (Mid) and at the end of the season (Final).
Source: [103]

**Table 4.B.7. Methyl Iodide Trial Results for Florida Fresh Market Tomato, Spring 1995 Experiment 2**

| | | | M. incognita per 100 cc soil | |
|---|---|---|---|---|
| **Treatment** | **Plot Rate (ml)** | **Nutsedge Density/Microplot** | **Pre** | **Post** |
| Check | | 4.75 [a] | 405 [a] | 843 [a] |
| Methyl iodide | 2.0 | 0.014 [b] | 774 [a] | 0 [b] |
| Methyl iodide | 4.0 | 0.0 [b] | 472 [a] | 0 [b] |

Note: Nematode and nutsedge counts followed by same letter are not significantly different (P=0.05). Nematode counts taken preplant (Pre) and at the end of the season (Post).
Source: [103]

**Table 4.B.8. South Carolina Tomato Research Results Using Metam Sodium**

| Treatment, rate/A, (injector spacing) | Disease incidence[1] | Weight marketable fruit (lb/50 ft) |
|---|---|---|
| Vapam 50 gal/A, (5 in.) | 11.2 | 138 |
| Vapam 75 gal/A, (5 in.) | 7.0 | 149 |
| Vapam 100 gal/A, (5 in.) | 7.0 | 126 |
| Vapam 100 gal/A, (10 in.) | 5.0 | 155 |
| Methyl Bromide 200 lb/A, (10 in.) | 10.6 | 148 |
| Untreated | 57.7 | 106 |
| Least Significant Difference | 14.5 | NS |

[1] Percentage of plants with symptoms of southern stem blight and signs of *Sclerotium rolfsii*.
Source: [76]

**Table 4B.9. South Carolina Solarization Trial Results for Fresh Market Tomato**

| | Marketable Yield (lb./10 ft.)[1] | |
|---|---|---|
| **Type of Plastic** | **1992** | **1993** |
| Control | 102.7 | 6.6 |
| Clear | 111.8 | 7.3 |
| Black | 110.0 | 8.3 |
| Infrared-transmitting | 109.6 | 5.4 |

[1] Yields recorded from three harvests in 1992 and from one harvest in 1993. Southern stem blight was severe in 1993 but not detected in 1992.
Source: [77]

**Table 4.B.10. Georgia Fresh Market Tomato Solarization Trial Research Results**

| | | Plastic film[1] | | | |
|---|---|---|---|---|---|
| **Treatment** | **Rate per m[2]** | **Clear, GI** | **White** | **Clear** | **IRT** |
| | | Yield (mt/ha) | | | |
| None | | 45.4[a] | 23.2[c] | 48.5[a] | 42.6[ab] |
| Cabbage | 8.0 kg | 51.7[a] | 28.7[c] | 50.9[a] | 32.2[bc] |
| Metam Sodium | 5.8 g | 53.7[a] | 46.2[a] | 42.0[ab] | 45.7[a] |
| MBC | 13.1 + 6.5 g | 46.7[a] | 49.3[a] | 47.0[a] | 46.0[a] |

[1] Clear, GI=clear, gas-impermeable solarization film; white-white on black, coextruded, LDPE; clear=clear LDPE solarization film; and IRT= a photoselective solarization film. Means for the interaction of soil treatment and plastic film followed by the same letter do not differ according to the Waller-Duncan *k*-ratio *t* test (P<=0.05).
Source: [28]

**Table 4.B.11. Large Scale Solarization Trials Research Results for Fresh Market Tomato in Georgia**

| | | Yield (25-lb. cartons/acre) | | |
|---|---|---|---|---|
| **Farm** | **Treatment (rate per acre)** | **Total** | **Extra Large** | **Root Galls[1]** |
| 5 | Solarization | 1790 | 1384 | 0.8 |
| 5 | Solarization + 1,3-D (10 gal.) | 2254 | 1493 | 0.8 |
| 5 | Methyl Bromide (400 lbs.) | 2472 | 1521 | 0.0 |
| 6 | Solarization | 1723 | 812 | 0.6 |
| 6 | Solarization + 1,3-D + Chloropicrin (17.5 gal.) | 1466 | 824 | 0.1 |
| 6 | Methyl Bromide (400 lbs.) | 1819 | 1184 | 0.0 |

[1] Root gall ratings on a scale of 1 to 5.
Source: [79]

**Table 4.B.12 Average Relative Yields Under Methyl Bromide Alternatives from Florida Fresh Market Tomato Research Trials[1]**

| Treatment | Average Yield Relative to MBC (%) | Number of Results | Standard Error[2] | Minimum (%) | Maximum (%) |
|---|---|---|---|---|---|
| Methyl Iodide + Chloropicrin | 100.5 | 2 | 2.1 | 99 | 102 |
| Solarization + Telone C-17 | 97.3 | 3 | 16.2 | 88 | 116 |
| Telone C-17 + Metam Sodium | 96.0 | 2 | 15.6 | 86 | 107 |
| Telone C-17 + Pebulate | 94.5 | 24 | 10.9 | 75 | 117 |
| Solarization | 94.1 | 9 | 9.5 | 81 | 107 |
| Basamid + Pebulate | 93.2 | 5 | 13.8 | 82 | 116 |
| Telone C-35 + Pebulate | 89.9 | 14 | 10.2 | 69 | 102 |
| Telone C-17 | 88.9 | 13 | 19.4 | 55 | 146 |
| Chloropicrin + Pebulate | 88.0 | 9 | 20.1 | 58 | 119 |
| Telone II | 82.0 | 4 | 16.5 | 62 | 102 |
| Metam Sodium + Chloropicrin + Pebulate | 81.7 | 7 | 9.3 | 72 | 95 |
| Basamid | 81.1 | 18 | 19.2 | 52 | 107 |
| Metam Sodium + Chloropicrin | 81.0 | 4 | 11.2 | 71 | 93 |
| Metam Sodium + Pebulate | 80.5 | 13 | 20.8 | 48 | 121 |
| Metam Sodium | 78.4 | 43 | 24.0 | 19 | 129 |
| Methyl Iodide | 77.5 | 2 | 10.6 | 70 | 85 |
| Chloropicrin | 74.7 | 13 | 24.8 | 16 | 100 |

[1] Research results summarized here only include treatments Telone, Chloropicrin, Metam Sodium, Basamid, Methyl Iodide and Solarization, with or without Pebulate, and combinations thereof. Solarization results only presented for fall trials using clear LDPE.

[2] Standard error of average of relative yields from research trials.

**Table 4.B.13 Methyl Bromide Alternatives Research Results for Florida Fresh Tomato Production[1]**

| Study/Reference Number | Year | Location | Season | Treatment | Rate per Acre | Yield Relative to MB/C[2] |
|---|---|---|---|---|---|---|
| Chase, et al. 1997 [89] | 1996 | Gainesville | Spring | Solarization | | 77% |
| Chellemi 1998 [60] | 1996 | | Fall | Solarization | | 85% |
| | 1996 | | Fall | Solarization + Telone II | 95 lbs. | 91% |
| | 1997 | | Fall | Solarization | | 92% |
| Chellemi, et al. 1997[3] [79] | 1995 | Gadsden County | Fall | Solarization | | 99% |
| | | | | Solarization | | 107% |
| | | | | Solarization | | 85% |
| | | | | Solarization + Telone C-17 | 173 lbs. | 88% |
| | | | | Solarization + Telone C-17 | 347 lbs. | 116% |
| Chellemi, et al. 1997 [28] | 1995 | Northern Florida (Site I) | Fall | Telone C-17 | 351 lbs. | 116% |
| | | | | Solarization + Telone C-17 | 175 lbs. | 88% |
| | 1995 | Northern Florida (Site II) | Fall | Solarization | | 107% |
| | 1995 | Northern Florida (Site III) | Fall | Solarization | | 99% |
| Dickson 1994 [38] | | | Spring/Summer | Chloropicrin | 347 lbs. | 74% |
| | | | | Chloropicrin + Pebulate | 347 lbs. + 4 lbs. | 60-65% |
| | | | | Telone C-17 | 344 lbs. | 72% |
| | | | | Telone C-17 + Pebulate | 344 lbs. + 4 lbs. | 77% |
| | | | | Basamid | 401 lbs. | 51-54% |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | Metam Sodium (surface) | 318 lbs. | 60-65% |
| | | | | Metam Sodium (drip) | 318 lbs. | 60-65% |
| Dickson 1997 [39] | 1997 | Gainesville | Spring | Telone C-17 +<br>Pebulate | 346 lbs. +<br>4 lbs. | 86%<br>(92-94%)[4] |
| | | | | Telone C-35 +<br>Pebulate | 129 lbs. +<br>4 lbs. | 91-93%<br>(101%) |
| | | | | Telone C-35 +<br>Pebulate | 193 lbs. +<br>4 lbs. | 91-93%<br>(101%) |
| | | | | Telone C-35 +<br>Pebulate | 257 lbs. +<br>4 lbs. | 83-84%<br>(101%) |
| | | | | Chloropicrin +<br>Pebulate | 234 lbs. +<br>4 lbs. | 77-78% |
| Dickson, et al. 1995 [49] | 1995 | Gainesville | Spring | Chloropicrin +<br>Pebulate | 40 gal. +<br>4 lbs. | 93% |
| | | | | Telone C-17 +<br>Pebulate | 346 lbs. +<br>4 lbs. | 93% |
| | | | | Basamid +<br>Pebulate | 399 lbs. +<br>4 lbs. | 86% |
| | | | | Telone C-17 +<br>Metam Sodium (drip) | 346 lbs. +<br>239 lbs. | 85% |
| | | | | Metam Sodium (drip) +<br>Pebulate | 318 lbs. +<br>4 lbs. | 72% |
| | | | | Telone II (drip) | 126 lbs. | 62% |
| Dickson, et al. 1998 [52] | 1998 | Gainesville | Spring | Telone C-17 +<br>Pebulate | 347 lbs. +<br>4 lbs. | 92% |
| | | | | Telone C-35 +<br>Pebulate | 258 lbs. +<br>4 lbs. | 80% |
| | | | | Telone C-35 +<br>Pebulate | 322 lbs. +<br>4 lbs. | 94% |
| | | | | Telone C-35 +<br>Pebulate | 386 lbs. +<br>4 lbs. | 102% |
| | | | | Metam Sodium + | 239 lbs. + | 80% |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | Pebulate | 4 lbs. | |
| | | | | Metam Sodium +<br>Chloropicrin | 239 lbs. +<br>150 lbs. | 71% |
| | | | | Metam Sodium +<br>Chloropicrin +<br>Pebulate | 239 lbs. +<br>75 lbs. +<br>4 lbs. | 74% |
| | | | | Metam Sodium +<br>Chloropicrin +<br>Pebulate | 239 lbs. +<br>100 lbs. +<br>4 lbs. | 87% |
| | | | | Metam Sodium +<br>Chloropicrin +<br>Pebulate | 239 lbs. +<br>150 lbs. +<br>4 lbs. | 95% |
| Gilreath, et al. 1994 [47] | 1993 | | Spring | Chloropicrin | 200 lbs. | 100% |
| | | | | Basamid | 346 lbs. | 107% |
| | | | | Telone II | 182 lbs. | 102% |
| | | | | Telone C-17 | 227 lbs. | 105% |
| | | | | Telone C-17 | 371 lbs. | 99% |
| | | | | Metam Sodium (injected) | 318 lbs. | 95% |
| | | | | Metam Sodium (injected) | 636 lbs. | 98% |
| | | | | Telone C-17 +<br>Chloropicrin | 227 lbs. +<br>149 lbs. | 88% |
| | | | | Telone C-17 +<br>Metam Sodium (injected) | 227 lbs. +<br>159 lbs. | 107% |
| | | | | Telone C-17 +<br>Pebulate | 227 lbs. +<br>4 lbs. | 102% |
| | | | Fall | Chloropicrin | 200 lbs. | 68% |
| | | | | Basamid | 346 lbs. | 85% |
| | | | | Basamid | 446 lbs. | 78% |
| | | | | Metam Sodium (surface) | 318 lbs. | 70% |
| | | | | Telone C-17 +<br>Pebulate | 227 lbs. +<br>4 lbs. | 89% |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | Telone C-17 + Pebulate | 371 lbs. + 4 lbs. | 87% |
| Gilreath, et al. 1994 [7] | 1994 | Immokalee | Spring | Chloropicrin | 350 lbs. | 92% |
| | | | | Metam Sodium (pre-bed) | 318 lbs. | 92% |
| | | | | Metam Sodium (drip) | 318 lbs. | 87% |
| | | | | Telone C-17 | 347 lbs. | 98% |
| | | | | Basamid | 400 lbs. | 86% |
| | 1994 | Bradenton | Spring | Chloropicrin | 347 lbs. | 53% |
| | | | | Telone C-17 | 346 lbs. | 55% |
| | | | | Telone C-17 + Pebulate | 346 lbs. + 4 lbs. | 101% |
| | | | | Telone C-17 + Pebulate | 212 lbs. + 4 lbs. | 117% |
| | | | | Basamid | 392 lbs. | 54% |
| | | | | Metam Sodium (pre-bed) | 102 lbs. | 19% |
| | | | | Metam Sodium (pre-bed) + Pebulate | 102 lbs. + 4 lbs. | 48% |
| | | | | Metam Sodium (drip) | 102 lbs. | 47% |
| Gilreath, et al. 1997 [15] | 1996 | Bradenton | Fall | Telone C-17 + Pebulate | 347 lbs. + 4 lbs. | 99% |
| | 1996 | Myakka | Fall | Telone C-17 + Pebulate | 347 lbs. + 4 lbs. | 81% |
| | 1996 | Ruskin | Fall | Telone C-17 + Pebulate | 347 lbs. + 4 lbs. | 88% |
| | 1997 | Bradenton | Spring | Telone C-17 + Pebulate | 347 lbs. + 4 lbs. | 104% |
| | 1997 | Ruskin | Spring | Telone C-17 + Pebulate | 347 lbs. + 4 lbs. | 107% |
| | 1997 | Naples | Spring | Telone C-17 + Pebulate | 347 lbs. + 4 lbs. | 113% |
| Jones, et al. 1978 [81] | 1974 | | Spring | Telone II | 237 lbs. | 85% |

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|---|---|---|---|---|---|---|
| | 1975 | | Spring | Telone C-15 | 24 gal. | 82% |
| | | | | Telone C-15 | 20 gal. | 80% |
| | | | | Telone C-15 | 14 gal. | 80% |
| | 1975 | | Fall | Telone II | 190 lbs. | 79% |
| Jones, et al. 1985[5] [4] | 1985 | | Spring | Metam Sodium (inject) | 159 lbs. | 47% |
| | | | | Metam Sodium (inject) | 159 lbs. | 68% |
| Jones, et al. 1995 [8] | 1995 | Bradenton | Spring | Chloropicrin + Pebulate | 350 lbs. + 4 lbs. | 93% |
| | | | | Metam Sodium (surface) + Pebulate | 318 lbs. + 4 lbs. | 121% |
| | | | | Basamid + Pebulate | 400 lbs. + 4 lbs. | 116% |
| | | | | Telone C-17 + Pebulate | 347 lbs. + 4 lbs. | 95% |
| Locascio, et al. 1997 [59] | 1994 | Gainesville (Horticultural Unit) | Spring | Chloropicrin | 347 lbs. | 61% |
| | | | | Chloropicrin + Pebulate | 347 lbs. + 4 lbs. | 85% |
| | | | | Telone C-17 | 346 lbs. | 69% |
| | | | | Telone C-17 + Pebulate | 346 lbs. + 4 lbs. | 84% |
| | | | | Basamid | 392 lbs. | 64% |
| | | | | Basamid (irrigated) | 392 lbs. | 61% |
| | | | | Metam Sodium (surface) | 102 lbs. | 45% |
| | | | | Metam sodium (drip) | 102 lbs. | 64% |
| | 1995 | Gainesville (Horticultural Unit) | Spring | Chloropicrin + Pebulate | 347 lbs. + 4 lbs. | 111% |
| | | | | Telone C-17 + Pebulate | 346 lbs. + 4 lbs. | 100% |

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|---|---|---|---|---|---|---|
| | | | | Basamid + Pebulate | 392 lbs. + 4 lbs. | 82% |
| | | | | Metam sodium (surface) + Pebulate | 102 lbs. + 4 lbs. | 75% |
| | 1994 | Gainesville (Green Acres) | Spring | Chloropicrin | 347 lbs. | 72% |
| | | | | Chloropicrin + Pebulate | 347 lbs. + 4 lbs. | 58% |
| | | | | Telone C-17 | 346 lbs. | 70% |
| | | | | Telone C-17 + Pebulate | 346 lbs. + 4 lbs. | 75% |
| | | | | Basamid | 392 lbs. | 52% |
| | | | | Metam Sodium (surface) | 102 lbs. | 63% |
| | | | | Metam Sodium (drip) | 102 lbs. | 62% |
| | 1995 | Gainesville (Green Acres) | Spring | Chloropicrin + Pebulate | 347 lbs. + 4 lbs. | 93% |
| | | | | Telone C-17 | 346 lbs. | 57% |
| | | | | Telone C-17 + Pebulate | 346 lbs. + 4 lbs. | 93% |
| | | | | Basamid + Pebulate | 392 lbs. + 4 lbs. | 86% |
| | | | | Metam Sodium (surface) + Pebulate | 102 lbs. + 4 lbs. | 72% |
| | 1994 | Bradenton | Spring | Chloropicrin | 347 lbs. | 53% |
| | | | | Telone C-17 + Pebulate | 346 lbs. + 4 lbs. | 101% |
| | | | | Basamid | 392 lbs. | 54% |
| | | | | Metam Sodium (surface) | 102 lbs. | 19% |
| | | | | Metam Sodium (surface) + Pebulate | 102 lbs. + 4 lbs. | 48% |
| | | | | Metam Sodium (drip) | 102 lbs. | 47% |

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|---|---|---|---|---|---|---|
| | 1994 | Bradenton | Fall | Chloropicrin + Pebulate | 347 lbs. + 4 lbs. | 119% |
| | | | | Telone C-17 + Pebulate | 346 lbs. + 4 lbs. | 107% |
| | | | | Basamid + Pebulate | 392 lbs. + 4 lbs. | 96% |
| | | | | Metam Sodium (surface) + Pebulate | 102 lbs. + 4 lbs. | 101% |
| Locascio, et al. 1998 [53] | 1997 | Gainesville | Fall | Metam Sodium (surface) | 102 lbs. | 70% |
| | | | | Metam Sodium (surface, irrigated) | 100 lbs. | 62% |
| | | | | Metam Sodium (surface) + Pebulate | 100 lbs. + 4 lbs. | 80% |
| | | | | Metam Sodium (surface, irrigated) + Pebulate | 100 lbs. + 4 lbs. | 72% |
| | | | | Metam Sodium (surface) + Chloropicrin | 100 lbs. + 150 lbs. | 88% |
| | | | | Metam Sodium (surface, irrigated) + Chloropicrin | 100 lbs. + 150 lbs. | 93% |
| | | | | Metam Sodium (surface, irrigated) + Chloropicrin + Pebulate | 100 lbs. + 150 lbs. + 4 lbs. | 91% |
| | | | | Telone C-35 + Pebulate | 193 lbs. + 4 lbs. | 69% |
| | | | | Telone C-35 + Pebulate | 257 lbs. + 4 lbs. | 92% |
| | 1998 | Gainesville | Spring | Metam Sodium (surface) + Pebulate | 100 lbs. + 4 lbs. | 79% |
| | | | | Metam Sodium (surface) + | 100 lbs. + | 72% |

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|---|---|---|---|---|---|---|
| | | | | Chloropicrin | 150 lbs. | |
| | | | | Metam Sodium (surface) + Chloropicrin + Pebulate | 100 lbs. + 75 lbs. + 4 lbs. | 72% |
| | | | | Metam Sodium (surface) + Chloropicrin + Pebulate | 100 lbs. + 100 lbs. + 4 lbs. | 80% |
| | | | | Metam Sodium (surface) + Chloropicrin + Pebulate | 100 lbs. + 150 lbs. + 4 lbs. | 73% |
| | | | | Telone C-35 + Pebulate | 257 lbs. + 4 lbs. | 78% |
| | | | | Telone C-35 + Pebulate | 321 lbs. + 4 lbs. | 92% |
| | | | | Telone C-35 + Pebulate | 385 lbs. + 4 lbs. | 81% |
| | | | | Telone C-17 + Pebulate | 346 lbs. + 4 lbs. | 85% |
| McGovern, et al. 1998 [2] | 1992-93 | Immokalee | Winter | Metam sodium (inject) | 318 lbs. | 97% |
| | 1992-93 | Immokalee | Fall/Winter | Metam Sodium (drip) | 238 lbs. | 95% |
| | | | | Metam Sodium (drip) | 318 lbs. | 63% |
| | 1993 | Immokalee | Winter/Spring | Metam Sodium (inject) | 318 lbs. | 129% |
| | 1994 | Immokalee | Spring | Metam Sodium (drip) | 318 lbs. | 94% |
| | | | | Metam Sodium (pre-bed surface) | 318 lbs. | 99% |
| | 1994-95 | Immokalee | Winter/Spring | Metam Sodium (pre-bed surface) + Pebulate | 318 lbs. + 4 lbs. | 93% |
| | | | | Metam Sodium (rotovated) + | 318 lbs. + 4 lbs. | 105% |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | Pebulate | | |
| | 1994-95 | Immokalee | Fall/Winter | Metam Sodium (rotovated) | 318 lbs. | 91% |
| McMillan, et al. 1996 [83] | 1995-96 | Dade County | Winter | Methyl iodide | 375 lbs. | 70% |
| | | | | Methyl iodide+ Chloropicrin | 375 lbs. + 75 lbs. | 99% |
| | | | | Chloropicrin | 75 lbs. | 99% |
| McMillan, et al. 1996 [88] | 1994-95 | Dade County | Winter | Methyl iodide | 375 lbs. | 85% |
| | | | | Methyl iodide + Chloropicrin | 375 lbs. + 75 lbs. | 102% |
| | | | | Chloropicrin | 75 lbs. | 89% |
| McSorley, et al. 1985 [42] | 1983-84 | Homestead | Winter | Metam Sodium (surface) | 318 lbs. | 84% |
| | | | | Basamid (plastic seal) | 530 lbs. | 97% |
| | | | | Basamid (water seal) | 530 lbs. | 95% |
| | 1984-85 | Homestead | Winter | Metam Sodium (surface) | 159 lbs. | 86% |
| | | | | Metam Sodium (Trapex 40) (inject) | 25 gal. | 100% |
| | 1984-85 | Homestead | Winter | Metam Sodium (Trapex 40) (inject) | 25 gal. | 75% |
| | | | | Metam Sodium (surface) | 159 lbs. | 85% |
| | | | | Metam Sodium (Busan 1020) (surface) | 50 gal. | 51% |
| | | | | Chloropicrin (Soilex C-17) | 25 gal. | 16% |
| McSorley, et al. 1986 [26] | 1985-86 | Homestead | Fall/Winter | Solarization | | 81% |
| McSorley, et al. 1986 [40] | 1985-86 | Homestead | Winter | Metam Sodium (Trapex 40) (inject) | 25 gal. | 116% |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | Metam Sodium (Trapex 40) (inject) | 35 gal. | 126% |
| Olson, et al. 1994 [86] | 1993 | Quincy | Spring | Metam Sodium (drip) | 159 lbs. | 89% |
| | | | | Metam Sodium (drip) | 239 lbs. | 87% |
| | | | | Metam Sodium (drip) | 318 lbs. | 91% |
| | | | | Metam Sodium (surface) | 318 lbs. | 96% |
| | | | | Telone C-17 | 212 lbs. | 91% |
| | | | | Basamid | 150 lbs. | 93% |
| | | | | Basamid | 300 lbs. | 85% |
| | 1994 | Quincy | Spring | Chloropicrin | 350 lbs. | 97% |
| | | | | Metam Sodium (drip) | 318 lbs. | 92% |
| | | | | Metam Sodium (surface) | 318 lbs. | 93% |
| | | | | Telone C-17 | 347 lbs. | 86% |
| | | | | Basamid | 400 lbs. | 95% |
| Olson, et al. 1996 [41] | 1995 | Quincy | Spring | Telone C-17 | 347 lbs. | 92% |
| | | | | Metam Sodium (pre-bed) | 318 lbs. | 86% |
| | | | | Basamid (pre-bed) | 400 lbs. | 96% |
| | | | | Chloropicrin | 350 lbs. | 97% |
| Overman, et al. 1984[6] [82] | 1984 | | Spring | Metam Sodium (Trapex 40) (inject) | 25 gal. | 82% |
| | | | | Metam Sodium (Trapex 40) (inject) | 25 gal. | 84% |
| Overman, et al. 1986 [43] | 1985 | | Fall | Solarization | | 92% |
| Robinson, et al. 1996 [87] | | Immokalee | | Basamid | 350 lbs. | 100% |
| | | | | Basamid | 450 lbs. | 106% |

[1] Research results summarized here only include treatments Telone, Chloropicrin, Metam Sodium, Basamid, Methyl Iodide and Solarization, with or without Pebulate, and combinations thereof. Solarization results only presented for trails using clear LDPE.
[2] Relative yields calculated in comparison to highest yielding methyl bromide/chloropicrin treatment.
[3] Results from trials at different locations.
[4] One of six blocks infested with pseudomonas solanacearum. Yields in parentheses exclude the infested block.
[5] First result from plots with pH of 5.5; second result from plots with pH of 7.5.

[6] Chloropicrin and Telone C-17 treated plots planted with 'Sunny' and Metam Sodium treated plots planted with 'Olympic.'
[7] First result from plots inoculated with Fusarium wilt; second result from plots inoculated with Fusarium crown rot.

**Table 4.B.14 Methyl Bromide Use and Loss Estimates for Fresh Tomato Production from 1993 NAPIAP Report[1]**

| State | Production Acres | Production Total Tons | Acres Treated | Yield Loss w/o MB (Tons) | Per Acre Change in Control Cost | Net Revenue Change Without Imports ($1,000) | Net Revenue Change With Imports ($1,000) |
|---|---|---|---|---|---|---|---|
| **California** | 38,000 | 479,000 | 592 | 5,147 | -675 | | |
| **Florida** | 55,800 | 825,840 | 54,684 | 161,865[2]<br>404,661[3] | 299[2]<br>132[3] | | |
| **Georgia** | 3,100 | 36,800 | 2,790 | 16,740[4]<br>23,436[5] | -245[2]<br>-100[3] | | |
| **North Carolina** | 3,387 | 49,496 | 1,400 | 10,220[4]<br>14,308[5] | 91[2]<br>113[3] | | |
| **South Carolina** | 4,000 | 70,000 | 4,000 | 21,000[4]<br>63,000[6] | -12[2]<br>285[3] | | |
| **TOTALS** | | | | | | **60,600[2,4]**<br>**81,700[3,4]** | **-86,300[2,4]**<br>**-180,600[3,4]** |

[1] Impacts assuming other fumigants available. Revenue changes assuming elasticity of demand of –0.5580, total U.S. production of 1,717,000 tons, and production loss offset by imports of 70%.
[2] Assuming Vorlex is available.
[3] Assuming Vorlex is not available.
[4] Loss in first year.
[5] Loss in subsequent years.
[6] Loss in third and later years.
Source: [74]

**Table 4.B.15 Methyl Bromide (MB) Use on Fresh Tomatoes in 1993 – Impact of Withdrawal – from 1998 NAPIAP Tomato Assessment**

| State | Major Targeted Pests | % Acres Currently Treated with MB | Acres Treated with MB | LB Al Per Acre | Total LB MB Applied | Alternatives Used if MB was Not Available (% Acreage Treated) | % Yield Change on MB Treated Acres using Alternatives To MB |
|---|---|---|---|---|---|---|---|
| AL | Nematodes | 50 | 2,500 | 350 | 875,000 | Metam sodium (80), 1,3 D (20). Crop rotation (5) | -10 |
| CA | Weeds | 1.5 | 570 | 350 | 199,500 | Metam sodium (100) | -10 |
| FL | Soilborne Pathogens, nematodes, All Weeds (Especially Nutsedges) Insects | 98 | 51,783 | 191 | 9,890,553 | Metam sodium (93), 1,3 D (97). Pebulate (75) | -40 |
| GA | SoilBorne Pathogens, Nematodes, All Weeds | 100 | 2,940 | 250 | 733,500 | Metam sodium (95), dazomet (5) | -50 |
| IN | Nematodes | 5 | 67 | 350 | 23,450 | None | -30 |
| MD | Nematodes, Annual Weeds, yellow Nutsedge | 25 | 695 | 300 | 208,500 | Handweeding (50) | -10 |
| NJ | Phythopthora | 5 | 242 | 350 | 84,700 | Metam sodium (100) | -0.1 |
| OH | Root-knot | 10 | 296 | 420 | 124,320 | Metam Sodium | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Nematodes | | | | | (100) | |
| SC | Nematodes All Weeds (especially nutsedges) | 99 | 3,564 | 196 | 698,544 | Chloropicrin (50) | -30 |
| TN | Nematodes, Soilborne fungi, Bacterial Diseases, Weeds, Nutsedge | 40 | 1,760 | 117 | 205,920 | Metribuzin (90), paraquat (50), cultivation (50), metam sodium (10), chloropicrin (100) | -40 |
| VA | Nematodes, Weeds, Grasses | 90 | 2,989 | 350 | 1,014,300 | None | -35 |
| **U.S. Totals** | | **50.1** | **67,315** | **209** | **14,059,787** | | **-23.4** |

**Source [62]**

**Note: Although published in 1998, data for this table were collected in 1994.**

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## C. Perennial Crops

### 1. Introduction

Methyl bromide is used in orchards and vineyards before planting new trees and vines. Methyl bromide has been especially useful in replant situations where an existing orchard or vineyard is being replanted to the same or different crop. The use of methyl bromide increases plant growth by eliminating plant pathogens, nematodes, and insects and by remedying myriad other detrimental factors commonly present in old orchard sites. These detrimental conditions (known as the replant problem, which is described further later) are commonly present in old orchard and vineyard sites to varying degrees throughout the country.

The U.S. has approximately 4.4 million acres in orchard and vineyard crops. California accounts for slightly less than one-half of this acreage. (See Table 4.C.1.) The regular use of methyl bromide in replant situations is more common in California than in other states. The reasons that methyl bromide is not regularly used in other states vary: (1) the benefits of its use in these states have not been demonstrated (2) soil conditions preclude its use (3) its cost is too high in relation to the potential benefits and (4) in some states the replant problem has not yet been linked to specific causes or has been linked to causes that are treated with other techniques.

The analysis herein of methyl bromide use in perennial crops is limited to California. A discussion of the reasons that methyl bromide is not regularly used in perennial crops in states other than California is provided in the section entitled "Other States."

2. California

There are approximately 2 million acres of fruit and nut crops in California with an annual production value of $5 billion. Table 4.C.2 lists the major fruit and nut crops that are grown in California. Grapes and almonds account for nearly half of California's perennial crop acreage. Both of these crops have been expanding acreage in recent years. Citrus and walnuts also occupy large acreages.

Major table and raisin grape production comes from the San Joaquin Valley. Fresno is the dominant raisin grape producing county. Tulare, Kern, Fresno and Riverside Counties are the major table grape growing counties. Wine grape production was reported from 28 California counties in 1996. Fresno and San Joaquin Counties are the largest wine grape growing counties, though counties with the highest value production are Sonoma, Napa and Monterey Counties. Citrus production is primarily located in the San Joaquin and Imperial Valleys. Walnut production is concentrated in the Sacramento and San Joaquin Valleys [77].

*Soil Fumigation*

Soil fumigation was developed over a century ago in France where carbon disulfide was used to control phylloxera in grape vineyards [3]. After World War I, it was discovered that leftover chloropicrin, a tear gas, was an effective soil fumigant for killing insects and nematodes in pineapple growing areas [3]. In the 1940s and 1950s, several other fumigants were developed: 1,2-dichloropropane (1,2-D), 1,3-dichloropropene (1,3-D), ethylene dibromide (EDB), dibromochloropropane (DBCP) and methyl bromide. DBCP was unique in that it could be used on living plants and was used either for preplant applications or for postplant spot fumigation in orchards [3]. EDB, 1,2-D and DBCP were all banned for use in the U.S. in the 1970s and 1980s.

Currently, the two fumigants commonly used in replant situations are 1,3-D and methyl bromide. Perennial crops may remain productive for a decade to a century, after which they are removed and replanted [3]. An old orchard site will have all the nematode pests of trees and vines that have built up to high population levels over the lifetime of the planting [1]. Populations will be present at depths as great as roots have penetrated – tree roots in soil die slowly and offer food and protection to nematodes for several years after the tree has been removed [1]. If trees are to be planted into old orchards or vineyards, old roots and associated soil-dwelling pests need to be eliminated before planting [3].

Fumigants are capable of destroying most life stages of soil-dwelling organisms as well as the roots of old trees and grapevines. Grapevine roots can remain alive in soil for 10 years after the vine trunk has been ripped out of the ground [6]. Roots of peach, plum, apple and walnut deteriorate faster than those of grape, but viable roots are likely to be present for at least three years after tree removal [6]. These woody roots provide a food source for a variety of soilborne nematodes, plant pathogens and insects. Viruses, bacteria and other microorganisms will also persist in soil as long as the old roots remain viable.

Fumigation using 250-700 lb/acre of methyl bromide or 1,3-D to soil addresses these potential problems. It kills old roots in the surface 4 to 6 feet of the soil profile, and most life stages of soilborne pathogens and insects, promoting growth and vigor in a replanted orchard or vineyard [6] [43]. Field replant sites treated with 1,3-D or methyl bromide frequently exhibit nematode population reductions of 95% up to two years after fumigation [6]. The beneficial effects of preplant fumigation can last up to six years [72] [53]. Preplant soil fumigation allows a deciduous fruit or nut tree time to develop a healthy root system that ultimately can withstand or tolerate some nematode damage when the populations rebounds [2].

Scientists cannot entirely explain the powerful benefit of fumigating soil before replanting perennial crops. Evidence suggests that many detrimental factors commonly present in old orchard sites are remedied by fumigation and soil profile disruption [6]. But the doubling of plant growth in the years that follow is only partially accounted for by the elimination of plant pathogens, nematodes and insect pests. Trees and vines planted following soil fumigation have an increased growth response. This response appears to be the result of improved nitrogen availability or status [65]. The methyl bromide–treated trees have larger root systems, more able to scavenge for nitrogen and nutrients than nontreated trees.

If an orchard is replanted into nonfumigated soil, growth of the newly planted orchard may be hindered. This is due to a phenomenon known as the "replant problem," which occurs to varying degrees worldwide. The symptoms of a replant problem include poor growth with nutritional deficiencies such as phosphorus and zinc distributed nonuniformly across the field. Nematodes, phytophthora, phylloxera and other soil pests may be abundant along the roots. Plants do not develop adequate root systems, and all of this can be apparent by midsummer of the first year [6].

Methyl bromide treatments are typically performed in the fall. Vines and trees are pulled out after harvest but before the rains begin [56]. The dry soil is deep ripped. Methyl bromide usually is shanked in by tractors through hollow tubes driven into the soil and penetrates to depths up to 4 ft. Application rates are typically 300 to 500 lb/acre. As required by law, methyl bromide is mixed with a small amount (2%) of chloropicrin that serves as a warning agent in case there are leaks [56]. Many growers cover the soil surface with plastic sheets to hold the gas in the soil and improve efficacy. Other growers feel that this is not necessary so long as the soil is disked and rolled immediately after injecting the gas [56].

Methyl bromide is used in California orchards and vineyards only when vines or trees are being planted into an old vineyard or orchard or into soil that is known to have soilborne pest problems. Methyl bromide is not used when planting into virgin soil or soil that is not known to have soilborne pest problems.

The use of methyl bromide in California orchard crops increased in 1990 because of the suspension of the use of 1,3-D. (See Table 4.C.3.) Usage of methyl bromide was fairly constant in perennial crops 1990–95. 1,3-D was reinstated for use in 1995; final estimates of pesticide use for California have not yet been released for more recent years. Estimated treated acreage for several perennial crops is provided in Table 4.C.4. An explanation of estimates of treated acreage is provided elsewhere in this report. Table 4.C.5 includes a comparison of estimates of the acres planted to selected crops in 1996, where information was available on plantings, with the adjusted acreage estimates fumigated with methyl bromide in 1995, since fumigation is usually performed in the fall prior to planting the following spring. As can be seen, 13 to 23% of the newly planted acres of prunes, almonds, walnuts and grapes were estimated to be fumigated with methyl bromide.

_Nematodes_

Nematodes are tiny multicellular, unsegmented roundworms that feed on plant roots of most tree, nut and vine crops. Nematode pests of fruit and nut trees and grapevines are distributed widely throughout the principal producing areas of California [2]. The major nematode pests of deciduous fruit and nut trees and grapevines are root-knot nematode, ring nematode, and dagger nematode [2]. Endoparasitic nematodes, which live within the roots of a plant, include root-knot and root lesion nematodes. Ectoparasitic nematodes live outside the plant. Examples of ectoparasitic nematodes are dagger, ring and stubby root nematodes [49].

Eggs of root-knot nematodes are deposited in the root or on the root surface. Microscopic larvae hatch and enter the root and begin to feed on the conductive tissue [2]. As they feed, the host root produces a gall around each nematode that gradually enlarges [2]. These galls hinder flow of nutrients and water throughout the tree [2]. As many as 1500 eggs may be produced by a single adult female in a grape root [49]. Root lesion nematodes girdle and effectively prune the roots in the process of feeding; small feeder roots are most susceptible. The root lesion nematode penetrates roots and migrates through them, the females laying eggs as they go [1]. Ring and dagger nematodes do not enter tree roots but feed on them from the outside, mainly at the root tips. Population levels of ring nematodes can reach 10,000 per kilogram of soil, but populations of 2000/kg are most common [63].

Nematodes puncture plant cells with a needlelike device called a stylet or spear that enables the nematode to remove the cell contents [2]. Nematodes are most damaging when trees and vines are undergoing their major period of root development during the nonbearing years immediately following planting [2]. The first year is particularly critical. At this time high numbers of nematodes can hinder root development even in trees that are planted on nematode resistant rootstock [2]. After the first few years, young trees planted on root-knot resistant rootstocks can tolerate feeding by root-knot nematodes. Established vineyards that later become infected with nematodes may remain productive for years before starting to decline, but young vines suffer severely from the outset and will produce irregular stands that will never recover completely [50]. Vigorous, mature trees can tolerate feeding by low populations of root-knot, root lesion or ring nematodes, but if populations get very high, even well-established trees can decline in vigor and yield [2].

Nematode-infested trees and vines have poorly developed, inefficient root systems and frequently exhibit nitrogen and other nutrient and water deficiencies. In addition to reducing root efficiency, nematode feeding is also associated with a reduction in fruit size. Nematode damage to the root creates a "sink effect," in which plant nutrients are diverted from the upper portion of the tree to the roots, making the nutrients unavailable for fruit production [2]. Aboveground symptoms of nematode damage are lack of vigor, small leaves, dieback of twigs and yield reduction [2].

Various estimates have been made of the extent of infestations of several nematode species in California nut and fruit crops:

- Ring nematodes, prune orchards: 33% of acreage [1]
- Dagger nematodes, prune orchards: 67% of acreage [1]
- Root lesion nematodes, almond orchards: 25% of acreage [4]
- Root lesion nematodes, walnut orchards: 85% of acreage [5]

With even a low population of either root-knot, root lesion, citrus, dagger or ring nematodes, grape growers should expect a 10 to 25% yield reduction [52]. A long-term study of peaches revealed a 20% loss in cumulative fruit weight because of root-knot nematodes [63].

Nematode disease of grapes were first reported about 100 years ago. Research has shown that grapes are afflicted with a wide variety of nematode species, all of them root parasites [48]. They occur worldwide wherever grapes are grown. Nematodes seldom kill grapevines; more often plants decline in vigor and are more susceptible to stress. Nematodes cause greater damage in newly planted vineyards [48]. Infested vines may fail to become established, and those that do are weak and do not grow enough to permit training onto stakes or trellises.

*Alternative Fumigants*

Prior to its suspension in 1990, 1,3-D was the preferred soil fumigant for replant problems. 1,3-D was considerably less expensive than methyl bromide. 1,3-D has been reinstated for limited use in California. The price of 1,3-D products was increased when it was reintroduced in California and is now similar to the price of methyl bromide. In addition, there are area-wide restrictions and a maximum application rate of 350 lb/acre (35 gal/acre) [5]. If the soil is dry, this amount of 1,3-D produces effective control [67]. However, there is a new surface water moisture requirement to limit volatilization of 1,3-D. The requirement of high surface moisture at time of treatment will make 1,3-D less effective except on sandier soils [67]. If water applied to the surface penetrates to lower soil depths, 1,3-D may not be effective, except for very deep roots and pests [42]. In old orchards and vineyard sites, 1,3-D treatment rates of 400 kg/ha (357 lb/acre), applied to dry soil, were adequate to kill remnant roots down to 1.5 m (4.9 ft.) depth and provide 99.5% control of endoparasitic nematodes compared to untreated plots as much as two years after treatment [46]. Treatment rates of 150 lb/acre of 1,3-D gave nematode control only in the surface 3 ft of soil profile and did not kill all the old roots in that zone [6].

Current research with 1,3-D includes testing approaches that may be used to mitigate volatilization at higher treatment rates. If volatilization of 1,3-D from treated fields can be reduced, then the maximum application rates might be increased. These application methods include sealing treated fields with tarps, injecting 1,3-D at greater depths and drenching the field with 15 cm (5.9 in.) of water mixed with emulsified 1,3-D [46]. Also 1,3-D might be used with metam sodium, which could provide improved pest control at shallower soil depths [42]. Properly applied, the treatment of 1,3-D, delivered via subsurface drip lines and metam sodium and applied to the surface via microsprinklers or drippers, has the potential to replace methyl bromide on those soils that are drenchable [70].

Although it is a very good biocide, the fumigant metam sodium actually has poor fuming action. It penetrates the soil more thoroughly if it is moved with water [6]. However, metam sodium does not penetrate plant roots very well. The relatively ineffective root-killing ability of 100 gal/acre of metam sodium is a serious limitation [47]. The only reason that 200 gal/acre of metam sodium must be used on old tree or vine sites is to kill of roots to 4- or 5-ft depths [47]. If metam sodium is drenched properly to 5 feet at 200 gal/acre, it can provide 98 to 99.9% nematode control [47]. Metam sodium is seldom as effective as methyl bromide due to the difficulty achieving proper application to a 4- to 5-ft depth [71].

A new procedure for drenching metam sodium involves the use of a portable soil drenching device (PSDD). The PSDD consists of a dripper-emitter that is temporarily located on each square foot of field surface that is drenched [6]. The drencher mixes the metam sodium with water and distributes the two through the soil profile over an eight-hour period. The cost of the PSDD is estimated at $150 per acre plus chemicals. Tests have shown that drenching, when used to apply metam sodium with 6 in. of water to soil prepared properly, came very close to being as effective as soil fumigation with methyl bromide [6]. However, the metam sodium treatments do not kill old tree roots below 2-ft soil depths when applied at 327 lb/acre. At double the treatment rate, old roots may be killed down to 4 ft. However, replants placed in the soil six months later grew more poorly than those planted in methyl bromide–fumigated soil [6]. At the 327 lb/acre rate, grapevines planted one month after treatment and plums on nemaguard rootstock planted three months after treatment did grow as well as the fumigated comparison [6]. The lack of root killing power with metam sodium may be more of a problem in old orchard sites than in vineyards, where smaller roots are more common [6].

Growers have an incentive to put in low-volume irrigation devices well before replanting as a means of delivering metam sodium [24]. After the last harvest, existing irrigation systems can be used for drenching with metam sodium to kill existing trees or vines [6]. The metam sodium treatments need to be followed by 18 months of crops antagonistic to nematodes in order to provide nematode control equivalent to methyl bromide applications [51].

*Nonfumigant Pesticides*

Enzone is a liquid that breaks down in soil to release carbon disulfide. It can be used both pre- and postplant and needs to be applied in water. Enzone currently has registrations in California on citrus, grapes, prunes, plums, peaches and almonds. Several small-scale field trials have shown that flood applications of Enzone can reduce ring nematode populations in prunes and almonds and can reduce the incidence of bacterial canker, associated with infestations by this nematode, thus prolonging tree life [21]. In an experiment in which Enzone was applied at planting and yearly postplant, trunk circumference with Enzone treatment were the equivalent of those trees on which methyl bromide was used preplant [25].

Small-scale field studies have shown that ozone injected into the soil can provide control of plant-parasitic nematodes. A research trial indicated that ozone would move effectively at a high rate for 6 to 12 in. This is less than with methyl bromide or 1,3-D but further than metam sodium [25]. In field soil, ozone treatments reduced ring nematode populations by 41% at 150 lb/acre and 87% at 600 lb/acre. With the addition of an inert carrier gas, the reductions were 63% and 100%, respectively [25].

*Postplant Nematicides*

In the 1950s and 1960s several nonfumigant nematicides were developed. Primarily organophosphates or carbamates, these chemicals were formulated as granular or emulsifiable concentrates, applied broadcast or as a band in the crop row and worked into the soil [3]. Movement of these materials in the soil generally depends upon water or mechanical soil mixing. The duration of protection is short, even at relatively high application rates [44]. The nematicides are generally not as effective as fumigants for controlling nematodes and improving tree growth and yield [62].

All organophosphate and carbamate nematicides must be followed immediately after application with an irrigation to release, activate and move the material to its target. The nematicides are seldom lethal to nematodes [49]. These nematicides, however, are capable of disorienting and interfering with normal life processes, such as feeding, root penetration, egg hatching, locomotion and sensory perceptions [49]. The available nematicides are of greatest benefit against endoparasitic nematodes and provide only medium population reductions of ectoparasitic nematodes [49]. The nematicide treatments reduce populations of endoparasites by 50 to 70% for up to six months and disorient ectoparasitic nematodes for 30 to 45 days, after which time they resume feeding on roots [49]. With three to five treatments per year, effective control of root-knot nematodes has been achieved with the use of various postplant applied nematicides [49].

Fenamiphos is registered for use in apples, cherries, citrus, grapes, kiwi, nectarines and peaches. Although fenamiphos is highly effective in reducing root lesion nematodes in walnuts, the registrant has decided not to pursue a registration for walnuts [6] [25]. There are no postplant nematicides available for walnuts. Fenamiphos residues are an issue since the chemical does redistribute throughout the tree and may enter fruit [45].

*Herbicide Treatments*

Experiments have been conducted with a variety of systemic herbicides in an attempt to kill remnant roots in orchards and vineyards. Herbicide treatments have been performed in the fall after harvest is completed. Late-November systemic herbicide treatments with triclopyr and glyphosate were too late to provide adequate translocation and eventual root kill by the time trees were pulled in January [19]. Trees replanted without a full year of fallow following the herbicide treatments exhibited extensive replant problems, regardless of the treatment [19]. Aboveground portions of the trees were killed with most of the treatments, but adequate root death may not be possible with fall treatments [19]. Plant growth benefits following treatments of glyphosate or triclopyr do not occur unless replanting is 18 months after such root killing treatments [70].

Foliar applied glyphosate resulted in 85 to 95% root kill in a peach orchard six months after treatment. Unfortunately, the eggs of nematodes species remained within killed roots for two years after treatment [21]. Applications of herbicides to cut trunks provided greater root destruction. Root kill of 97% plus reductions in nematode populations of 98% resulted from a trunk treatment of triclopyr plus diesel oil [21].

*Resistant Cultivars*

An EPA case study suggests that for many California vine and orchard crops, nematode resistant cultivars have been developed: grapes, peaches, plums, apricots, nectarines, walnuts, almonds and citrus [69]. The EPA also notes that 95 to 100% of the orchard crop production occurs on nematode-resistant cultivars often in conjunction with preplant methyl bromide–fumigation [69]. Nematode resistance is the genetically conferred ability to reduce or eliminate nematode reproduction on the crop plant. Tolerant rootstocks grow as well in the presence of nematode feeding as in their absence [9]. To be viable, the crop also must be able to tolerate the initial attack without adverse effects on yield or quality.

Mixed nematode species present problems, because the rootstock may be resistant to only one nematode species. For example, Nemaguard rootstock provides excellent resistance to root-knot nematode in peach, nectarine and almond but is highly susceptible to root lesion and ring nematodes [3]. Plum and prune rootstocks resistant to root-knot and tolerant of root lesion nematodes are highly susceptible to ring nematode and the associated bacterial canker complex. In pistachio, some California seed sources of the common rootstock are susceptible to root lesion nematodes. Black walnut rootstocks have resistance to root-knot nematodes but are highly susceptible to root lesion nematodes [3]. A diversity of nematode species are present in most grape growing regions as there are at least 10 different types of nematodes depending on soil type and grape variety [53].

California researchers have screened 200 deciduous fruit and nut cultivars to identify root lesion nematode-resistant germplasm [8]. Resistance to root lesion nematodes has been identified in a few genetically diverse cultivars. Whether these root lesion nematode resistant accessions will be acceptable as root stock remains to be demonstrated [8]. More than 500 grape cultivars were screened for resistance to 3 nematode species [9]. Thirteen of the cultivars exhibited resistance in terms of a lack or near lack of reproduction of the nematodes on the cultivar over a 2-year period [9]. Other than their resistance to nematodes, nothing else is known about these rootstocks, including their viticulture characteristics [51].

The notion that these resistant rootstocks or any others will replace methyl bromide is premature [9]. Methyl bromide solves the replant problem by killing nematodes and most everything else in soil. Although these rootstocks do not permit nematode reproduction, they may not stop nematode feeding. Since remnant grape roots can survive in soil as much as a decade after vine removal, there can be an abundant supply of nematodes and viruses in the proximity of newly planted grape roots.

At least three additional screenings are needed to assess how well these potential rootstocks will perform as replacements for soil fumigation. First, growth should be evaluated using four or five different replant soils compared to nonreplant or fumigated soil. This test is now under way. Second, tolerance to nematode feeding should be tested. The third screening should be across a variety of common soil pests, as well as for their performance in droughty soils, calcareous soils, shallow soils, etc. Decades of field-level rootstock trials can provide only partial answers to specific soil and pest questions [9].

Resistance to nematodes is a helpful tool once the vineyard is established, but there are no examples of it being useful in solving the replant problems where vineyards or orchards are removed one year and replanted the next [9]. Without preplant fumigation the nematode-resistance mechanisms in grape varieties cannot withstand the pressure that comes fom nematode reinfestation in the early years of vineyard establishment [51].

One of the problems with building a trait in a rootstock is that at the same time some other trait can be taken away. For example, some of the new grape rootstocks that are phylloxera resistant are nematode susceptible [54]. A factor limiting the wider use of resistant rootstocks is the lack of rootstocks tailored to raisin and table grape production [55]. Current nematode resistant rootstocks tend to be overly vigorous leading to delayed maturity, decreased bud fertility and reduced berry color [55].

The complexity of rootstock selection is well demonstrated by Nemaguard rootstock, a peach rootstock that is widely used by growers of almond, peach, plum, nectarine and prune. It provides field resistance to all races of root-knot nematodes but has no resistance against root lesion nematodes or to the ring nematode. These latter nematodes can be quite damaging to stone fruits, but their distribution is more limited than that of root-knot nematode. Improved selections of Nemaguard continue to be released, but as with every other rootstock, they have limitations. Most peach rootstocks, including Nemaguard, do not grow as well in fine-textured soils or in soil susceptible to waterlogging; in such conditions plum rootstocks have greater longevity. In the sandiest soils, where ring nematode can be prevalent, Nemaguard is susceptible to bacterial canker complex. Since stone fruit growers wish to establish orchards in sandy areas as well as on fine-textured soils, certain production blocks may be reserved for peach and other for plum or prune. Unfortunately, it is quite common to have several different soil textures within a single production block [44].

The planting of Nemaguard without fumigation only partially corrects the nematode problem since young Nemaguard roots may be damaged severely by attempted feeding of root-knot nematode juveniles [63]. When replanting a young perennial with resistance only to nematode development, there can be substantial damage to the plant if many nematodes are present around young roots. Nemaguard rootstock is very useful for control of nematodes, but it is practical only under specific conditions and situations [44]

*Biological Controls*

Metabolites produced by a fungus were recently reported as nematicidal under the brand name DiTera (also known as ABG-9008), discovered by Abbott Laboratories in 1987. The product is produced by fermentation of a fungus, originally isolated from a cadaver of the soybean cyst nematode. The active ingredient is a microbial composition containing fermentation solids and solubles of the fungus [11]. DiTera kills nematodes on contact and, depending on its concentration, inhibits hatching of plant-parasitic nematode eggs. The product can be incorporated into the soil, either mechanically or with water, prior to planting, at emergence or as a postplant treatment [11]. Performance of this product has been highly variable in small plot research, and there is much about this product that is not understood. DiTera is now receiving commercial evaluation in three walnut groves [5].

There are no known biological agents that are deliverable to soil or the surfaces of roots that will provide relief from endoparasitic nematodes, such as root lesion nematodes [5].

*Fallowing/Rotation*

Four years of dry fallowing prior to replanting is generally adequate to avoid most of the replant problems [18] [6]. However, most growers specializing in perennial crops are not willing to leave land out of production [43]. Fallowing would be an expensive means of nematode control, in terms of foregone production [44]. Few farmers can afford to idle their land for the four to five years necessary to achieve adequate relief from the replant problem [5].

Crop rotation for 18 months has been investigated as an alternative. Research has shown that although rotation crops can be antagonistic to nematodes, old tree roots protect nematodes within the roots [22]. Replants that followed the rotation crops have grown very well, and some of the replant problems appear to be solved [22]. However, after two years the dead roots continue to be a source of nematodes, presumably surviving as eggs within [22]. Repeated irrigations of the rotation crops did not appear to rot old roots or to hatch out the nematodes from within. In one trial, an 18-month crop rotation involving nonhosts for nematodes gave no protection against nematode buildups and achieved only half the growth customary with methyl bromide treatments [18].

*Solarization*

The laying of clear plastic on the soil surface traps solar radiation and heats the soil. The elevated soil temperatures might be expected to reduce soilborne pests, including certain nematode species, fungal pathogens and nonspecific replant diseases [64]. Solarization is more likely to control soilborne pathogens in the top 6 to 9 in. of soil than at lower depths. In an orchard replant situation, this is limiting since roots of the prior crop are likely to be deep.

An EPA case study describes research with solarization for management of soilborne pests in orchards [68]. The study concluded that although soil solarization can be a reliable alternative to methyl bromide in orchards, there are limitations to its use. Heat levels often are not adequate to penetrate into deeper soil levels [68]. It was suggested that soil solarization in combination with other soil fumigants, such as 1,3-D and metam sodium, would increase the efficacy of both the chemicals and solarization compared with their stand-alone uses [68].

In a test conducted on peach and almonds replanted into an old California vineyard, a 6-ft-wide black tarp mulch remained in place for two years around the tree trunks [64]. The habitat created was of uniform moisture and high heat, which proved deleterious to citrus nematode and root lesion nematode within the old grape roots, but root-knot nematodes flourished within 6 in. beneath the tarp [24]. Higher populations of root-knot nematodes occurred in the solarized soil than were present in the untreated check. During the hot months of June–August soil temperatures at 15 cm (5.9 in.) deep were frequently higher than 40°C for five to six hours daily, and reproduction of root-knot nematodes may have been inhibited. However, during the cooler months of September–November, the warmer, but nonlethal, soil temperatures beneath the mulch may have increased numbers of nematodes present [64]. There was no methyl bromide treatment in this study for comparison.

Another limitation to solarization is injury to young trees caused by excessive root temperatures. Trunk diameters of peach trees were increased in one experiment, but those of almond trees were reduced by solarization [64]. Many of the mulched almond trees were observed to have stopped growing during July and August. Once soil temperatures dropped, mulched almond trees grew rapidly. However, this late growth was not enough to catch up to the nonmulched almond trees [64].

Solarization treatment using black plastic mulch is not sufficient to minimize root-knot nematodes on a susceptible host without preplant fumigation, especially in a replant situation with residual roots from the previous crop remaining in the soil [64]. Solarization may be considered part of a potential system, but not as a stand-alone treatment in perennial crops.

*Other Nonchemical Soil Treatments*

Several other treatments have been studied, with mixed results. At 300 lb/acre of nitrogen in 6 in. of water, urea provided 95% control of nematodes in soil but provided no reduction of the nematodes present in remnant roots [18].

Two procedures have been evaluated for creating anaerobic conditions in the surface foot of soil. Forty days of flooding followed by fallowing did not reduce population levels of endoparasitic nematodes, but did produce first year growth of replants similar to those achieved with methyl bromide treatments.

The application of 15,000 lb/acre of marigold residues in water also produces anaerobic conditions in soil. Marigold is antagonistic to various nematode species [6]. Since there is a residual phytotoxicity associated with marigold use, the treatments include the application of 40 in. of water 30 days after treatment to leach out the phytotoxicity. This leaching process has not proven successful, and marigold treatments have tended to produce poorer plants than the nontreated check [22].

Steam at 1200°F and 130 lb/in.$^2$ was injected into a soil test site and thermal movements monitored [24]. Temperatures of 140°F were not detected beyond 6 in. even when the injection point was stationary for several minutes. Treatments resulted in the formation of "bricks" of hard soil directly out from each point but little lateral movement of the heat [24].

*Integrated Pest Management*

Many large-scale California grape growers do not use methyl bromide as a preplant treatment [66]. These growers rely on long-term integrated pest management (IPM) practices to manage soilborne pests. Some growers forego preplant fumigation and rely instead on postplant pesticides, such as carbofuran, fenamiphos and enzone [66]. Others use nonchemical methods in combination with alternative preplant fumigants, such as 1,3-D or metam sodium [66]. It is not clear how many of the IPM successes have come from vineyards planted into soils that are known to have serious soilborne pest problems. We have found no experiments comparing the IPM approach with methyl bromide, so we cannot compare growth in newly planted trees of nematode population levels. As with any pest control tactic, data are needed for several years following replant into old vineyard soils or soils with known soilborne pest problems before the validity of the IPM alternatives as a substitute for methyl bromide can be determined.

*Organic Production*

There are several thousand acres of certified organic vineyards in California. Some organic growers do not fumigate for philosophical or other reasons, while other organic grape growers do fumigate before planting their vineyards [56]. Fumigated vineyards can qualify for organic certification because state certification laws require a three-year transition period from conventional to organic practices [56]. Therefore, a grower of grapes (or any perennial crop) can fumigate a piece of land, plant the vines and then enter the certification program. The land can become certified as organic just as the three-year-old vines begin to bear [56].

In recent congressional testimony, a prominent California organic grape grower explained the importance of methyl bromide in their operations:

> At this point, we still use methyl bromide as a preplant fumigant prior to replanting our grape vines. As organic growers, we prefer to use the safest and most natural pest control methods, so our first choice would not be methyl bromide. Right now, however, we haven't found a replacement for fumigation in replant situations that is as economically viable as methyl bromide [57].

Organic producers who choose to forego fumigation would likely use combinations of some of the nonchemical approaches described earlier including biological control and soil solarization, and some approaches on which there is little published research, including the use of microbial products, composts or other soil amendments [85].

3. <u>Other States</u>

Problems with replanting fruit trees have been reported from numerous fruit growing regions in the U.S. [26]. In Michigan, tree decline has been associated with low soil pH, some nutritional disorders and winter injury [27]. There is no indication that nematodes are a significant factor in cherry tree decline in Michigan. Methyl bromide is not used in Michigan orchards [31] [32] [58].

The cause of the replant problem for tree crops, such as apples, in North Carolina has not been determined [23]. Sites vary in the degrees of the problem. Methyl bromide at 900 lb/acre is used as a preventative measure by growers establishing high-density orchards [23]. Approximately 50 acres are treated yearly [23]. Chloropicrin is also effective but is not used.

The peach industry in the southeastern U.S. continues to be plagued by the disease complex known as Peach Tree Short Life (PTSL). Tree loss averages 3 to 5% annually in Georgia and South Carolina. In South Carolina alone, this disease complex was responsible for killing 1.5 million trees between 1980 and 1990, costing growers over $6 million per year in lost production [28]. The primary biological pest that is responsible for making peach trees more susceptible to PTSL is the ring nematode. Methyl bromide and 1,3-D are recommended in the Southeast as a preplant nematicide treatment for the ring nematode [28]. However, the cost of fumigation, (about $1000 per acre) typically prevents growers from using these products [37].

In Washington, fruit growers rarely plant trees on sites that have not grown apples or pears previously. Poor tree growth caused by orchard replant disease is a significant problem on about 80% of replanted apple and pear acres in Washington [29]. In Washington, both methyl bromide and methyl bromide have improved long-term tree growth and yields most reliably [29]. Both products appear to be equally effective. Soil was fumigated on only about 5% of the replanted pears and apples in 1985. Because of the recorded responses in experimental trials and demonstrations, the use of fumigation increased to over 85% of replanted acreage prior to the 1992 production season [29]. More recent research in Washington suggests that apple replant disease in Washington State is primarily a fungal phenomenon [30].

The cause of the replant problem has not yet been identified in New York [34]. Research has shown that it is not caused by nematodes. The most recent evidence suggests that the replant problem is caused by a micro-organism that builds up in orchard soils. The organisms persist in soils for many years after orchards are removed; fallowing or planting nonorchard crops between orchard plantings has not proved effective in correcting replant problems. Methyl bromide is seldom used for tree crops in New York for three reasons [33]: (1) Benefits have not been documented adequately, (2) treatment is very expensive, and (3) effective treatment is very difficult in the rocky soils used to grow tree fruit in some parts of New York. Horticulturists at Cornell currently are investigating benefits of metam sodium to control apple replant disease. Metam sodium is preferred because treated soil does not need to be covered after treatment, and there is less applicator exposure risk [33].

Methyl bromide is a preplant fumigant option for Oregon tree fruit growers. Since methyl bromide must be applied by custom applicators from outside the state, more growers are opting for less expensive, liquid products like metam sodium that they can apply themselves [60]. A 1996 survey of tree fruit pesticide use in Oregon indicated that metam sodium was the only fumigant used in site preparation on 390 acres of apples, cherries and pears [59]. In 1998, one company fumigated 800 acres of tree crop land in Oregon with methyl bromide prior to planned replanting in the spring of 1999 [61].

Nearly all of the cultivated pineapple acreage in Hawaii is fumigated two weeks prior to planting with methyl bromide or 1,3-D to control nematodes [35]. Researchers have estimated that the pineapple crop would not be harvestable for fresh fruit without some form of nematode control. Research has shown that preplant use of ethoprop, oxamyl, or fenamiphos is effective in reducing nematode problems. The preplant fumigant of choice in Hawaii is 1,3-D, not methyl bromide [36].

## 4. Current Status of Alternatives

The current status of alternatives to methyl bromide for preplant fumigation of perennial crops has been delineated recently by a University of California specialist (Mike McKenry) [42]. The alternatives have been defined in terms of yield losses that would be expected from their use compared to methyl bromide. These estimated yield losses are shown in Table 4.C.8. The yield loss estimates represent the average yearly loss in crop yields expected following the preplant treatment.

For most perennial crops the expected yields following methyl bromide treatment are the same as those expected following four years of fallowing. The exception is for grapes, for which four years of fallowing is not expected to perform as well as methyl bromide–treatment because grape roots do not die until more than eight years after removal of the old vine trunk. This provides refuge for all the root feeding microbes as well as Grape Fan Leaf Virus, as though there was no fallow period.

Expected yield losses are different depending on the crop. For example, yield losses are predicted to be higher in walnuts than in almonds and stone fruits; losses for premium wine grapes are expected to be higher than for raisin grapes. The reasons for these differences are twofold:

(1) Several crops have rootstock with significant resistance to nematode damage. Nemaguard Peach, Marianna 2624 Plum, N.C. Black Walnut, citrus, and pistachio have dependable resistance to root-knot nematode, a common soil pest, but ring nematode, root lesion nematodes, citrus nematodes, phylloxera and other pests can also cause damage.
(2) Several crops are grown in soils that interfere with treatments. Walnut, citrus, pistachio and certain of the wine grapes are grown in soils of medium to fine texture. The higher water-holding capacity of these soils makes them more difficult to fumigate properly.

Significant yield differences are predicted for most crops if one year of fallowing or metam sodium is substituted for methyl bromide. These treatments do not provide adequate control of soilborne pests, and resulting higher populations of the pests would lead to more crop damage.

1,3-D plus metam sodium is the chemical treatment that comes closest to methyl bromide in terms of preventing yield loss. However, yield losses are expected with substituting metam sodium plus 1,3-D for methyl bromide for two reasons: (1) The 1,3-D amount is limited to 350 lb/acre, a rate at the low end of efficaciousness; and (2) the requirement that the soil be wet before applying the 1,3-D means reduced efficacy. These fields commonly receive deep soil ripping (3 to 7 ft deep) prior to planting. This procedure must come before preplant soil treatments. Most of these growers do not have sprinklers, but even if they do, it is difficult to wet the soil surface without moving water throughout the ripped soil profile. Timely rainfalls do not occur in California. The water's movement through the soil reduces the effectivness of 1,3-D.

For certain crops, the 1,3-D plus metam sodium treatment is combined with a one-year fallow period. These are crops that are harvested later than August 1, including walnut, wine and raisin grapes, almond, kiwifruit, and some stone fruits. Citrus may be harvested nearly any time of year while apples are harvested from June through October. Methyl bromide should not be applied in winter or to wet soils, but it frequently has been because its efficacy is relatively unaffected by higher soil moisture copmared to other materials. If 1,3-D is applied after 2 in. of fall rains (usually mid-November) a reduction in efficacy can be expected. This constraint is less important for early harvested crops such as most stone fruits, half of the table grape varieties and citrus. The grower has to remove the previous planting, dispose of it, dry soil, rip and relevel the field and then fumigate before 2 in. of rainfall.

5. Previous Studies

The USDA's NAPIAP conducted a study in 1993 of the potential impact on perennial crops following a loss of methyl bromide [41]. NAPIAP collected expert opinions from Extension Service specialists who profiled likely replacements for methyl bromide and estimated changes in production that would be expected from the substitution. For tree and vine crops in California (almonds, apples, apricots, cherries, grapes, nectarines, peaches, plums/prunes and walnuts), the specialists indicated that metam sodium would be the primary replacement (on 70 to 85% of the acreage) with fallowing, nonfumigant nematicides and no treatment making up the remainder. The cost of metam sodium was estimated at $525 per acre, which was less than the cost of methyl bromide. Yield losses were predicted because of the lower pest control efficacy provided by metam sodium and nonfumigant nematicides. Table 4.C.6 summarizes the 1993 NAPIAP study's production loss and yield change estimates resulting from banning methyl bromide.

In a 1994 study conducted at the University of California, metam sodium or crop rotation was estimated to be the best alternative to methyl bromide/chloropicrin for perennial crops [38]. The substitutions varied by crop and region. For example, crop rotation was selected as the best alternative for cherries in all regions, while for grapes metam sodium was selected as the best alternative in three out of six regions. The University of California study combined projected losses in output (5% yield reduction) with declines in pesticide and harvest costs and discounted the values by 4% so that future nominal profit change could be expressed in current dollars. The aggregate impacts of canceling methyl bromide for perennial crops, as estimated in the 1994

University of California study, are presented in Table 4.C.7. At the time of the 1994 study, 1,3-D had been suspended for use in California, and as a result, it was not considered as a possible replacement. 1,3-D is now permitted for use in California under several restrictive labels. In the most recent University of California analysis for perennials, 1,3-D in combination with chloropicrin is considered the primary alternative with an associated yield loss of 3 to 4%. Crop rotation or fallowing is no longer considered the preferred alternative for any crop in any region [39].

### 6. Perennial Impacts

Following are impacts of the scheduled methyl bromide ban for several perennial crops. Only California perennial crops are considered because of more widespread use of methyl bromide there than in other states. These impacts represent the present value of the losses associated with eliminating the use of methyl bromide on one year's plantings, over the life span of those plantings. Yield losses are assumed to occur at a constant rate over the life of the tree. Future losses have been discounted to current dollar values using an interest rate of 4%. Three-year average commodity prices are used from the period 1994–1996. Prices are assumed to remain constant. The crop values used in the impact analysis are shown in Table 4.C.9.

The impact calculations differ from those presented in the NAPIAP report [41]. In that study, the loss calculations for perennials represented the value of losses associated with eliminating the use of methyl bromide on one year's plantings, but only for the first bearing year of those plantings. The method used to calculate impacts here is similar to that used in the University of California reports [38], though best alternatives, yield losses, cost changes and affected acreage assumptions differ.

The methodology does not take into account losses on acreage planted in years subsequent to the first year after a ban on methyl bromide. Eventually, all acreage will be replanted without methyl bromide treatment. These losses are not considered in order to calculate an “annual” loss comparable to calculations made for annual crops, as described in other sections herein.

To evaluate the impact of a ban on methyl bromide, it was necessary to determine what the best alternatives were that growers were likely to adopt. For all the perennial crops, the best alternative includes treatment with 1,3-D. The availability of 1,3-D is limited in California to a maximum amount applied annually within 36-square-mile areas called townships. The results of an analysis of these impacts and the underlying assumptions of that analysis are described elsewhere in this report. Table 4.C.10 shows the impact of 1,3-D restrictions on perennial crops in California.

Details on alternatives, changes in yields and treatment costs, harvest costs, commodity prices and life spans of plantings are all variables that influence impact calculations. The assumptions used to calculate impacts are presented for each of the major methyl bromide–using perennial crops in California.

*Almonds*

For almond growers, the best alternative to methyl bromide is expected to be a combination of one-year fallow followed by treatment with 1,3-D and metam sodium. A year of fallow is necessary because soil conditions are too wet and cold for effective treatment using 1,3-D by the time the crop is harvested and the fields are prepared. As a result, growers would have to wait until the next year to treat and replant. For acreage exceeding the township limits it is assumed that after the fields are prepared they will be treated with metam sodium and left fallow for one year before replanting. The year of fallow is necessary to avoid potential phytotoxicity to new plantings caused by the lingering effects of metam sodium. All acreage in the Sacramento Valley is expected to be treated with 1,3-D, as the township restrictions were not found to be binding in that region for almond growers.

Eighty-five percent of new almond plantings are assumed to be on nemaguard rootstock and have a lifespan of 30 years [42]. The remaining 15% were assumed to be on other rootstock and to last 25 years [42]. For 1,3-D treated acreage, a yield loss of 10% was assumed for plantings on nemaguard rootstock, and a 4% yield loss was assumed for other plantings, which are assumed to be in areas with lower pest pressure [42]. Acreage that is treated with metam sodium alone is expected to suffer a 25% yield loss on nemaguard rootstock and 9% on other rootstock [42]. A price of $1.96/lb for almonds was assumed in the impact calculations, a three-year average for 1994 to 1996 [12].

Almond yields were obtained from University of California Cooperative Extension budgets for almonds in the Sacramento and San Joaquin Valleys [73] [80]. However, information in those budgets was for nonfumigated plantings. Fields requiring methyl bromide fumigation are expected to yield 5% less if planted on Nemaguard rootstock and 1% less on other rootstock than unfumigated plantings [42]. The yields used here have been adjusted accordingly. Current methyl bromide fumigation costs for almonds are assumed to be approximately $550 per acre, similar to nontarped fumigation for other perennial crops. Treatment costs are expected to be $957.50 per acre for acreage treated with 1,3-D and metam sodium and $410 per acre for metam sodium alone. Yields and harvest cost comparisons for almonds in the Sacramento and San Joaquin Valleys are given in Tables 4.C.11–4.C.14.

Almond growers are expected to sustain losses of $45 million on one year's planting. Most of these losses are anticipated in the San Joaquin Valley, where the majority of acreage is located. Impact estimates are given in Table 4.C.24.

*Grapes*

The best alternative to methyl bromide for grape growers is expected to be a year of fallow followed by treatment with a combination of 1,3-D and metam sodium, similar to that for almond growers. For acreage not allowed to be treated with 1,3-D, the next best alternative is metam sodium alone with one year of fallow before planting. Premium wine grape growers are assumed to experience a 15% yield loss on acreage treated with 1,3-D and metam sodium and a 35% yield loss on acreage treated with metam sodium alone [42]. Grape growers in the Central Valley will suffer a 5% yield loss on acreage treated with 1,3-D and 15% without 1,3-D [42]. Premium wine grape plantings were assumed to have a life span of 40 years, Central Valley wine and raisin grapes 50 years and table grapes 30 years [42]. Prices used in impact calculations are $0.51/lb for premium wine grapes, $0.14/lb for wine grapes in the Central Valley, $0.11/lb for raisin grapes and $0.55/lb for table grapes, which are three-year average prices from 1994 to 1996 [12]. Harvest costs are assumed to be $0.06/lb for premium wine grapes, $0.02/lb for raisin grapes and wine grapes in the Central Valley, and $0.11 for table grapes [78] [81] [82]. Table grape growers send their first year of yields for wine production. Therefore, the first year of impact for table grape growers considers prices and harvest costs for wine grapes.

Premium wine grape growers are assumed to pay $1400 per acre for custom fumigation with methyl bromide [78]. Other grape growers are assumed to pay $550 per acre for untarped methyl bromide fumigation [81] [82]. Treatment costs are expected to be $957.50 per acre for acreage treated with 1,3-D and metam sodium and $410 peracre for metam sodium alone. Yield comparisons for premium wine grapes, wine grapes in the Central Valley and table grapes are shown in Tables 4.C.15–4.C.17.

The impact on California grape growers is expected to be $75 million for one year's planting without methyl bromide. Most of the losses are expected to be sustained by premium wine grape growers. Impact estimates are provided in Table 4.C.24.

*<u>Peaches/Nectarines</u>*

Peach and nectarine growers' best alternative to methyl bromide is expected to be a combination treatment of 1,3-D and metam sodium. For acreage exceeding the 1,3-D limits, metam sodium and one year of fallow was assumed to be the next best alternative, similar to almond growers. Eighty-five percent of the plantings are assumed to be on nemaguard rootstock with a lifespan of 15 years, while other plantings are expected to last 25 years [42]. For 1,3-D treated acres, a 5%

yield loss is expected for plantings on nemaguard and 4% for plantings on other rootstock [42]. For acreage treated with metam sodium, a yield loss of 25% is anticipated for plantings on nemaguard, and a 9% yield loss are expected for other plantings [42]. Harvest costs are $0.20/lb [76]. Peach prices are assumed to be $0.31/lb. and nectarine prices to be $0.38/lb, which are three-year average prices from 1994 to 1996 [77]. Peach and nectarine growers are assumed to use nontarped methyl bromide fumigation currently, at a cost of $500 per acre [76]. Treatment costs are expected to be $957.50 per acre for acreage treated with 1,3-D and metam sodium and $410 per acre for metam sodium alone. Yield comparisons for peaches and nectarines are shown in Table 4.C.18.

Peach and nectarine growers are estimated to experience $5.7 and $8 million in losses without the use of methyl bromide on one year's plantings. Impact estimates are given in Table 4.C.24.

*Prunes*

The best alternative to methyl bromide for prune plantings is expected to be a combination of 1,3-D and metam sodium treatments. Acreage not treated with 1,3-D will be treated with metam sodium and a year of fallow. Yields for growers in the San Joaquin and Sacramento Valleys were obtained from University of California Cooperative Extension budgets [83] [84]. However, information for Sacramento Valley prune orchards was for nonfumigated plantings. For acreage requiring methyl bromide fumigation, yields are expected to be 5% less on nemaguard rootstock and 1% less on other rootstock [42]. Yields used here have been adjusted accordingly. Prune growers are assumed to pay $1485 per acre for custom, tarped methyl bromide fumigation currently. Treatment costs are expected to be $957.50 per acre for acreage treated with 1,3-D and metam sodium and $410 per acre for metam sodium alone. The price of prunes is assumed to be $0.51/lb on a dry weight basis. Harvest costs in the Sacramento Valley are assumed to be $0.047/lb and in the San Joaquin Valley assumed to be $0.063/lb. Average lifespan of a prune tree assumed to be 30 years [42]. Yield comparisons for prunes grown using methyl bromide and alternative treatments are given in Tables 4.C.19 and 4.C.20.

The estimated losses for prune producers in California is expected to be $4.9 million without methyl bromide fumigation on one year's plantings. Impact estimates are provided in Table 4.C.24.

*Walnuts*

The best alternative to methyl bromide for walnut plantings is expected to be a combination of one year of fallow followed by 1,3-D and metam sodium treatments, similar to almond, peach and nectarines plantings. Acreage not treated with 1,3-D will be treated with metam sodium and a year of fallow. A price of $0.66/lb was assumed in the following impact calculations [77]. Harvest costs in the San Joaquin Valley were assumed to be $0.11/lb and in Sacramento Valley $0.10/lb [74] [75]. The average lifespan of a walnut tree was assumed to be 50 years.

Walnut growers in the Sacramento Valley are assumed to pay $1300 per acre for tarped methyl bromide fumigation, while growers in the San Joaquin Valley pay $1485 [74] [75]. However, these costs may be overestimates. There is some indication that San Joaquin growers' fumigation costs may be as low as $600 to 800 if they are able to do untarped fumigation [40]. Treatment costs are expected to be $957.50 per acre for acreage treated with 1,3-D and metam sodium and $410 per acre for metam sodium alone. Yield comparisons for walnuts in the San Joaquin and Sacramento Valleys are given in Tables 4.C.21 and 4.C.22.

Walnut growers are expected to suffer losses of $3.4 million without the use of methyl bromide on one year's plantings. Impact estimates are shown in Table 4.C.24.

## 7. Aggregate Costs

Table 4.C.23 displays cost estimates of alternative fumigant treatments for perennial crops in California. The two alternatives to methyl bromide treatments are a combination of Telone II plus metam sodium or metam sodium alone.

Table 4.C.24 displays estimates of the per acre and aggregate changes in yields and treatment costs as a result of substituting the most efficacious alternative for methyl bromide treatments for perennial crops. The total impact of a ban on methyl bromide for California perennial crops is estimated at $142 million per year. This estimate is made up of changes in treatment costs per acre plus changes in yields per acre. These impacts represent the present value of the losses associated with eliminating the use of methyl bromide on one year's planting over the life span of those plantings.

**TABLE 4.C.1**
**Land in Orchards (1992)**

| State | (Acres) |
|---|---|
| Alabama | 34,000 |
| Arizona | 68,000 |
| California | 2,200,000 |
| Florida | 900,000 |
| Georgia | 150,000 |
| Hawaii | 38,000 |
| Michigan | 162,000 |
| New York | 113,000 |
| Oklahoma | 50,000 |
| Oregon | 96,000 |
| Pennsylvania | 57000 |
| S. Carolina | 42,000 |
| Texas | 216,000 |
| Virginia | 32,000 |
| Washington | 256,000 |
| Total | 4,414,000 |

Source: [10]

**TABLE 4.C.2**
**California Fruit and Nut Production: 1996**

| | Bearing Acres | Total Value ($1000/yr.) | $/acre/yr. |
|---|---|---|---|
| Almonds | 405,000 | 1,008,576 | 2,490 |
| Apples | 36,200 | 148,770 | 4,109 |
| Apricots | 20,200 | 32,169 | 1,592 |
| Cherries | 12,900 | 45,430 | 3,521 |
| Citrus | 269,900 | 776,775 | 2,878 |
| Grapes | 655,500 | 2,158,543 | 3,293 |
| Nectarines | 33,700 | 115,029 | 3,413 |
| Peaches | 65,300 | 249,335 | 3,818 |
| Plums | 41,300 | 93,257 | 2,258 |
| Prunes | 80,200 | 198,000 | 2,458 |
| Walnuts | 169,000 | 322,400 | 1,908 |
| Total | 1,789,200 | 5,148,285 | 2,870 |

Source: [12]

**TABLE 4.C.3**
**Methyl Bromide Use: California Orchard Crops (field use only)**

(1000 lbs/yr)

| | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 |
|---|---|---|---|---|---|---|---|
| Almonds | 382 | 714 | 630 | 1,420 | 782 | 885 | 930 |
| Apples | 32 | 180 | 64 | 118 | 154 | 61 | 10 |
| Apricots | 12 | 30 | 38 | 8 | 20 | 10 | 1 |
| Cherries | 24 | 89 | 71 | 182 | 97 | 57 | 62 |
| Citrus | 46 | 140 | 199 | 241 | 81 | 69 | 87 |
| Grapes | 673 | 1,925 | 1,479 | 1,930 | 1,300 | 2,107 | 1,730 |
| Nectarines | 12 | 316 | 348 | 125 | 64 | 44 | 37 |
| Peaches | 172 | 634 | 873 | 711 | 406 | 434 | 364 |
| Plums | 14 | 180 | 279 | 45 | 54 | 5 | 5 |
| Prunes | 31 | 114 | 111 | 141 | 131 | 88 | 147 |
| Walnuts | 110 | 191 | 282 | 276 | 316 | 279 | 260 |

Source: [13]

**TABLE 4.C.4**
**Methyl Bromide Use: California Orchard Crops (1995)**

| | Acreage Treated |
|---|---|
| Almonds | 4,648 |
| Apples | 32 |
| Apricots | 16 |
| Cherries | 187 |
| Citrus | 240 |
| Grapes | 4,608 |
| Nectarines | 128 |
| Peaches | 1,300 |
| Plums | 16 |
| Prunes | 527 |
| Walnuts | 1,000 |

The adjustment was made by examining the individual use records for 1995 and excluding records for which the application rate per treated acre was less than 50 pounds active ingredient (AI).

**TABLE 4.C.5**
**Newly Planted Acres Treated with Methyl Bromide**

| Crop | # of Acres Planted 1996[1] | # of Acres Treated with Methyl Bromide 1995[2] | % New Plantings Treated with MBr |
|---|---|---|---|
| Prunes | 2,215 | 527 | 23 |
| Almonds | 21,827 | 4,648 | 21 |
| Walnuts | 4,621 | 1,000 | 21 |
| Grapes | 34,412 | 4,608 | 13 |

[1]Source: [14] – [17]
[2]Source: Table 4.C.4

**TABLE 4.C.6**
**Impacts of Replacing Methyl Bromide: California Perennial Crops (NAPIAP)**

| | | With MBr Alternatives | | | |
|---|---|---|---|---|---|
| | Methyl bromide–treated Acres | Control Costs ($/A) | Total Production (Tons) | Value of Production $/Ton | Total Impact ($1000) |
| Almonds | 1,803 | -475 | -77 | 2,005 | +702 |
| Apples | 450 | -85 | -2,106 | 289 | -571 |
| Apricots | 75 | -25 | -158 | 358 | -55 |
| Cherries | 224 | -25 | -126 | 843 | -101 |
| Grapes | 4,838 | -250 | -13,061 | 307 | -2,801 |
| Nectarines | 791 | -138 | -2,009 | 482 | -859 |
| Peaches | 1,586 | -138 | -3,965 | 330 | -1,089 |
| Plums/Prunes | 740 | -25 | -1,554 | 317 | -475 |
| Walnuts | 481 | -25 | -501 | 1,047 | -513 |

Source:[41] Estimates are based on 1990-91 production. The primary treatment alternative to methyl bromide was identified as metam sodium at a cost of $525 per acre. For most crops the cost of methyl bromide treatment was estimated at $550 to $755 per acre. For almonds the cost of methyl bromide was estimated at $1000 per acre. The production and impact estimates are for the first bearing year after a ban on acres that would have been treated with methyl bromide.

**TABLE 4.C.7**
**Impact of Canceling Methyl Bromide in California Perennials**
**(1994 University of California Study)**

| Crop | ($000) |
|---|---|
| Almonds | -1,920 |
| Grapes | -4,973 |
| Nectarines | -3,995 |
| Peaches | -7,208 |
| Walnuts | -1,473 |

Source: [38]

**TABLE 4.C.8**
**Perennial Crop Yield Loss with Alternative Preplant Treatments**

| Crop/Treatment | % Yield Loss[1] | % Difference from Methyl Bromide |
|---|---|---|
| Walnuts | | |
| Methyl Bromide | 10 | - |
| Four Year Fallow | 10 | 0 |
| One Year Fallow | 30 | -20 |
| Metam Sodium | 25 | -15 |
| 1,3-D + Metam Sodium + One Year Fallow | 15 | -5 |
| Cherry/Apricot/Prunes | | |
| Methyl Bromide | 1 | - |
| Four Year Fallow | 1 | 0 |
| One Year Fallow | 25 | -24 |
| Metam Sodium | 10 | -9 |
| 1,3-D + Metam Sodium | 5 | -4 |
| Peach/Plum Nectarine | | |
| (Nemaguard Rootstock)[2] | | |
| Methyl Bromide | 5 | - |
| Four Year Fallow | 5 | 0 |
| One Year Fallow | 40 | -35 |
| Metam Sodium | 30 | -25 |
| 1,3-D + Metam Sodium | 10 | -5 |
| (Other Rootstock) | | |
| Methyl Bromide | 1 | - |
| Four Year Fallow | 1 | 0 |
| One Year Fallow | 25 | -24 |
| Metam Sodium | 10 | -9 |
| 1,3-D + Metam Sodium | 5 | -4 |
| Almonds | | |
| (Nemaguard Rootstock)[2] | | |
| Methyl Bromide | 5 | - |
| Four Year Fallow | 5 | 0 |
| One Year Fallow | 40 | -35 |
| Metam Sodium | 30 | -25 |
| 1,3-D + Metam Sodium + One Year Fallow | 15 | -10 |

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**TABLE 4.C.8 (Cont.)**
**Perennial Crop Yield Loss with Alternative Preplant Treatments**

| Crop/Treatment | % Yield Loss | % Difference from Methyl Bromide |
|---|---|---|
| Almonds | | |
| (Other Rootstock) | | |
| Methyl Bromide | 1 | - |
| Four Year Fallow | 1 | 0 |
| One Year Fallow | 25 | -24 |
| Metam Sodium | 10 | -9 |
| 1,3-D + Metam Sodium + One Year Fallow | 5 | -4 |
| Grapes: Raisins/Wine (Central Valley) | | |
| Methyl Bromide | 5 | - |
| Four Year Fallow | 10 | -5 |
| One Year Fallow | 25 | -20 |
| Metam Sodium | 20 | -15 |
| 1,3-D + Metam Sodium + One Year Fallow | 10 | -5 |
| Grapes: Premium Wines | | |
| Methyl Bromide | 5 | - |
| Four Year Fallow | 25 | -20 |
| One Year Fallow | 50 | -45 |
| Metam Sodium | 40 | -35 |
| 1,3-D + Metam Sodium + One Year Fallow | 20 | -15 |
| Grapes: Table | | |
| Methyl Bromide | 5 | - |
| Four Year Fallow | 10 | -5 |
| One Year Fallow | 25 | -20 |
| Metam Sodium | 20 | -15 |
| 1,3-D + Metam Sodium + One Year Fallow | 10 | -5 |

[1]Yield losses compared to areas not treated with methyl bromide, where soilborne pathogens are not present.
[2]85% of acreage planted on Nemaguard rootstock.
Source: [42]

**Table 4.C.9. California Perennial Crop Acreage and Value[1]**

| Crop | Bearing Acres | Crop Value ($1,000) |
|---|---:|---:|
| **Almonds** | 405,000 | 951,558 |
| **Grapes, Raisin** | 269,333 | 551,844 |
| **Grapes, Table** | 76,367 | 354,748 |
| **Grapes, Wine** | 307,667 | 1,004,417 |
| **Nectarines** | 31,633 | 92,396 |
| **Peaches** | 62,067 | 198,582 |
| **Prunes** | 79,300 | 198,870 |
| **Walnuts** | 169,667 | 296,320 |

[1] Bearing acreage and crop value are averages from 1994 to 1996 from [12].

**Table 4.C.10 The Impact of 1,3-D Restrictions on California Perennial Crops**

| Crop | Acres Fumigated with Methyl Bromide[1] | Acres Exceeding 1,3-D Township Restrictions |
|---|---:|---:|
| **Almonds** | 5,134 | 1,748 |
| **Grapes** | 6,712 | 2,075 |
| **Nectarines** | 1,779 | 350 |
| **Peaches** | 1,842 | 441 |
| **Prunes** | 1,723 | 368 |

[1] Calculations of methyl bromide use and expected 1,3-D demand by township based on 1995 California Pesticide Use Database. Assumes each crop is entitled to 1,3-D in proportion to its demand.

**Table 4.C.11 Sacramento Valley Almond Yield and Harvest Cost Comparisons for Acreage Planted with Nemaguard Rootstock**

| | Methyl Bromide | | Nemaguard + 1,3-D + Metam Sodium + One Year Fallow | | |
|---|---|---|---|---|---|
| **Year After Planting** | **Yield (lb/acre)** | **Harvest Cost ($/lb)** | **Yield (lb/acre)** | **Harvest Cost ($/lb)** | **Yield Loss (lb/acre)** |
| **3** | 285 | .44 | 0 | - | 285 |
| **4** | 570 | .27 | 257 | .44 | 314 |
| **5** | 1140 | .22 | 513 | .27 | 627 |
| **6** | 1520 | .16 | 1026 | .22 | 494 |
| **7** | 1900 | .16 | 1368 | .16 | 532 |
| **8+** | 1900 | .16 | 1710 | .16 | 190 |

Source: Yields and harvest costs for almond acreage treated with methyl bromide based on [73].
A 5% yield reduction assumed for acreage treated with methyl bromide.

**Table 4.C.12 Sacramento Valley Almond Yield and Harvest Cost Comparisons for Acreage Not Planted on Nemaguard Rootstock**

| | Methyl Bromide | | 1,3-D + Metam Sodium + One Year Fallow | | |
|---|---|---|---|---|---|
| **Year After Planting** | **Yield (lb/acre)** | **Harvest Cost ($/lb)** | **Yield (lb/acre)** | **Harvest Cost ($/lb)** | **Yield Loss (lb/acre)** |
| **3** | 297 | .44 | 0 | - | 297 |
| **4** | 594 | .27 | 285 | .44 | 309 |
| **5** | 1188 | .22 | 570 | .27 | 618 |
| **6** | 1584 | .16 | 1140 | .22 | 444 |
| **7** | 1980 | .16 | 1521 | .16 | 459 |
| **8+** | 1980 | .16 | 1901 | .16 | 79 |

Source: Yields and harvest costs for almond acreage treated with methyl bromide based on [73].
A 1% yield reduction assumed for acreage treated with methyl bromide

**Table 4.C.13 San Joaquin Valley Almond Yield and Harvest Cost Comparisons for Acreage Planted on Nemaguard Rootstock**

| | Methyl Bromide | | Nemaguard + 1,3-D + Metam Sodium + One Year Fallow | | | Nemaguard + Metam Sodium + One Year Fallow | | |
|---|---|---|---|---|---|---|---|---|
| **Year After Planting** | **Yield (lb/acre)** | **Harvest Cost ($/lb)** | **Yield (lb/acre)** | **Harvest Cost ($/lb)** | **Yield Loss (lb/acre)** | **Yield (lb/acre)** | **Harvest Cost ($/lb)** | **Yield Loss (lbs./acre)** |
| **3** | 380 | 0.36 | 0 | - | 380 | 0 | - | 380 |
| **4** | 760 | 0.22 | 342 | 0.36 | 418 | 285 | 0.36 | 475 |
| **5** | 1520 | 0.16 | 684 | 0.22 | 836 | 570 | 0.22 | 950 |
| **6** | 1710 | 0.15 | 1368 | 0.16 | 342 | 1140 | 0.16 | 570 |
| **7** | 1900 | 0.15 | 1539 | 0.15 | 361 | 1283 | 0.15 | 618 |
| **8** | 2090 | 0.15 | 1710 | 0.15 | 380 | 1425 | 0.15 | 665 |
| **9+** | 2090 | 0.15 | 1881 | 0.15 | 209 | 1568 | 0.15 | 523 |

Source: Yields and harvest costs for almond acreage treated with methyl bromide based on [80]. A 5% yield reduction assumed for acreage treated with methyl bromide.

**Table 4.C.14 San Joaquin Valley Almond Yield and Harvest Cost Comparisons for Acreage Not Planted on Nemaguard Rootstock**

| | Methyl Bromide | | 1,3-D + Metam Sodium + One Year Fallow | | | Metam Sodium + One Year Fallow | | |
|---|---|---|---|---|---|---|---|---|
| **Year After Planting** | **Yield (lb/acre)** | **Harvest Cost ($/lb)** | **Yield (lb/acre)** | **Harvest Cost ($/lb)** | **Yield Loss (lb/acre)** | **Yield (lb/acre)** | **Harvest Cost ($/lb)** | **Yield Loss (lbs./acre)** |
| **3** | 396 | 0.36 | 0 | - | 396 | 0 | - | 396 |
| **4** | 792 | 0.22 | 380 | 0.36 | 412 | 360 | 0.36 | 432 |
| **5** | 1584 | 0.16 | 760 | 0.22 | 824 | 721 | 0.22 | 863 |
| **6** | 1782 | 0.15 | 1521 | 0.16 | 261 | 1441 | 0.16 | 341 |
| **7** | 1980 | 0.15 | 1711 | 0.15 | 269 | 1622 | 0.15 | 358 |
| **8** | 2178 | 0.15 | 1901 | 0.15 | 277 | 1802 | 0.15 | 376 |
| **9+** | 2178 | 0.15 | 2091 | 0.15 | 87 | 1982 | 0.15 | 196 |

Source: Yields and harvest costs for almond acreage treated with methyl bromide based on [80]. A 1% yield reduction assumed for acreage treated with methyl bromide.

**Table 4.C.15 Premium Wine Grape Yield Comparisons**

| | Methyl Bromide | 1,3-D + Metam Sodium + One Year Fallow | | Metam Sodium + One Year Fallow | |
|---|---|---|---|---|---|
| **Year After Planting** | **Yield (lb/acre)** | **Yield (lb/acre)** | **Yield Loss (lb/acre)** | **Yield (lb/acre)** | **Yield Loss (lb/acre)** |
| **3** | 3,000 | 0 | 3,000 | 0 | 3,000 |
| **4** | 7,000 | 2,550 | 4,450 | 1,950 | 5,050 |
| **5** | 10,000 | 5,950 | 4,050 | 4,550 | 5,450 |
| **6** | 12,000 | 8,500 | 3,500 | 6,500 | 5,500 |
| **7+** | 12,000 | 10,200 | 1,800 | 7,800 | 4,200 |

Source: Yields for premium wine grape acreage treated with methyl bromide from [78].

**Table 4.C.16 Wine Grape Yield Comparisons for San Joaquin Valley**

| | Methyl Bromide | 1,3-D + Metam Sodium + One Year Fallow | | Metam Sodium + One Year Fallow | |
|---|---|---|---|---|---|
| **Year After Planting** | **Yield (lb/acre)** | **Yield (lb/acre)** | **Yield Loss (lb/acre)** | **Yield (lb/acre)** | **Yield Loss (lb/acre)** |
| **3** | 12,000 | 0 | 12,000 | 0 | 12,000 |
| **4** | 14,667 | 11,400 | 3,267 | 10,200 | 4,467 |
| **5** | 17,333 | 15,439 | 1,894 | 12,467 | 4,866 |
| **6** | 20,000 | 16,466 | 3,534 | 14,733 | 5,267 |
| **7+** | 20,000 | 19,000 | 1,000 | 17,000 | 3,000 |

Source: Yields for first bearing year and for vines at maturity for wine grape acreage treated with methyl bromide from [81]. Assumed yield increases in second and third bearing years to be equal.

**Table 4.C.17 Table Grape Yield Comparisons for San Joaquin Valley**

| | Methyl Bromide | 1,3-D + Metam Sodium + One Year Fallow | | Metam Sodium + One Year Fallow | |
|---|---|---|---|---|---|
| **Year After Planting** | **Yield (lb/acre)** | **Yield (lb/acre)** | **Yield Loss (lb/acre)** | **Yield (lb/acre)** | **Yield Loss (lb/acre)** |
| **3** | 12,000 | 0 | 12,000 | 0 | 12,000 |
| **4** | 14,700 | 11,400 | 3,300 | 10,200 | 4,500 |
| **5+** | 14,700 | 13,965 | 735 | 12,495 | 2,205 |

Source: Yields for first bearing year and for vines at maturity for wine grape acreage treated with methyl bromide from [82]. First year of table grape yields is sold for wine production.

**Table 4.C.18 Peach/Nectarine Yield Comparisons**

| | Methyl Bromide | Nemaguard + 1,3-D + Metam Sodium | | 1,3-D + Metam Sodium | | Nemaguard + Metam Sodium + One Year Fallow | | Metam Sodium + One Year Fallow | |
|---|---|---|---|---|---|---|---|---|---|
| **Year After Planting** | **Yield (lb/acre)** | **Yield (lb/acre)** | **Yield Loss (lb/acre)** | **Yield (lb/acre)** | **Yield Loss (lb/acre)** | **Yield (lb/acre)** | **Yield Loss (lb/acre)** | **Yield (lb/acre)** | **Yield Loss (lbs./acre)** |
| 3 | 5,875 | 5,581 | 294 | 5,640 | 235 | 0 | 5,875 | 0 | 5,875 |
| 4 | 11,750 | 11,163 | 588 | 11,280 | 470 | 4,406 | 7,344 | 5,346 | 6,404 |
| 5 | 18,800 | 17,860 | 940 | 18,048 | 752 | 8,813 | 9,987 | 10,693 | 8,107 |
| 6 | 25,850 | 24,558 | 1,293 | 24,816 | 1,034 | 14,100 | 11,750 | 17,108 | 8,742 |
| 7 | 32,900 | 31,255 | 1,645 | 31,584 | 1,316 | 19,388 | 13,512 | 23,524 | 9,376 |
| 8+ | 32,900 | 31,255 | 1,645 | 31,584 | 1,316 | 24,675 | 8,225 | 29,939 | 2,961 |

Source: Yields for methyl bromide–treated acreage from [76].

**Table 4.C.19 Prune Yield Comparisons in the San Joaquin Valley[1]**

| | Methyl Bromide | 1,3-D + Metam Sodium | | Metam Sodium + One Year Fallow | |
|---|---|---|---|---|---|
| **Year After Planting** | **Yield (lb/acre)** | **Yield (lb/acre)** | **Yield Loss (lb/acre)** | **Yield (lb/acre)** | **Yield Loss (lb/acre)** |
| **4** | 280 | 269 | 11 | 0 | 280 |
| **5** | 1420 | 1,363 | 57 | 255 | 1,165 |
| **6** | 2860 | 2,746 | 114 | 1,292 | 1,568 |
| **7** | 3800 | 3,648 | 152 | 2,603 | 1,197 |
| **8** | 7600 | 7,296 | 304 | 3,458 | 4,142 |
| **9+** | 7600 | 7,296 | 304 | 6,916 | 684 |

[1] Prune yields given in net dry weight per acre.

Source: Yields for acreage treated with methyl bromide from [83].

**Table 4.C.20 Prune Yield Comparisons in the Sacramento Valley[1]**

| | Methyl Bromide | 1,3-D + Metam Sodium | | Metam Sodium + One Year Fallow | |
|---|---|---|---|---|---|
| **Year After Planting** | **Yield (lb/acre)** | **Yield (lb/acre)** | **Yield Loss (lb/acre)** | **Yield (lb/acre)** | **Yield Loss (lb/acre)** |
| **4** | 1584 | 1489 | 95 | 0 | 1584 |
| **5** | 2633 | 2475 | 158 | 1441 | 1192 |
| **6** | 5287 | 4970 | 317 | 2396 | 2891 |
| **7** | 7920 | 7445 | 475 | 4811 | 3109 |
| **8+** | 7920 | 7445 | 475 | 7207 | 713 |

[1] Prune yields given in dry weight per acre.

Source: Yields based on [84] for untreated land. A one percent yield loss penalty for methyl bromide fumigation is assumed here.

**Table 4.C.21 San Joaquin Valley Walnut Yield and Harvest Cost Comparisons[1]**

| | Methyl Bromide | | 1,3-D + Metam Sodium + One Year Fallow | | | Metam Sodium + One Year Fallow | | |
|---|---|---|---|---|---|---|---|---|
| **Year After Planting** | **Yield (lb/acre)** | **Harvest Cost ($/lb)** | **Yield (lb/acre)** | **Harvest Cost ($/lb)** | **Yield Loss (lb/acre)** | **Yield (lb/acre)** | **Harvest Cost ($/lb)** | **Yield Loss (lbs./acre)** |
| **4** | 300 | .37 | 0 | - | 300 | 0 | - | 300 |
| **5** | 700 | .38 | 285 | .37 | 415 | 255 | .37 | 445 |
| **6** | 1,500 | .15 | 665 | .38 | 835 | 595 | .38 | 905 |
| **7** | 3,500 | .11 | 1,425 | .15 | 2,075 | 1,275 | .15 | 2,225 |
| **8** | 4,000 | .11 | 3,325 | .11 | 675 | 2,975 | .11 | 1,025 |
| **9+** | 4,000 | .11 | 3,800 | .11 | 200 | 3,400 | .11 | 600 |

[1] Yields in dry, inshell pounds.

Source: Yields and harvest costs for walnut acreage treated with methyl bromide from [74].

**Table 4.C.22 Sacramento Valley Walnut Yield and Harvest Cost Comparison[1]**

| | Methyl Bromide | | 1,3-D + Metam Sodium + One Year Fallow | | | Metam Sodium + One Year Fallow | | |
|---|---|---|---|---|---|---|---|---|
| **Year After Planting** | **Yield (lb/acre)** | **Harvest Cost ($/lb)** | **Yield (lb/acre)** | **Harvest Cost ($/lb)** | **Yield Loss (lb/acre)** | **Yield (lb/acre)** | **Harvest Cost ($/lb)** | **Yield Loss (lbs./acre)** |
| **4** | 300 | .60 | 0 | - | 300 | 0 | - | 300 |
| **5** | 900 | .21 | 285 | .60 | 615 | 255 | .60 | 645 |
| **6** | 1,400 | .15 | 855 | .21 | 545 | 765 | .21 | 635 |
| **7** | 2,800 | .10 | 1,330 | .15 | 1,470 | 1,190 | .15 | 1,610 |
| **8** | 5,400 | .10 | 2,660 | .10 | 2,740 | 2,380 | .10 | 3,020 |
| **9+** | 5,400 | .10 | 5,130 | .10 | 270 | 4,590 | .10 | 810 |

[1] Yields in dry, inshell pounds.

Source: Yields and harvest costs for walnut acreage treated with methyl bromide from [75].

**Table 4.C.23 Fumigation Cost Estimates for Perennial Crops in California**

**A. Costs of Methyl Bromide Treatments**

| | **Cost Per Acre** |
|---|---|
| **Almonds** | $550 |
| **Wine grapes** | $1,400 |
| **Other grapes** | $550 |
| **Peaches/Nectarines** | $500 |
| **Prunes** | $1,485 |
| **Walnuts** | $1,300 |

**B. Costs of Un-Tarped Telone II + Metam Sodium Application**

| | **Cost Per Acre** |
|---|---|
| **Telone II**[1] | $507.50 |
| **Vapam**[2] | $410 |
| **Application Costs** | $40 |
| **Total** | $957.50 |

[1] Assuming Telone II application rate of 35 gal per acre at $14.50 per gal
[2] Assuming Vapam application rate of 100 gal per acre at $4.10 per gal

**C. Costs of Metam Sodium Treatment**

| | **Cost Per Acre** |
|---|---|
| **Vapam**[1] | $410 |
| **Total** | $410 |

[1] Assuming Vapam application rate of 100 gal per acre at $4.10 per gal

Table 4.C.24 Impacts of a Ban of Methyl Bromide on California Perennial Crops

| Crop | Alternative[9] | Treated Acres[1] | Yield Loss (%) | Cost Change Per Acre[2] ($) | Yield Impact Per Acre[8] ($) | Total Impact $/yr (000) |
|---|---|---|---|---|---|---|
| **Almonds-San Joaquin Valley[3]** | Nemaguard + 1,3-D + Metam Sodium + One Year Fallow | 2,562 | 10% | 408 | 6,958 | 18,870 |
| | 1,3-D + Metam Sodium + One Year Fallow | 452 | 4% | 408 | 3,635 | 1,827 |
| | Nemaguard + Metam Sodium + One Year Fallow | 1,485 | 25% | -140 | 14,422 | 21,209 |
| | Metam Sodium + One Year Fallow | 262 | 9% | -140 | 5,910 | 1,512 |
| **Almonds-Sacramento Valley[4]** | Nemaguard + 1,3-D + Metam Sodium + One Year Fallow | 316 | 10% | 408 | 6,222 | 2,095 |
| | 1,3-D + Metam Sodium + One Year Fallow | 56 | 4% | 408 | 3,244 | 204 |
| **Grapes: Premium Wine[5]** | 1,3-D + Metam Sodium + One Year Fallow | 2,172 | 15% | -443 | 16,521 | 34,923 |
| | Metam Sodium + One Year Fallow | 666 | 35% | -990 | 33,912 | 21,926 |
| **Grapes: Wine Central Valley[6,7]** | 1,3-D + Metam Sodium + One Year Fallow | 1,132 | 5% | 408 | 3,778 | 4,737 |
| | Metam Sodium + One Year Fallow | 864 | 15% | -140 | 8,288 | 7,040 |
| **Grapes: Raisin[7]** | 1,3-D + Metam Sodium + One Year Fallow | 518 | 5% | 408 | 2,833 | 1,679 |
| | Metam Sodium + One Year Fallow | 138 | 15% | -140 | 6,216 | 839 |
| **Grapes: Table[7]** | 1,3-D + Metam Sodium + One Year Fallow | 903 | 5% | 408 | 1,097 | 1,359 |
| | Metam Sodium + One Year Fallow | 282 | 15% | -140 | 10,577 | 2,943 |
| **Nectarines** | Nemaguard + 1,3-D + Metam Sodium | 1,215 | 5% | 458 | 2,200 | 3,229 |
| | 1,3-D + Metam Sodium | 227 | 4% | 458 | 2,827 | 746 |
| | Nemaguard + Metam Sodium + One Year Fallow | 298 | 25% | -90 | 12,270 | 3,630 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Metam Sodium + One Year Fallow | 40 | 9% | -90 | 8,834 | 350 |
| **Peaches** | Nemaguard + 1,3-D + Metam Sodium | 1,190 | 5% | 458 | 1,345 | 2,145 |
| | 1,3-D + Metam Sodium | 210 | 4% | 458 | 1,728 | 459 |
| | Nemaguard + Metam Sodium + One Year Fallow | 375 | 25% | -90 | 7,499 | 2,778 |
| | Metam Sodium + One Year Fallow | 66 | 9% | -90 | 5,399 | 350 |
| **Prunes-San Joaquin Valley[3]** | 1,3-D + Metam Sodium | 899 | 4% | -528 | 3,165 | 2,371 |
| | Metam Sodium + One Year Fallow | 297 | 9% | -1075 | 5,160 | 1,213 |
| **Prunes-Sacramento Valley[4]** | 1,3-D + Metam Sodium | 455 | 4% | -528 | 2,864 | 1,063 |
| | Metam Sodium + One Year Fallow | 71 | 9% | -1075 | 5,160 | 290 |
| **Walnuts-San Joaquin Valley[3]** | 1,3-D + Metam Sodium + One Year Fallow | 410 | 5% | -528 | 3,047 | 1,033 |
| | Metam Sodium + One Year Fallow | 88 | 15% | -1075 | 6,514 | 479 |
| **Walnuts-Sacramento Valley[4]** | 1,3-D + Metam Sodium + One Year Fallow | 440 | 5% | -343 | 4,233 | 1,712 |
| | Metam Sodium + One Year Fallow | 50 | 15% | -890 | 4,689 | 190 |
| **TOTAL** | | | | | | 143,201 |

1 Treated acreage from the 1995 California Pesticide Use Database, adjusted to exclude applications for which the treatment rate was less than 50 pounds/acre. (See Table 4.C.4.) A further adjustment was made in the methyl bromide usage estimates in three counties (Fresno, Madera and Tulare) for which the crop was "unspecified" for a large number of methyl bromide applications. The "unspecified" treatment acres for these counties were distributed to individual crops based on discussions with the county Agricultural Commissioners.

2 Differences in cost between current methyl bromide treatments and alternatives. (See Table 4.C.23.)

3 Includes acreage in Fresno, Kern, Kings, Madera, Merced, San Joaquin and Stanislaus Counties.

4 Includes acreage in Butte, Colusa, Sutter, Tehama, Yolo and Yuba Counties.

[5] Includes wine grape acreage and value for Mendocino, Monterey, Napa, Nevada, Sacramento, San Benito, San Luis Obispo, San Mateo, Solano, Sonoma and Yolo counties, which each had per acre revenues over $3,500 on average over 1994 to 1996.

[6] Includes wine grape acreage and value for all counties besides those determined to be high value wine grape producing counties, as listed above.

[7] The California Pesticide Use Database reports fumigated acreage for two categories of grapes, wine grapes and grapes. Information on planted acreage by type of grape was used to divide fumigated acreage into wine, raisin and table grapes [79].

[8] Calculated from data in Tables 4.C.11–4.C.22. The yield losses over the life of the orchard are calculated and monetized on an annual basis. Reduction in harvest costs because of reduced yields are taken into account. Future years have been discounted using an interest rate of 4%. The per pound values of the crops are listed in the text.

[9] Nemaguard rootstock not considered in costs of alternatives because it is already being used in conjunction with methyl bromide fumigation. It is noted to distinguish between lifespan and yield losses on acreage planted to Nemaguard or other rootstock.

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## D. Nursery and Ornamental Crops

### 1. Introduction

The nursery industry is diverse, comprising such varied operations as the production of potted plants, cut flowers and greens, ornamental nursery plants, fruit and nut tree nursery plants, sod, bulbs, vegetable transplants and seeds. The most recent comprehensive production statistics available for the nursery industry are from the 1992 Census of Agriculture. At that time, California had the highest sales value for its nursery industry at over $1.6 billion. Florida's nursery industry had the next highest sales at over $1 billion. Illinois, Michigan, New York, Ohio, Oregon, Pennsylvania and Texas had sizable industries, each with sales of at least $200 million in 1992 [33].

Methyl bromide is heavily used in certain segments of the industry and not as widely used in others. However, there are few statistics on methyl bromide use by nursery growers. The segments that are believed to be most reliant on methyl bromide are annual and perennial transplants, cut flowers, sod, and bulb and herbaceous material that is grown in ground. In a recent survey of the memberships of the American Nursery and Landscape Association and the Society of American Florists, 12% of respondents indicated use of methyl bromide in their operations [13]. (See Table 4.D.1.) These two organizations represent most segments of the nursery industry, with the exception of sod growers and with lesser representation of bulb growers. Estimates of methyl bromide use by California nursery growers, obtained through a survey of county agricultural commissioners, are provided in Table 4.D.2 [5]. Methyl bromide use estimates for California nurseries are also available from the California Pesticide Use Database and are provided in Table 4.D.3. Though these figures provide little detail about the segment of the nursery industry in which methyl bromide is being used, they do provide a general idea of the amount of methyl bromide that is being used by nursery growers. A survey of Florida wholesale ornamental nursery growers indicated that only 1% of respondents used methyl bromide, since more growers have adopted containerized production systems and purchase sterile growing media [17] [44] [45].

One important segment of the nursery industry, and one with a distinct set of issues, is the production of nursery stock, or transplants, for annual and perennial food crops, and some ornamentals. Pest control requirements in this setting are more rigorous due to the risk of spreading pests into areas where those pests do not currently exist. There are regulatory programs at various governmental levels in place to limit the spread of pests through nursery stock.

In California, there is a registration and certification program for nematode control that specifies acceptable treatments for nursery stock that is sold for on-farm use. This applies to both food and ornamental crops. The program currently certifies field-grown nursery stock that is grown in soil treated with either methyl bromide or 1,3-D. For container-grown stock, treatments with steam, solarization or methyl bromide are allowed [71]. Alternatively, nursery stock may be certified nematode-free at the time of harvest if sampling fails to detect nematodes [11]. In addition to the nematode certification program, all nurseries are subject to a general cleanliness standard, which is enforced through visual inspection of the nurseries. Methyl bromide may be used to control pests that would otherwise cause a nursery to fail to meet this standard. Through these programs, the California nursery industry has built a reputation for providing high-quality nursery stock for domestic and international markets. The township restrictions on 1,3-D use in California are likely to limit the amount of nursery acreage that could be treated to meet the registration and certification program.

Shipments of nursery stock between states, as well as foreign imports, are subject also to regulations at the state and federal level. Each state may have phytosanitary and quarantine standards for materials imported from out of state. Frequently these standards require the general cleanliness of nursery products entering the state, accepting certification by the exporting state or a federal agency. In addition, each state may identify specific pests that are quarantined on plant material originating either in specific states or everywhere [1]. An example of a state quarantine for nursery products is the control of reniform nematode by several states [1]. The USDA Animal and Plant Health Inspection Service also has specific programs to limit the spread of pests between different areas of the country. Methyl bromide use in the nurseries may be a component of production practices that ensure the cleanliness of nursery stock that crosses state boundaries. Also, methyl bromide may be used to eliminate a pest that is found on incoming shipments.

Though other states may not require specific treatments, as the California nursery certification program does, nursery stock is held to high standards and methyl bromide has provided the means to ensure high quality plants.

### 2. Perennial Nurseries

California grapevine, fruit tree and nut tree nursery growers supply nearly all California growers with their trees and vines, as well as supporting a substantial export market. Growers who supply nursery stock to commercial farms are required by the California Department of Agriculture to be certified nematode free, as discussed earlier. For stock that is grown in the ground, methyl bromide fumigation is one of three ways to become certified. Otherwise, 1,3-D may be used, or a grower can submit to sampling at harvest time, although this is considered too risky since the crop would be destroyed if nematodes were detected. In addition to the nematode certification program, growers must also meet general cleanliness standards [52].

Perennial nursery stock takes between ten months and three years in the ground, depending on whether it is grafted and the type of tree [10][18]. California growers currently rotate their fields, either into another nursery crop that is not required to meet the nematode registration and certification program requirements, such as an ornamental crop that would benefit from the fumigation of the previous crop, a cash crop that helps control pests, or to dry land pasture [10][18][36].

Currently, field comparison of various treatments are under way for various tree and vine nurseries, including combinations of 1,3-D injections followed by a drench with metam sodium, which is the most promising treatment, providing a visual growth benefit that surpassed that of methyl bromide. Trees receiving monthly postplant drenchings of oxamyl exhibited excellent growth and nematode control when soil samplings were conducted in the treated zone. Methyl iodide, an MITC liberator (e.g. metam sodium, dazomet) and sodium tetrathiocarbonate all resulted in visible tree damage [23].

Four potential alternatives have been identified as having the greatest chance for field success: (1) a combination treatment of 1,3-D injected at a 45-cm depth, followed by a sprinkler application treatment of MITC over four days; (2) a drench of MITC by sprinkler or portable soil drenching device in eight hours or less, followed by a clean fallow for one year; (3) a drench of MITC by a portable drenching device in five to eight hours, or sprinkler or basin irrigation delivery; and (4) a drench treatment of enzone. The first two alternatives are for situations where endoparasitic nematodes along with other soil pests (except oak root fungus) are known to be present. The last two treatments are considered appropriate only for situations in which ectoparasitic nematodes are the only pests present or where remnant roots are fully decayed. Research is under way to evaluate these and other alternatives [68].

Some perennial nursery stock is currently grown in containers, such as olive trees [30]. Solarization has been investigated as an alternative disinfestation method for planting mixes used in containerized production and was recently accepted as a certifiable treatment under the California nematode certification program [71]. In experiments in the San Joaquin Valley near Kearney, field soil naturally infested with the citrus nematode (*Tylenchulus semipenetrans*) and the fungal pathogen *Pythium ultimum* was solarized in black polyethylene planting sleeves, and pests were reduced by 89 to 99% in sleeves treated for four weeks. The organisms were undetectable after treatment in either single- or double-tented bags. Solarization of soil mounds infested with the lesion nematode *Pratylenchus vulnus* reduced nematode counts to undetectable levels [31] [67].

Additional tests of solarization near Oakdale on field soils naturally infested with lesion (*Pratylenchus vulnus*) and ring (*Criconemella xenoplax*) nematodes, resulted in nearly undetectable levels of *P. vulnus* by the end of the two-week treatment period, using either a single-or double-tent method. Experiments on soil infested with southern root-knot nematode (*Meloidogyne incognita*), a two-week treatments reduced nematode infestation to undetectable levels [66] [67].

*Strawberry*

A discussion of the strawberry nursery production system is provided in the chapter on strawberries.

*Tobacco*

The use of methyl bromide in tobacco seedling production has declined in recent years due to the adoption of greenhouse production systems. However, there are areas where seedling producers continue to rely on methyl bromide for nematode and disease control. In Georgia, large commercial seedling producers continue to grow transplants in outdoor seedbeds on about 650 acres [24]. Florida tobacco fields are supplied with plants grown on about 75 acres of outdoor seedbeds [53]. In other southeastern states, producers have shifted away from field production of transplants. Between 80 and 90% of tobacco seedling production in South Carolina has been converted to float production systems in recent years, and the remaining acreage is anticipated to switch to greenhouse production soon [12]. In 1993, 46% of North Carolina transplants were produced in greenhouses [57]. It is now believed that about 95% of North Carolina seedling production has been converted to greenhouse systems [70]. Although these growers no longer use methyl bromide to fumigate soil, they are fumigating the trays that they use in their production system and are reportedly using approximately 5000 lb/year for that use [70]. Since 1990, the percent of acreage of tobacco seedbeds in Tennessee treated with MB has decreased from 98 to 35% [16]. In Kentucky, less than 1% of tobacco acreage is currently treated with methyl bromide [26].

The shift away from ground production of tobacco transplants is believed to be due to labor shortages. Transplant production under perforated plastic in field beds requires labor to manage covers and to pull transplants. In a greenhouse, much less labor is required, and many procedures can be mechanized [12] [53] [57].

Research has been conducted to identify potential alternatives for tobacco transplant production. In tests conducted in Georgia, combination treatments have been shown to be the most promising [8] [56]. In test plots inoculated with *Rhizoctonia* and *Pythium*, the combination of soil fumigants metam sodium with either chloropicrin, Telone C-17 or Telone C-35, tended to be the best for reducing populations of fungi in the soil. Stand counts and height measurements suggested that the combination fumigants were superior to some of the fumigants alone and in some instances superior to methyl bromide [8]. In test plots inoculated with *Phytophthora parasitica* var. *nicotianae*, metam sodium, Telone C-17 and a combination treatment of Telone C-17 and metam sodium all controlled pathogens [9]. Several years of test results indicated that many treatments performed well, including metam sodium, dazomet and combinations of metam sodium, dazomet, 1,3-D and chloropicrin. Weed control was very good by almost all of the treatments with the exception of dazomet, which controlled yellow nutsedge poorly [6].

In research studies conducted with basamid in North Carolina between 1986 and 1988, weed control and plant stands were similar to those obtained with methyl bromide when dazomet was applied in the fall. The need for proper aeration of the beds before seeding was underscored, as reduced emergence was observed when dazomet was applied in the spring or when beds were seeded the same day the cover was removed [57] [58].

### 3. Ornamentals

#### *Caladium*

Caladium is an ornamental plant that is grown from tubers. Approximately 95% of the world's caladium tubers are produced on about 1400 acres of muck soils in the area around Sebring, Florida [50]. Growers produce tubers that are sold either to greenhouses to grow out the plants in containers or directly to consumers. Approximately two-thirds of total acreage is treated with methyl bromide each year. Methyl bromide is used to control nematodes, diseases and weeds, including off-variety "rogue" plants. Trials are currently under way to evaluate methyl bromide alternatives for Caladium growers [22], although some growers have been experimenting on their own with 1,3-D and metam sodium [28][29]. Weed control is anticipated to become a particular problem. Research has been conducted to assess phytotoxicity associated with several herbicides [60]. Currently, growers may use two herbicides, oryzalin (Surflan) and metolachlor (Pennant), although growers have mixed success with these materials [28].

#### *Cut Flowers*

Much of the U.S. cut flower crop is grown using methyl bromide, although exact figures are unavailable. California has the largest cut flower industry, followed by Florida, Colorado, Hawaii, Michigan, Oregon, and Washington, each of which had over $10 million in wholesale sales in 1997 [34]. In general, the U.S. floral industry has faced increased foreign competition in recent years. In 1996, imports accounted for 90% of total carnation consumption, 71% of cut rose consumption and 89% of cut chrysanthemum consumption [33]. One strategy the industry has adopted has been to diversify into growing a greater variety of flowers in response to the increase in imports [25]. As a result, it has become more difficult to obtain accurate statistics, because the annual statistics that USDA collects for cut flowers include detailed figures for only the traditional flowers, such as roses, chrysanthemums, carnations, gladiola etc. Domestic production of cut flowers other than the major cuts has increased in recent years, valued at $251 million in 1996, up 20% from 1995 [33].

In California, the leading cut flower crops in terms of number of producers are sunflower, larkspur, limonium, snapdragon, red hybrid tea rose, leptospermum, colored hybrid tea rose, waxflower, hybrid delphinium, statice, lisianthus, bella donna delphinium, minicarnation and sweetheart rose [48]. About 45% of California's cut flowers are grown outdoors, and almost all of that acreage is fumigated with methyl bromide to control nematodes, diseases and weeds [43]. For these growers, materials such as 1,3-D, chloropicrin and basamid are likely substitutes for methyl bromide, although there is very little research in this area. The restrictions on 1,3-D use by township will limit the number of cut flower growers who will be able to use this material.

The California cut flower industry also faces other issues that may be more influential factors for production decisions in the future. Some cut flowers in California, such as carnations, are grown in ground beds inside greenhouses and use methyl bromide. For carnation growers in particular, the control of Fusarium wilt is critical. Until recently, growers would drive tractors through the greenhouses, applying methyl bromide in the same manner as for other field crops. However, greenhouse growers in California are now limited to hot-gas application of methyl bromide due to restrictions that do not allow a tractor driver to be in a shelter at the time of methyl bromide application. Hot-gas application is performed by laying perforated tubing across the tops of the beds through which the methyl bromide is applied and covering the area with a tarp. In this manner, no workers are in the structure at the time of methyl bromide application. Although these growers are still using methyl bromide, the hot-gas method of application has not been as effective at controlling diseases. As a result, these growers are already in a precarious situation, and conversion to raised beds and steam sterilization is already under way for growers who can afford the technology [21]. Therefore, a ban on methyl bromide may be a secondary concern to growers who are already finding it difficult to adapt to the current regulatory restrictions on methyl bromide. The application of 1,3-D inside greenhouses is restricted in a similar manner, and although alternative application methods, such as chemigation, could alleviate the problem, they are not currently allowed.

Research has been conducted on carnations grown in ground beds to evaluate alternative practices. Two methods of soil heating, steam and electronic heating, were tested for their efficacy in controlling inoculum of *Fusarium oxysporum* f.sp. *dianthi*. Electronic heat treatments were found to provide relatively uniform heating of soil and eliminated inoculum to significant depths, though it was not considered practical on a large scale. Steam heating of ground beds did not provide uniform soil heating and allowed foci of high inoculum survival [21].

In tests comparing methyl iodide and dazomet to methyl bromide for in-ground carnations, methyl iodide out-performed methyl bromide in control of *Fusarium oxysporum* f. sp. *dianthi* at tested depths. Disease was slower to develop in methyl iodide treated plots, and the plots yielded more fancy-grade flowers. Dazomet provided the best weed control of the three treatments, with a weed reduction of 66% when compared to the control plots followed by methyl iodide, which reduced weeds 47%, and methyl bromide, which reduced weeds by 15% [27]. The use of biological control agents on carnations is also under investigation [20].

California cut rose growers comprise another segment of the California cut flower industry that is already converting to an alternative production technology that eliminates the use of methyl bromide. Fresh cut roses are currently the strongest component of the cut flower industry in California, which produces 80% of the U.S. total. Roses are also grown primarily in greenhouses in ground beds. However, a substantial portion of the rose growers in California have already converted to hydroponic production systems in recent years and no longer use methyl bromide. The hydroponic system has allowed the production of high-quality, long-stem roses comparable to imported roses from South America where growing conditions are more favorable for premium rose production. Although rose growers are switching to hydroponic systems for their rose production, they are simultaneously expanding their outdoor production into other flowers. The diversification within individual operations has been inspired by the unpredictable nature of prices, which may change drastically with surges of shipments from abroad. By producing several different varieties, growers are less susceptible to widely fluctuating prices for any particular crop [25]. The diversification by rose growers into outdoor production of other flowers increases rose growers' dependence upon methyl bromide [25].

Chrysanthemum is another cut flower crop in California that is dependent on methyl bromide. Several botanical extracts have been tested for control of *Fusarium oxysporum* f. sp. c*hrysanthemi*, one of the most widespread and destructive diseases of chrysanthemum. Pepper, clove and cassia extracts reduced population densities in soil by 99.9, 97.5 and 96.1%, respectively, after three days incubation when added as 10% aqueous emulsions. When added as a 5% aqueous emulsion, the pepper extract also reduced population densities by 99.9%. Researchers concluded that the extracts may have a role in biologically based management strategies in combination with the introduction of beneficial biological agents [4].

Florida cut flower growers are dependent upon methyl bromide to control nematodes, diseases and weeds. Gladiolas accounted for over 50% of the value of the total cut flower crop in Florida in 1997. Florida is the largest gladiola producing state, growing nearly 45% of the total U.S. crop in 1997 [40]. Total cut flower acreage in Florida was 4721 in 1988, the last year for which there are estimates of total acreage [41]. In 1997, gladiolas were grown on 3384 acres [40]. It is estimated that 10% of the gladiola acreage and 80 to 100% of the acreage in other cut flowers is fumigated with methyl bromide. A limited amount of research has been conducted to identify alternatives for cut flower growers in Florida. In tests intended to evaluate weed control of various treatments in plots not known to be infested with nematodes or soilborne pathogens, yields of gladiola and sunflower were generally improved using metam sodium or dazomet [39]. (See Tables 4.D.5 and 4.D.6.) Additional research into alternatives for Florida cut flower growers is in progress [22].

*<u>Propagative Plant Material</u>*

A common theme in the nursery industry is the control of pests in the production of plant material that will be sold to commercial growers. For crops where a particular disease or insect is problematic, methyl bromide may be used to insure the cleanliness of such nursery stock. In some instances, shipments to out-of-state destinations may face quarantines for specific pests, and methyl bromide may be used to control the pest of concern. One example of this type of use of methyl bromide is in the production of chrysanthemum cuttings, vegetative material with no leaves or roots, that is sold to producers who grow potted flowering chrysanthemums or cut flowers.

Most of the foundation stock for chrysanthemum cutting propagation is grown in the southeastern U.S. Fusarium wilt of florists' chrysanthemum caused by *Fusarium oxysporum* f. sp. *chrysanthemi* is one of the most widespread and destructive diseases of this crop. The threat of spread of this pathogen is of concern because infected, nonsymptomatic vegetative cuttings can be produced and distributed. A goal of the commercial chrysanthemum propagator is to produce 100% pathogen-free cuttings. To accomplish this, extensive preventive procedures are employed to maintain healthy stock plants. Culture indexing, certified stock block multiplication, and integrated control practices in field production are employed to keep the distribution of infected cuttings to a minimum [19].

A major chrysanthemum cutting producer in Florida grows on 70 acres, on which four crops a year are produced. The fields are fumigated at the maximum label rate before each crop. Fumigation controls *Fusarium oxysporum*, *Erwinia carotovora*, *Pythium spp.*, *Rhizoctonia solani*, and weeds. Freedom from certain species of nematodes (e.g., *Radopholus similis*, the burrowing nematode) is essential to meet quarantine standards established by some states [2]. The company has been converting to a steam system for about 20% of the acreage, the portion that is under roof, so that rains would not affect the treatment [3]. The system comprises high-efficiency oil-fired boilers that generate superheated steam. The steam is introduced to field areas under tarps that cover an area of 4760 $ft^2$, and treatment takes about eight hours to complete. The steam treatment is only used to treat a small acreage of less than two acres each week, which fits with their production system where there is near-continuous planting [2] [48]. Soils of nearly 100% sand are rapidly and freely penetrated by the steam treatment. Limitations to expansion of the use of steam in the company's operation are the high capital and maintenance cost of the boilers, high costs of tarps, problems of application if soils are exposed to rain prior to or during a treatment and fuel and labor costs. Chemical alternatives are currently under investigation for use on the remaining acreage [2].

*Rose Plants*

California rose plant producers grow plants for sale to retailers, commercial cut flower growers and for export and are located primarily in Kern County [42]. California grows approximately 70% of the rose plants produced in the U.S. [69]. Rose nursery stock is subject to varying levels of regulatory standards depending on its destination, though nearly all acreage is believed to be fumigated with methyl bromide currently. All stock is subject to general cleanliness standards. Stock destined for cut flower growers is also subject to nematode-free certification. All California rose nurseries are located in two townships, and the 1,3-D township restrictions will limit the total acreage that is allowed to be fumigated in any particular year. Rose plants take two years to mature to a saleable crop.

Researchers have compared the efficacy of methyl iodide to methyl bromide against lesion nematodes harbored in rose roots. Muslin bags filled with rose roots were buried in containers filled with soil and fumigated. Methyl iodide was found to penetrate the root tissue effectively and was consistently superior to methyl bromide [49].

*Sod/Turf*

Florida and California are the leading sod producing states, and the states where sod producers are believed to rely the most heavily on methyl bromide. Texas and Georgia also have significant sod production industries, based on acreage and sales [33]. Sod producers rely on methyl bromide primarily to control weeds and off type grasses when establishing a field, then again every few years when a field must be cleaned and reestablished because of weed infestation. For southeastern sod growers, a voluntary certification program has been organized through the Southern Seed Certification Association that requires "fumigation." Most growers choose to fumigate with methyl bromide. Currently, only bermudagrass acreage is being certified, which accounts for 4% of total sod acreage in Florida. St. Augustine grass accounts for over 70% of acreage [61], and a substantial portion of this acreage is probably fumigated, although it is not currently in the certification program [32].

Research is under way in Florida to compare the efficacies of various alternative treatments [35]. For southeastern sod growers it has been estimated that production time for each crop will be longer without methyl bromide fumigation and that the marketable crop from each acre in production will be lower. Costs are expected to increase due to increased expenditures on herbicides, insecticides, nematicides and fertilizers [14][15].

In California, the sod industry is subject to the general cleanliness standards discussed previously. These standards specifically address weed pests in turf and indicate that treatment with methyl bromide may be required where a history of weed pest problems exists [11] [51]. No research was located on alternatives for California sod production. However, growers have been experimenting with chemical alternatives on their own. It is expected that quality of the crop will decline and that it will take twice as long to get a saleable crop. Also, the marketable yield per acre is anticipated to decrease [38].

4. Previous Studies

Previous economic analyses by NAPIAP and the University of California have estimated losses in the nursery industry resulting from a ban on methyl bromide [54] [55] [64] [65]. The NAPIAP report included loss estimates for ornamental/nursery plants and tobacco as shown in Tables 4.D.7 and 4.D.8, respectively. Loss estimates from the 1993 University of California report are presented in Table 4.D.9. One important point to consider when comparing the impact calculations made in this report and in previous studies is the effect of assumptions about the availability of alternative fumigants. At the time that the NAPIAP study and University of California study were prepared, 1,3-D was not available in California, which caused impact estimates to be higher in many cases than those assumed in this report. In addition, the NAPIAP study includes loss estimates for the case where Vorlex would be available.

In the NAPIAP report, aggregate losses for nurseries in California and North Carolina were reported without detail as to which specific crops in those states use methyl bromide and would suffer losses due to a ban. In California, greenhouse growers were assumed to switch to steam treatment at a cost of $4500-7500 per acre plus the cost of fuel. For field-grown nursery crops in California, all acreage was assumed to be treated with metam sodium for $550 per acre and an herbicide at $200 per acre. An average of 87.5% of the acreage was assumed to be treated with a fungicide with three applications at a cost of $175 per acre, and a nematicide was assumed to be used on 50% of the acreage at $175 per acre. No breakdown of California nursery acreage between greenhouse and outdoor production was given.

All Florida Caladium growers were assumed to use metam sodium. Of the Florida cut flower acreage, 98% was assumed to be treated with Vorlex, and the remaining 2% was assumed to be treated with metam sodium. Of the North Carolina nursery growers, 70% was assumed to switch to Nemacur, with the remaining 30% of acres equally divided as using either Vapam, Sectagon or Basamid. All North Carolina nursery acreage was assumed to be hand weeded at a cost of $6000 per acre.

For tobacco plant beds in the southeast states, 40% of the plant beds in Georgia and 70% of the plant beds in North Carolina were assumed to be converted to greenhouse production systems, while the rest of the growers in those states and growers in Kentucky and South Carolina were assumed to switch to either metam sodium, Vorlex or basamid. Impacts stemming from the loss of methyl bromide for use in tobacco seedling production include increased costs and decreased yields in the production field due to lower quality seedlings. NAPIAP impact calculations for tobacco account for potential price increases due to the smaller quantity available, as well as the potential for imports to offset production losses of U.S. growers.

In the 1993 University of California report, cut flower growers were expected to adapt steam treatment for indoor production and dazomet for outdoor production. For rose plants, fruits, vines and nuts, and strawberry plants, growers were expected to substitute increased crop rotations for methyl bromide. 1,3-D was not available for use in California at the time and was not considered as an alternative [54] [65].

## 5. Nursery Impacts

Short-run impacts for each of the segments of the nursery industry discussed are presented in Table 4.D.11. Generally, there is a lack of research into alternatives for nursery crops. Therefore, the impact calculations presented are best considered hypothetical. A significant effort was made to understand which alternatives were the most likely to be adopted by growers in each of these production categories. Further, these losses are calculated without considering any market adjustments in terms of price or production changes.

In 1995, 1,3-D use was reinstated in California with several restrictions. These restrictions are anticipated to limit the amount of area that may be treated for many crops in California, including nursery crops. The California Pesticide Use Database may be used to make some preliminary calculation of 1,3-D demand by township for many crops, to better understand the extent to which these restrictions will affect growers who would choose to use it. However, it is not possible to identify specific nursery crops in that dataset, and so it is difficult to determine the impact of the 1,3-D restrictions on nursery growers. These restrictions are not taken into account in the impact calculations below.

For several nursery crops, methyl bromide is not used on an annual basis. This may be because the effects of fumigation last over more than one crop or because a crop takes more than one year to mature. The impacts presented here are similar to those for perennial crops, in that they are intended to represent an "annual" loss. These impacts represent the present value of the losses associated with eliminating the use of methyl bromide on one year's plantings, over the life span of those plantings. Yield losses are assumed to occur at a constant rate over the life of the crop. Future losses have been discounted to current dollar values using a real interest rate of 4%. Prices are assumed to remain constant.

The impact calculations presented here reflect the sum of increased costs and a proportion of total crop value based on the percentage of the crop affected and the yield loss.

In the absence of research results upon which to base yield loss estimates, Caladium growers in Florida are assumed to experience a 10% reduction in yield, using Telone C-17 as an alternative, similarly to that of Florida tomato growers. Costs are assumed to be similar to current costs and two-thirds of the acreage is assumed to be fumigated each year [29]. Estimated impacts are considerably smaller than those reported in the NAPIAP report due to the substantial cost increases assumed there.

Cut flower growers in California face different impact scenarios depending on current production practices. Carnation growers are assumed to switch to raised bench production systems, using steam to disinfest growing media. Cost estimates were obtained from a grower who has been converting his operation from ground beds to a raised bench system [59]. These costs are presented in Table 4.D.10. It is assumed that 95% of carnation growers use methyl bromide in ground production systems, and capital costs are annualized using an interest rate of 11%. Methyl bromide costs for ground bed production is estimated at $6 per bed ($522 per acre) [59]. No yield losses are assumed, since steam treatment in bench production systems works as well or better than methyl bromide in ground bed production systems, depending on soil type [59].

California pompon chrysanthemum production is assumed to take place in both fields and greenhouses, both systems being reliant on methyl bromide. Half of the total pompon acreage is assumed to be in greenhouses, 60% of which is fumigated with methyl bromide [43]. These growers are assumed to convert to steam treatment with costs similar to carnation growers. The other half of the pompon acreage is assumed to be grown in outdoor beds, and all of this acreage is assumed to be treated with methyl bromide [43]. Field-grown pompons are assumed to be treated with 1,3-D plus chloropicrin at a similar cost to methyl bromide, experiencing a 7.5% yield loss.

California cut rose growers are assumed to use methyl bromide on approximately 60% of their acreage, the rest of the crop being grown hydroponically [43]. A rose plant may produce cut roses for between six and ten years [25]. Capital costs of switching to steam are lower for rose growers than for carnation growers because these growers already own boilers to heat their greenhouses, and these boilers may be used for sterilizing media.

For other cut flower growers in California, 75% of the crop is assumed to be grown in outdoor fields treated with methyl bromide [43]. These growers are assumed to switch to 1,3-D plus chloropicrin, at a similar cost to methyl bromide treatment, and to experience a 7.5% yield loss.

Florida cut flower growers will also face losses when methyl bromide is no longer available. Ten percent of the gladiolas in Florida are assumed to be treated with methyl bromide, as is 90% of the rest of the cut flowers grown in Florida. All methyl bromide users are assumed to switch to 1,3-D plus chloropicrin and to experience a 10% yield loss, similar to that for Florida tomatoes.

Calculated impacts for Florida cut flower grower are much lower than those reported in the NAPIAP report, which is the result of a higher cost increase assumed by NAPIAP.

Sod producers in California, Florida and Georgia use methyl bromide approximately every fourth or fifth year. Growers are expected to experience higher costs using several inputs (including herbicides, insecticides, nematicides and fertilizer) in the place of methyl bromide [14] [15] and to experience a yield loss of approximately 30%. Impacts of a methyl bromide ban on sod production have not been estimated in previous studies.

Strawberry nurseries in California are assumed to experience a 15% yield and similar costs to methyl bromide fumigation loss using 1,3-D+chloropicrin. Yield loss estimates are based on research showing fewer runner plants produced per acre using alternative treatments. Impacts of less vigorous plants being used in the fruiting fields are taken into account as an additional yield loss for strawberries in the economic model.

Perennial nurseries in California are assumed to experience a 15% yield loss using 1,3-D plus chloropicrin as an alternative to methyl bromide. Rose plant growers are assumed to experience an 18% yield loss.

Tobacco seedling producers are assumed to experience a 10% yield loss and experience similar costs to methyl bromide treatment, using 1,3-D as an alternative to methyl bromide. The impacts on the tobacco industry calculated in the NAPIAP study are difficult to compare with those calculated here due to differing assumptions. The NAPIAP report presents impacts on tobacco resulting from lower quality nursery plants. Therefore, the impacts are in terms of tobacco production. Additionally, the NAPIAP calculations include assumed price increases resulting from curtailed production, in situations with and without imports. Impacts on tobacco production range from a loss of nearly $100 million in the case with imports to a gain of $103 million if no imports were allowed. These results are largely driven by the assumption on changes in prices. The impacts presented here are intended only to measure the loss of value at the nursery level and do not take into account losses in the production field.  No price changes are considered for seedlings.

Overall impacts on the nursery sector from a ban on methyl bromide are estimated at $108 million.  Over half of this impact is attributed to sod producers in California, Florida and Georgia.  Perennial nursery growers in California account for the next largest category of losses, followed by cut flower growers.

**Table 4.D.1. Nursery Growers Reporting Methyl Bromide Use by State[1]**

| State | Number of Respondents Reporting MB Use | Total Number of Respondents | Percent Reporting MB Use |
|---|---|---|---|
| Alabama | 0 | 10 | 0% |
| Arkansas | 0 | 1 | 0% |
| Arizona | 1 | 3 | 33% |
| California | 18 | 49 | 37% |
| Colorado | 0 | 5 | 0% |
| Connecticut | 0 | 7 | 0% |
| Delaware | 0 | 4 | 0% |
| Florida | 4 | 34 | 12% |
| Georgia | 4 | 10 | 40% |
| Hawaii | 0 | 4 | 0% |
| Iowa | 0 | 7 | 0% |
| Idaho | 0 | 4 | 0% |
| Illinois | 0 | 42 | 0% |
| Indiana | 2 | 13 | 15% |
| Kansas | 0 | 5 | 0% |
| Kentucky | 1 | 13 | 8% |
| Louisiana | 0 | 7 | 0% |
| Massachusetts | 0 | 17 | 0% |
| Maryland | 1 | 20 | 5% |
| Maine | 0 | 4 | 0% |
| Michigan | 5 | 43 | 12% |
| Minnesota | 2 | 16 | 13% |
| Missouri | 0 | 9 | 0% |
| Mississippi | 0 | 2 | 0% |
| North Carolina | 5 | 30 | 17% |
| North Dakota | 0 | 1 | 0% |
| Nebraska | 0 | 4 | 0% |
| New Hampshire | 1 | 6 | 17% |
| New Jersey | 5 | 28 | 18% |
| New Mexico | 0 | 2 | 0% |
| Nevada | 0 | 1 | 0% |
| New York | 2 | 36 | 6% |
| Ohio | 4 | 48 | 8% |
| Oklahoma | 1 | 6 | 17% |
| Oregon | 7 | 44 | 16% |
| Pennsylvania | 4 | 38 | 11% |
| Rhode Island | 0 | 7 | 0% |
| South Carolina | 0 | 7 | 0% |
| South Dakota | 0 | 1 | 0% |
| Tennessee | 4 | 24 | 17% |
| Texas | 2 | 17 | 12% |
| Utah | 0 | 4 | 0% |

**Table 4.D.1. (continued) Nursery Growers Reporting Methyl Bromide Use by State[1]**

| State | Number of Respondents Reporting MB Use | Total Number of Respondents | Percent Reporting MB Use |
|---|---|---|---|
| Virginia | 3 | 22 | 14% |
| Washington | 2 | 18 | 11% |
| Wisconsin | 3 | 25 | 12% |
| West Virginia | 1 | 2 | 50% |
| **TOTAL** | **82** | **703** | **12%** |

[1] Results from National Agricultural Pesticide Impact Assessment Program survey of American Nursery and Landscape Association and the Society of American Florists members. Source: [46]

**Table 4.D.2. Methyl Bromide Use in the California Nursery Industry**

| | Methyl Bromide Use (lbs.) |
|---|---|
| Cut Flowers and Cut Greens | 413,783 |
| Citrus Nursery Stock | 57,790 |
| Strawberry Nursery Stock | 277,560 |
| Rose Plants | 650,000 |
| Fruit Tree, Grapevine Nursery Stock | 442,356 |
| Potting Soil | 79,673 |
| Other Nursery Stock | 201,654 |
| Turf | 200,000 |
| Total | 2,322,816 |

Source: [5]

**Table 4.D.3. 1995 Methyl Bromide Use in California Nurseries[1]**

| Use Category | Treated Acres | MB Use (lbs.) |
|---|---|---|
| N-GRNHS GRWN CUT FLWRS OR GREENS | 500 | 140,853 |
| N-OUTDR GRWN CUT FLWRS OR GREENS | 1,181 | 373,137 |
| N-GRNHS GRWN PLANTS IN CONTAINERS | 68 | 10,287 |
| N-OUTDR CONTAINER/FLD GRWN PLANTS | 3,504 | 1,082,660 |
| N-GRNHS GRWN TRNSPLNT/PRPGTV MTRL | 3 | 535 |
| N-OUTDR GRWN TRNSPLNT/PRPGTV MTRL | 1,997 | 522,760 |
| CHRISTMAS TREE PLANTATIONS | 13 | 3,348 |
| ORNAMENTAL TURF (ALL OR UNSPEC) | 4,811 | 77,601 |
| **TOTAL** | **12,077** | **2,211,181** |

[1] Use includes records with unspecified treated units. N: Nursery
Source: [47]

**Table 4.D.4 California Cut Flower Production[1]**

| | 1995 | | 1996 | | 1997 | |
|---|---|---|---|---|---|---|
| | **Acreage** | **Wholesale Sales ($1,000)** | **Acreage** | **Wholesale Sales ($1,000)** | **Acreage** | **Wholesale Sales ($1,000)** |
| **Carnation, std.** | 187 | 13,386 | 151 | 10,146 | 113 | 7,127 |
| **Carnation, mini** | 104 | 9,699 | 81 | 6,292 | 87 | 6,383 |
| **Chrysanthemum, pompon** | 212 | 15,171 | 182 | 13,699 | 214 | 14,279 |
| **Roses, hybrid tea** | 468 | 64,470 | 428 | 60,240 | 445 | 64,441 |
| **Roses, sweetheart** | 40 | 4,950 | 35 | 5,174 | 32 | 4,775 |
| **Other** | 4,601 | 140,548 | 4,381 | 144,688 | 5,058 | 173,943 |

[1] Reported for operations with annual sales over $100,000.
Source: [40]

**Table 4.D.5. Alternatives Research Results for Gladiola in Florida**

| Treatment | Rate (lb./acre) | Yield relative to MB[a] |
|---|---|---|
| **Chloropicrin** | 350 | 91% |
| **Metam sodium** | 238.5 | 255% |
| **Dazomet** | 400 | 214% |
| **Telone C-17** | 346.5 | 118% |

[a] Results from test plots with no known nematode or soil pathogen infestation
Source: [39]

**Table 4.D.6. Alternatives Research Results for Sunflower in Florida**

| Treatment | Rate (lb./acre) | Yield relative to MB[a] |
|---|---|---|
| **Chloropicrin** | 350 | 58% |
| **Metam sodium** | 238.5 | 239% |
| **Dazomet** | 400 | 185% |
| **Telone C-17** | 346.5 | 70% |

[a] Results from test plots with no known nematode or soil pathogen infestation
Source: [39]

**Table 4.D.7. Methyl Bromide Use and Loss Estimates for Ornamental/Nursery Plants from NAPIAP Report[1]**

| Crop | State | Production Acres | Acres Treated | Yield Loss ($1,000) | Per Acre Cost Change | Total Impact ($1,000) |
|---|---|---|---|---|---|---|
| **Ornamental/Nursery** | **California** | 50,000 | 6,204 | 130,749 | -159 | -129,763 |
| **Caladium** | **Florida** | 1,000 | 750 | 5,063[2]<br>10,125[3] | 6,314[4]<br>7,763[5] | -9,799[2,4]<br>-14,861[3,4]<br>-10,885[2,5]<br>-15,947[3,5] |
| **Cut Flowers** | **Florida** | 782 | 743 | 5,320[2,4]<br>6,650[3,4]<br>9,380[2,5]<br>10,032[3,5] | 6,314[4]<br>7,763[5] | -10,011[2,4]<br>-11,341[3,4]<br>-15,148[2,5]<br>-15,800[3,5] |
| **Ornamental/Nursery** | **North Carolina** | 1,500 | 1,350 | 9,000 | 3,588 | -13,844 |
| **TOTALS** | | | | | | **-163,417[2,4]**<br>**-169,640[2,5]** |

1 Impacts assuming other fumigants available.
2 First year impact.
3 Second year impact.
4 Assuming Vorlex is available.
5 Assuming Vorlex is not available.
Source: [64]

**Table 4.D.8. Methyl Bromide Use and Loss Estimates for Tobacco Transplant Production from NAPIAP Report[1]**

| State | Crop | Production Acres | Acres Treated | Production (tons) | Yield Loss (tons) | Change in Control Cost Per Acre | Net Revenue Change Without Imports ($1,000) | Net Revenue Change With Imports ($1,000) |
|---|---|---|---|---|---|---|---|---|
| **Georgia** | **Field** | 41,500 | Not Given | 47,517 | 4,752[2]<br>5,040[3] | | | |
| | **Transplants** | 850 | 850 | Not Applicable | Included Above | 385[2]<br>330[3] | | |
| **Kentucky** | **Field** | 178,050 | Not Given | 199,418 | 2,200 | | | |
| | **Transplants** | 4,000 | 2,000 | Not Applicable | | | | |
| **North Carolina** | **Field** | 289,000 | 0 | 259,119 | 29,512 | | | |
| | **Transplants** | 4,566 | 4,475 | Not Applicable | Included Above | 876 | | |
| **South Carolina** | **Field** | 49,500 | Not Given | 53,398 | | | | |
| | **Transplants** | | 950 | Not Applicable | | 959[2]<br>932[3] | | |
| **TOTALS** | | | | | | | **102,600[2]**<br>**103,400[3]** | **-98,100[2]**<br>**-98,900[3]** |

[1] Impacts assuming other fumigants available. Revenue changes assuming elasticity of demand of -0.5, total U.S. production of 776,000 tons and production loss offset by imports of 90%.
[2] Assuming Vorlex is available.
[3] Assuming Vorlex is not available.
Source: [64]

**Table 4.D.9. Impact of Canceling Methyl Bromide for Soil Fumigation on Nurseries from 1993 University of California Report**

| Crop | Acreage | Value ($1,000) | Decrease in Production | Change in Costs ($/acre) | Acreage Applied with MB | Value Marginal Product ($/lb. MB) | Impact ($1,000) |
|---|---|---|---|---|---|---|---|
| **Rose Plants** | 2,167 | 36,571 | 60% | -1,100 | 95% | 28.7 | -18,628 |
| **Cut Flowers** | 10,035 | 305,850 | 40% | 4,030 | 15% | 40.5 | -24,998 |
| **Fruits, Vines and Nuts** | 1,675 | 75,363 | 50% | -7,900 | 85% | 41.7 | -20,865 |
| **Strawberry Plants** | 1,450 | 22,523 | 40% | -3,430 | 80% | 11.6 | -3,219 |
| **TOTAL** | | | | | | | **-67,710** |

Source: [65] [55]

**Table 4.D.10 Costs to Convert Carnation Production from Ground Bed to Raised Bench Production System.**

| | Total Cost Per Acre | Annualized Cost Per Acre[1] |
|---|---|---|
| **Soil, labor and other materials[2]** | $87,000 | 9,570 |
| **Boiler[3]** | 9,528 | 1,048 |
| **Natural gas[4]** | 3,045 | 3,045 |
| **Total** | **$99,573** | **$13,663** |

[1] Capital costs annualized using an interest rate of 11%.
[2] Soil, labor and other material costs estimated at $1,000 per bed. 320 beds of 400 square feet per greenhouse of 160,000 square feet.
[3] A boiler sufficient to heat enough soil for one greenhouse is assumed to cost $30,000-40,000.
[4] Operating costs for steaming estimated at $30-40 per bed.
Source: [59]

**Table 4.D.11 Nursery Impacts by State and Crop**

| Crop | State | Acres Planted Annually | % of Crop Treated | Annual Crop Value ($1,000) | Change in Yield | Change in Cost (per acre) | Total Impact ($1,000) |
|---|---|---|---|---|---|---|---|
| **Caladium** | Florida | 1400 | 67% | 18,000 | -10% | | -1,206 |
| **Cut Flowers** | | | | | | | |
| **Carnations** | California | 241 | 95% | 17,678 | | 13,141 | -3,009 |
| **Chrysanthemum-Pompon (Outdoor)** | California | 102 | 100% | 7,192 | -7.5% | | -539 |
| **Chrysanthemum-Pompon (Greenhouse)** | California | 102 | 67% | 7,192 | | 13,141 | -894 |
| **Roses** | California | 483 | 60% | 68,017 | | 550 | -160 |
| **Other Cut Flowers** | California | 4,680 | 75% | 153,060 | -7.5% | | -8,610 |
| **Gladiola** | Florida | 3,292 | 10% | 15,999 | -10% | | -160 |
| **Other Cut Flowers** | Florida | 281 | 90% | 11,269 | -10% | | -1,015 |
| **Sod** | California | 8,420 | 20% | 79,357 | -30% | 433 | -22,771 |
| | Florida | 52,030 | 20% | 64,215 | -30% | 433 | -22,332 |
| | Georgia | 10,510 | 20% | 34,643 | -30% | 433 | -10,535 |
| **Strawberry Plants** | California | 2,585 | 100% | 19,379 | -15% | | -2,907 |
| | Oregon | 345 | 100% | | | | |
| **Perennial Nurseries** | California | 2,255 | 100% | 124,217 | -15% | | -18,633 |
| **Rose Plant Nurseries** | California | 1,967 | 95% | 34,863 | -18% | | -6,275 |
| **Tobacco Plants** | Florida | 75 | 100% | 864 | 10% | | -86 |
| | Georgia | 800 | 80% | 9,215 | 10% | | -737 |
| | Tennessee | 12,000 | 35% | 48,380 | 10% | | -1,693 |
| **TOTAL** | | | | | | | -101,562 |

Sources: Acres planted and total crop value are calculated as averages from 1995 to 1997 for cut flowers. Caladium acreage and value from [50]. Sod acreage and value from [33]. Perennial nursery and rose plant nursery acreages from [43] and values calculated as averages from 1994 to 1996 [42]. Strawberry plant acreage from [62] and value from [42]. Tobacco plant acreages from [24] [53] and [57]. Tobacco seedbed acreage from [24] and [53]. Tobacco plant value calculated based on [63], assuming price of $119/thousand plants and 2000 plants produced per 100 sq. yd. of seedbed.

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## E. Other Crops

In addition to tomatoes, strawberries and the perennial crops, methyl bromide is used as a preplant treatment for many other crops. The following is a description of methyl bromide use and research into alternatives for the other crops that methyl bromide is most frequently used on. In general, the greatest quantity of other uses is in Florida and California. In California, while there is a substantial amount of use in crops besides strawberries and the perennials, for any given crop only a small portion of the total acreage is fumigated, usually in a localized production area. In Florida, for other methyl bromide using crops, such as peppers and eggplant, it may be used on nearly all the planted acreage. However, outside of California, it is difficult to know the extent that methyl bromide is used on other crops, especially for some of the smaller crops, due to lack of pesticide use data. Further, in California, the last year for which pesticide use data are available is 1995, the first year that 1,3-D was reintroduced. Any effect that its availability has had on methyl bromide use cannot be established until more recent data are released.

An important issue applies to crops that are rotated into fields treated with methyl bromide for a previous crop and therefore benefit from the lasting effects of the fumigation. Into this category fit many more crops than are covered here. While there are some standard rotations that are reliant on methyl bromide, such as tomatoes or peppers followed by a cucurbit crop in the southeastern states or lettuce following strawberries in California, many other crops may be part of such a rotation. For instance, in Dade County, Florida, crops such as beans or okra may follow tomatoes [45]. Statistics on rotations are generally unavailable, making characterization of any patterns difficult.

For many of the winter vegetable crops that use methyl bromide, particularly in Florida, increasing imports from Mexico also play a role in determining the future viability of these industries. Acreage devoted to many of these crops has been declining in recent years, as shown in Figures 4.E.1 to 4.E.5. Some of this decline may be due to competition from imports. The recent trade disputes have primarily concerned tomatoes and are discussed more thoroughly in that section of the report. However, imports of several other crop from Mexico have also increased in recent years.

Research into alternatives for these other crops is scarce. While much research has been focused on the major methyl bromide using crops, very little attention has been paid to any other uses. The available research into alternatives is summarized here.

## 1. Carrots

Methyl bromide is no longer available for use on carrots. In 1990, after 1,3-D was banned in California, carrot growers obtained a section 18 emergency exemption, which was renewed for several years. The last year a section 18 was granted was in 1997 [4].

California grows nearly three-quarters of the total U.S. fresh carrot production [1]. The vast majority are grown in Kern County [17]. The preferred fumigant for carrot growers in California is 1,3-D, used primarily for the control of nematodes. Metam sodium is also commonly used. When 1,3-D was not available, growers used either methyl bromide or metam sodium, depending on nematode populations and soil conditions. Methyl bromide works better than metam sodium during the winter months of January and February [2]. Since 1,3-D was reinstated in California, some of the carrot acreage in Kern County could not be treated with 1,3-D because of the township restrictions [20]. This is the only area where the 1,3-D township restrictions are known to be binding [3].

2. Cucumbers

Methyl bromide is not labeled for use on cucumbers. However, USDA National Agricultural Statistics Service estimates that 306,100 lb of methyl bromide were used on cucumbers in 1994, the last year for which there were sufficient reports on which to base estimates [5]. Cucumbers are included herein because of common double cropping practices in the southeastern states, where growers plant cucumbers into beds that were fumigated for a preceding crop of tomatoes or peppers, leaving plastic mulches and drip irrigation lines in place. The use of methyl bromide on a crop immediately preceding cucumbers controls damping off (*Pythium* and *Rhizoctonia* spp.), Fusarium wilt (*Fusarium oxysporum* f.sp. *cucumerinum*), sting and root-knot nematodes, and weeds. Only growers in Florida and Georgia are believed to practice double cropping to any great extent.

When considering alternatives to methyl bromide, it is necessary to consider the longevity of pest control and whether the available alternative materials would allow the continuation of current double cropping practices. It may be the case that additional pesticides will be needed before establishment of the second crop, some of which may be applied through drip tubes, leaving mulches in place. However, in some regions, drip irrigation is not used very extensively. Materials such as metam sodium (Vapam) or oxamyl (Vydate) are now used by some growers before establishment of the second crop. The emulsifiable concentrate of Telone (Telone EC) may be another option for use before the second crop but is not currently available. Also, additional applications of herbicides may be required through the growing season.

There is little research available to assess yields for second crops using different alternatives. In an initial trial comparing solarization to methyl bromide fumigation in cucumbers grown following peppers, marketable yields were 2.7 tons per acre higher in the methyl bromide–treated plots. There was a large increase in root galling and density of root-knot nematodes with solarization. *M. incognita* was subsequently identified from those soil samples [34]. Research trials evaluating other alternatives for second crops were scheduled to begin in the fall of 1998 in Florida [6]. Some researchers look for indications about the possibility of continued double cropping practices by assessing pest pressures at the end of trials of alternative treatments for first crops. For example, researchers have compared the level of root galling, caused by root-knot nematodes, on tomatoes at the end of the season, on plots treated with methyl bromide and plots treated with Telone C-17. The higher levels of galling found in Telone C-17–treated plots has led to speculation that a second crop would suffer severe damage. No resistant varieties of cucumber are available [7].

### 3. Eggplant

Florida is the largest eggplant producing state, growing over half of the U.S. total [1] [17]. Figure 4.E.6 charts Florida eggplant yields from 1980 to 1997. California and New Jersey are the other major eggplant growing states [1] [17]. Florida growers used methyl bromide on 76% of the planted acreage in 1996, up from 29 and 42% in 1992 and 1994, respectively [5]. In 1992, the only year that estimates were available, 7% of the New Jersey growers used methyl bromide [5]. Approximately 6% of the California growers used methyl bromide in 1995 [9]. Eggplant growers use methyl bromide to control damping off (*Fusarium*, *Pythium*, and *Rhizoctonia* spp.), bacterial wilt (*Pseudomonas solanacearum*), verticillium wilt, root-knot, stubby root and sting nematodes, and weeds.

No research could be found on methyl bromide alternatives on eggplant. Participants at the Florida workshop suggested that growers would choose to use Telone C-17 and that yield losses would be greater than for tomatoes. Growers who would be unable to use Telone, because of township restrictions in California or the manufacturer's restriction in Dade County, Florida, would be likely to switch to metam sodium. Napropamide is the only available preplant incorporated herbicide for use in eggplants. Weed control may become a limiting factor for eggplant growers due to the limited number of herbicides available for eggplant, especially in Florida where nutsedge is a prevalent problem. No resistant varieties of eggplant are available [7].

4. Lettuce

California is the leading lettuce producing state, with other major production coming from Arizona. From 1994 through 1996, approximately 70% of U.S. head lettuce production, over 80% of U.S. leaf lettuce and over 75% of U.S. romaine production came from California [1]. Methyl bromide is not registered in Arizona [8]. California lettuce growers used Telone until it was banned in 1990, at which time they switched to using methyl bromide. In 1995, lettuce growers used nearly 1 million lb of methyl bromide and ranked as the fifth highest crop category in terms of methyl bromide consumption in California [9]. However, in previous years use was much lower, so 1995 may have been out of the ordinary. In 1994, only 313,196 lb of methyl bromide were used on lettuce in California [18]. The percentage of lettuce acres that are treated with methyl bromide remains very low, at approximately 1 or 2% of the total crop each year. Methyl bromide is used to control root-knot (*Meloidogyne* spp.), needle (*Longidorus africanus*), stunt (*Merlineus* spp.), and spiral (*Rotylenchus* spp.) nematodes [10], and some diseases, although it does not completely control the diseases [11]. For lettuce growers, the high cost of methyl bromide is the major factor that limits use [11]. Otherwise, lettuce may be part of a rotation that benefits from fumigation [19], frequently following strawberries in the coastal regions, although this practice still only accounts for a small percentage of the total acreage in lettuce production [11]. Overall, the California lettuce industry is not concerned with research into alternatives, because very little of the crop is dependent upon methyl bromide use currently [11].

The effectiveness of 1,3-D fumigants, Telone and DD (1,2-dichloropropane+1,3-dichloropropene), in controlling nematodes and increasing head weights in California lettuce was reported in the late 1960s [23]. The yield response was attributed mainly to nematode control, partly to control of fungal pathogens, and partially to other unknown factors [23]. A trend towards earlier, more uniform crop maturity was noted, although it was not significant [23]. In a study comparing dazomet to methyl bromide for control of corky root of iceberg lettuce, both fumigants were found to lower plant disease scores and increase root dry weights compared to nonfumigated controls. Head weights were 39% and 52% higher in dazomet and methyl bromide–treated plots, respectively, compared to control plots [12]. Methyl bromide has also been found to reduce the population of the vector of the big-vein agent, *Olpidium brassicae,* and incidence of big vein for at least one season after fumigation [13].

## 5. Peppers

Bell pepper production accounts for the third largest methyl bromide use in the U.S. The majority of this use is in winter pepper production in Florida [5]. California is the number one pepper producing state, growing approximately 45% of the U.S. total crop, followed by Florida, which produces approximately one-third of the U.S. total each year, and New Jersey with 8% [1]. A small portion of the California acreage is fumigated each year, approximately 10% in 1995, although peppers may be part of a rotation that benefits from fumigation. Growers along the southern coast are more likely to fumigate than growers in other areas of the state [14] [21] [22]. In Florida, nearly all peppers are grown using a plasticulture system that includes fumigation with methyl bromide [5]. While Florida pepper acreage has remained stable since 1980, yields have approximately doubled since then. Figure 4.E.7 shows Florida pepper yields since 1980. Approximately 15% of peppers grown in North Carolina are produced on acreage treated with methyl bromide, about 95% of which are double cropped with cucumbers or squash [15].

In March 1996, Florida pepper growers were party to the petition of the ITC for economic relief against import surges of fresh tomatoes and bell peppers. On July 2, the ITC found that imports of fresh tomatoes and bell peppers are not a substantial cause of serious injury or threat of serious injury to the U.S. industries [48]. Imports of bell peppers from Mexico increased 42% between 1993 and 1996. The average tariff on Mexican bell peppers was 7.43% and is being phased out over 10 years, so it seems unlikely that the tariff reductions were the sole cause of growth in trade. Increased U.S. consumer demand, the peso devaluation and adverse weather in some periods may be more important factors in the increase in imports in recent years [48].

Methyl bromide is used to control damping off (*Pythium* and *Rhizoctonia* spp.), southern blight (*Sclerotium rolfsii*), root-knot (*Meloidogyne incognita* and *M. javanica*), stubby root (*Paratrichodorus minor*) and sting nematodes, Phytophthora blight, Sclerotinia stem rot (*Sclerotinia sclerotiorum*), and weeds.

Two new cultivars were recently released that have resistance to southern root-knot nematode, *Meloidogyne incognita*, ‘Charleston Belle’ and ‘Carolina Wonder’ [16]. The gene that conditions resistance to *M. incognita* has also been found to condition resistance to *M. arenaria* races 1 and 2 and *M. javanica* but not to *M. hapla* [24]. In tests to evaluate the heat stability of the resistance of ‘Charleston Belle’ and ‘Carolina Wonder’, susceptibility was found to increase as temperature increased. However, reproduction was only 20% of that of the susceptible cultivars at 32 C [29]. In spring 1998 trials with ‘Carolina Wonder’ and ‘Charleston Belle,’ yields were reduced 34 and 45% in fields with nematode pressure, compared to a 57% reduction in yields for a susceptible variety [6]. Seeds of these two varieties were to be made available in 1998 [16].

There is little research into the use of alternatives on peppers in Florida. The focus of preplant methyl bromide alternatives research in Florida has been tomatoes, in anticipation that those results would be transferable to other vegetable crops [25]. Large increases in pepper yields with fumigation are attributed to weed control due to the smaller canopy of the pepper plants, which makes peppers more susceptible to competition from weeds [26]. Weed control early in the season is critical. Depending on the weed species, pepper yield may be reduced significantly if the weed competes with newly established pepper for only a week [27]. The herbicide that has been shown to be most effective in control of nutsedge on tomato, pebulate, is not labelled for use on pepper, apparently because of concerns about its phytotoxicity to pepper [25].

In studies at Bradenton and Gainesville from 1994 to 1996, several herbicides were evaluated for tolerance by pepper [28]. Telone C-17 or Telone II was applied alone and in combination with the herbicide treatments. The herbicides evaluated included pebulate, napropamide, trifluralin, lactofen, clomazone, metolachlor, pendimethalin, rimsulfuron, thiazopyr, EPTC and oxyfluorfen. There were no differences in vigor or mean fresh weight of pepper plants between treatments in one trial, though nutsedge control was variable, with the highest control in the plots treated with pebulate at 2 or 4 lb/acre and napropamide at 2.0-lb preplant incorporated [28]. In another trial, 1,3-D alone appeared to stimulate sprouting and emergence of nutsedge tubers, and the highest yields were obtained from plots treated with 2.0 lb/acre of pebulate incorporated 4 in. [28]. Highest early and late vigor ratings in three other trials were in plots treated with lactofen applied pre-emergence, napropamide incorporated and rimsulfron pre-emergence. From those trials it was concluded that pepper has a good degree of tolerance to most of the herbicides evaluated, although EPTC and oxyfluorfen reduced vigor and yield at the highest rates tested [28].

In test plots that were heavily infested with purple nutsedge, several herbicides were tested on pepper in combination with Telone C-17, including napropamide, pebulate, ASC 67040, lactofen and metolachlor. Napropamide provided fair control of nutsedge while pebulate and metolachlor were found to provide good control. Overall, plant vigor was the highest with napropamide and pebulate and marginal with metolachlor applied to the bed. Although injurious in some seasons, metolachlor produced some of the highest yields, while pepper production with napropamide and pebulate was equal or slightly lower than that obtained with metolachlor [25].

Napropamide is the only herbicide with a label for use under polyethylene mulch in pepper production. Trifluralin is labeled for use in pepper, but the label does not mention use with mulch. Clomazone is also labeled for preplant incorporated use. Metolachlor is labeled for directed-shielded applications to pepper row middles [28].

Trials have been conducted to evaluate alternative fumigants alone and in combination with napropamide, pebulate and metolachlor. The tested fumigants include Telone C-17, Vapam, Basamid and a methyl bromide check. In test sites with a low to moderate nutsedge population and inoculated with root-knot nematodes, Fusarium wilt race 3 and Fusarium crown rot, little difference in plant vigor and yield was reported among the fumigant treatments in one test. In another test where an unidentified wilt disease occurred, methyl bromide was the only fumigant that reduced the number of wilted plants relative to the untreated control. In the experiment comparing herbicides, little, if any, difference among herbicides for pepper plant vigor or pepper production was observed [25].

Methyl iodide, both alone and in combination with chloropicrin, has also been compared to methyl bromide, alone and in a 67:33% formulation with chloropicrin, for control of *Phytophthora capsici*, root-knot nematode and yellow nutsedge. All fumigant treatments provided statistically significant control of root rot, root-knot nematode and nutsedge. Methyl bromide and methyl iodide + chloropicrin provided significantly more fruit than the other treatments including the control [30].

Trials to evaluate mulches and fumigants were undertaken in Alabama in 1991. In a comparison of methyl bromide-chloropicrin 67-33, methyl bromide-chloropicrin 98-2, and metam sodium at 1114 l/ha (727 gal/acre) and 2228 l/ha (1455 gal/acre), metam sodium at the lower rate resulted in higher marketable yields than methyl bromide fumigants or no fumigation. In plots with plastic mulch, metam sodium treatment at a low rate yielded 9% more than the highest yielding methyl bromide treatment [32]. Results of that study are presented in Table 4.E.1.

Initial work has been completed to evaluate the effectiveness of solarization in pepper production systems in Florida. In a study comparing solarization, alone and in combination with either 1,3-D or municipal solid waste compost, to methyl bromide fumigation, marketable yields and pest control were evaluated. Yields were 15.3 and 16.4 tons per acre in plots treated with solarization and methyl bromide, respectively. Suppression of nutsedge and density of root-knot nematodes were similar under both treatments. Pest levels were low in both treatments [34]. Additional trials of solarization in pepper production have also been performed. Results from large scale field demonstration/validation studies of solarization on pepper are presented in Table 4.E.2.

From 1992–95, three field tests were conducted in Southeast Florida to evaluate various composts and soil amendments for control of *Phytophthora* root and crown rot caused by *Phytophthora capsici*. Test plots were treated with either chitosan, crab shell waste, humate, municipal solid waste, perennial peanuts, seed peanuts, sewage sludge-yard trimmings or wood chips. Chitosan reduced disease incidence and severity compared with controls in one test. Perennial peanuts reduced disease incidence and severity in another test. Several treatments were found to increase total microbial activity and soil populations of certain microbial functional groups, some of which were negatively correlated with disease incidence and severity [33].

Research comparing polyethylene mulch to organic and living mulch has been performed in response to anticipated disposal problems with polyethylene mulches. Wood chips, sewage sludge-yard trimming compost and municipal solid waste were applied at 224 tons/ha on bed surfaces, and sod strips were applied to bed sides. Polyethylene mulch from a previous pepper crop was retained and replanted to pepper. All plots were treated with metam sodium. Total yields were higher in the polyethylene-mulched plots than in the plots with organic and living mulches. These yields occurred early, as only 2% of the plants were still living by the second harvest date, compared to between 40 and 73% in plots with organic and living mulches. Late season plant stands were lower in the polyethylene-mulched plots, presumably due to a higher incidence of *Phytophthora capsici* Poor nitrogen availability may have contributed to lower yields in plots treated with organic mulches [31].

There is no research yet available into the use of alternatives to methyl bromide for North Carolina pepper growers, although initial trials are under way [36].

### 6. Squash

Methyl bromide is not labeled for use on squash. Squash is included in our analysis because of common double cropping practices in the southeastern states, similar to those for cucumbers. The use of methyl bromide on a crop immediately preceding squash controls damping off (*Pythium* and *Rhizoctonia* spp.), sting and root-knot nematodes, and weeds. Only growers in Florida and Georgia are believed to practice double cropping of squash following a methyl bromide fumigated crop to any great extent. No resistant varieties of squash are available [7].

### 7. Sweet Potatoes

Sweet potato growers in California are currently allowed to use methyl bromide under a section 18 emergency exemption, which has been granted each year since 1,3-D was banned in 1990 [38]. Since 1,3-D was reinstated, growers now prefer methyl bromide because of better disease and nematode control; and while 1,3-D was less expensive before 1990, the price has increased to be the same as methyl bromide, so there is no longer a cost advantage. In 1995, methyl bromide was used to treat 2557 acres of sweet potato [9], out of a total of 7579 acres in production [17]. Methyl bromide use on sweet potatoes in other states is not permitted. California is the third largest sweet potato producing state, behind North Carolina and Louisiana [1]. Methyl bromide is also used in sweet potato seed beds, or "hot beds," where each grower will produce plantlets from seed tubers for use in their fields [37]. Methyl bromide is used to control diseases and nematodes. The three genus of nematodes that cause most of the damage to sweet potatoes in California are root-knot, stubby root and needle.

No research into methyl bromide alternatives for sweet potato was located. However, it is expected that the best alternative would be 1,3-D. After 1,3-D was suspended and before the first section 18 for methyl bromide, several thousand acres were treated with ethoprop (Mocap). Fields that were monitored had 60 to 80% infestation after application. Control was considered very poor [38].

8. Watermelon

Watermelon growers may use methyl bromide only in California and Florida. In California, a section 18 emergency exemption is in effect [39]. Florida growers currently have a section 24(c) registration for special local needs. The use of methyl bromide on watermelon in other states is not permitted. Until 1989, methyl bromide was available for watermelons according to the label which simply listed "melons." However, in August 1986, the USEPA published the "Guidance for the Reregistration of Pesticide Products Containing Methyl Bromide," which permitted use on muskmelons only [39] [40]. Nonetheless, there appears to be a substantial amount of methyl bromide use on watermelon in southeastern states. NASS estimates 66,000 lb used in North Carolina in 1996 [5]. In other states, there were insufficient reports on which to base estimates. Applicator companies, a grower group and several researchers have reported a substantial amount of use in Alabama, Georgia, Louisiana, Mississippi, North Carolina and South Carolina. Hendrix and Dail, a contract fumigation company operating in the eastern U.S., is pursuing special local needs labels in these other states [41]. California is the leading watermelon producing state, with other major production coming from Florida, Georgia and Texas [1]. Methyl bromide is used to control damping off (*Pythium, Fusarium* and

*Rhizoctonia* spp.), Fusarium wilt (*Fusarium oxysporum* f.sp. *niveum*), sting and root-knot nematodes, and weeds.

Even in California and Florida, the percentage of watermelon acreage that is treated with methyl bromide remains small. In California, approximately 10% of the acreage is fumigated [9], while in Florida only 3% of the acreage is fumigated [5]. Seedless watermelon growers in the inland southern regions of California use a cultural program involving use of a clear plastic tarp mulch and drip irrigation. Preplant weed control is important in production systems using clear plastic, as postplant control is not possible. Pathogenic fungus species such as Fusarium, Verticillium and Pythium flourish under the high humidity under the tarps. Seedless watermelon are grown in Imperial, Riverside and Kern Counties of California. They are generally grown from transplants. Yields without methyl bromide have been estimated at 21,000 lb/acre, compared to over 54,000 lb/acre with methyl bromide [39].

Watermelon production in south Florida began in the early 1980s typically on land previously used to grow other vegetables. Figure 4.E.8 charts Florida watermelon yields since 1980. It is in the southern growing regions that methyl bromide is believed to be used most on single crops of watermelon, likely because of the ability to produce during high-price market windows [40]. Root-knot nematode and fusarium wilt are considered to be the most serious and ubiquitous pests of watermelons in Florida [40]. In Florida, watermelon may also be grown as a second crop, following tomatoes or peppers and benefiting from fumigation of the previous crop. Similar to the situation with cucumbers and squash, the longevity of pest control from alternatives used on the first crops needs to be taken into account when considering the viability of continuing these double cropping practices.

There is very little available research into alternatives to methyl bromide for watermelon. In a field demonstration trial conducted in 1988 in Florida, comparing methyl bromide and metam sodium to an untreated control, yields from methyl bromide–treated areas were significantly higher than either the metam sodium or untreated plots, where no harvestable melons were produced. Root-knot nematode and gummy stem blight were largely responsible for the total crop failure in the study [40]. In a South Carolina study of three cropping sequences of watermelon crops, an intervening treatment of either incorporated cabbage residue and solarization or double crop of wheat and soybeans between two watermelon crops was compared to a three-year succession of watermelon crops. Incidence of gummy stem blight and growth and yield were evaluated. Plant stand, vine length and fruit set were increased by 31, 26 and 64%, respectively, in the cabbage-solarization plots compared with the other cropping sequences. On average, cabbage followed by soil solarization significantly increased the weight and number of marketable-sized and total healthy fruit compared to unsolarized treatments [43].

Weed control is anticipated to be a major limiting factor for watermelon production when methyl bromide is no longer availabe. Bensulide, Naptalam and a formulation combining the two, are the only preplant incorporated herbicides available for use in watermelons [7], and neither provides adequate weed control in the absence of fumigation. There is one study available that evaluates a relatively new herbicide, halosulfuron, on watermelon, finding that it provides significant control of yellow nutsedge [42].

## 9. Previous Studies

Two previous studies have assessed the impact that a ban on methyl bromide would have on other crops. The first was the NAPIAP report in 1993 [46]. The other crops covered in that report included carrots, cucumbers, eggplant, melons, peppers and sweet potatoes. The impact estimates on carrots made in that report are not discussed here because methyl bromide is no longer available for carrot growers. The impact on Florida cucumber growers was assumed to be total: that is, all cucumbers were assumed to be double cropped and therefore reliant on methyl bromide. It was assumed that cucumber production would no longer be feasible if methyl bromide were no longer available.

Similarly, Florida eggplant growers were also assumed to experience a total loss, as no alternatives were judged to be acceptable replacements to methyl bromide [46].

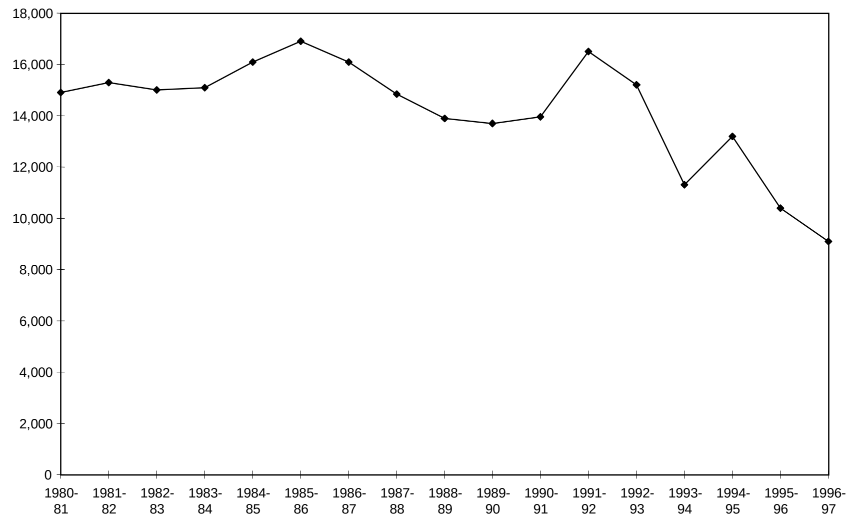
Melon growers were assumed to switch to various alternatives in different states. In California, 10% of the acreage was assumed to go into a rotation of 3 to 5 years, and the rest of the acreage would be treated with metam sodium at $525 per acre. In Georgia, 50% of the acreage was assumed to be treated with metam sodium at $700 per acre and sustain a 50% loss in production. Ten percent of the acreage was assumed to be treated with Vorlex at $550 per acre and also sustain a 50% yield loss. Half of the North Carolina acreage was assumed to be treated with metam sodium at $700 per acre, and 10% would use Vorlex at $555 per acre and sustain a 50% yield loss. Melon production in South Carolina was assumed to cease due to problems with nutsedge piercing through the plastic mulch [46].

Pepper growers in California were assumed to place 10% of the pepper acreage into rotation of 3 to 5 years. In Florida, 80% of growers were assumed to switch to Vorlex at $395 per acre, and the remaining 20% of growers were assumed to use metam sodium at $265 per acre. Half of the Georgia pepper growers were assumed to use metam sodium at $700 per acre, and 10% were assumed to use Vorlex at $550 per acre. All Georgia pepper acreage was assumed to be treated with Terrachlor (PCNB) at $18 per acre. Half of the North Carolina pepper growers were assumed to use metam sodium at $700 per acre and lose 50% in yields, and 10% would switch to Vorlex at $550 per acre, also losing 50% in yields. Ten percent of California sweet potato growers were assumed to put their land into rotation with a resulting loss of all production for one year, and the remaining 90% were assumed to use metam sodium at $525 per acre [46]. The NAPIAP report’s economic impact estimates are presented in Table 4.E.3.

Researchers at the University of Florida have also analyzed the effects of a methyl bromide ban on preplant uses in that state. Besides tomatoes and strawberries, their model includes cucumbers, eggplant, bell peppers, squash and watermelon. For all crops, Telone C-17 was assumed to be the best alternative to methyl bromide. In addition, pepper and eggplant growers were assumed to use napropamide as a preplant incorporated herbicide. For double-crop systems, it was assumed that metam sodium would be applied before planting the second crop if necessary. Additional practices are also discussed including off-season management to maintain weed-free fallow and additional herbicide applications throughout the season as necessary [47].

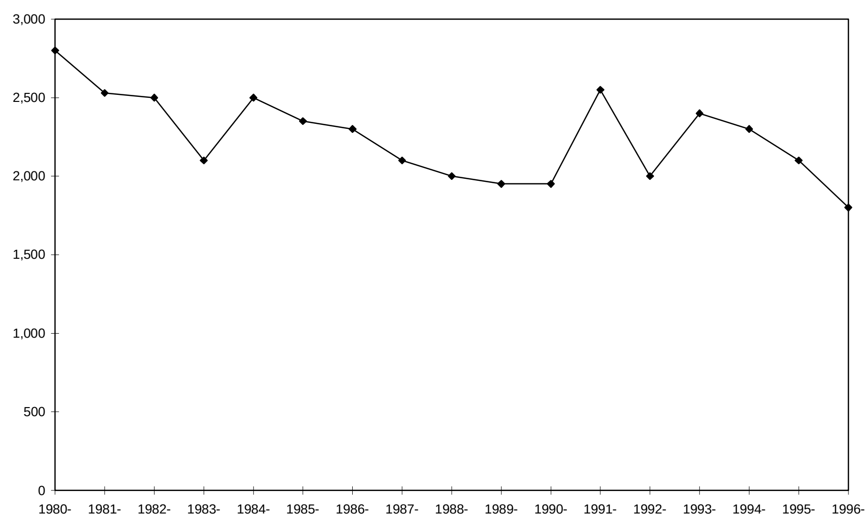
The University of Florida model includes, as well, production regions in other states that are able to respond to decreased production by Florida growers. For the other crops, imports from Mexico are included in the model. In addition, Texas is included as a producing region for bell peppers [47]. The University of Florida's economic impact estimates are presented in Tables 4.E.4 and 4.E.5.

**Figure 4.E.1. Florida Cucumber Harvested Acreage**



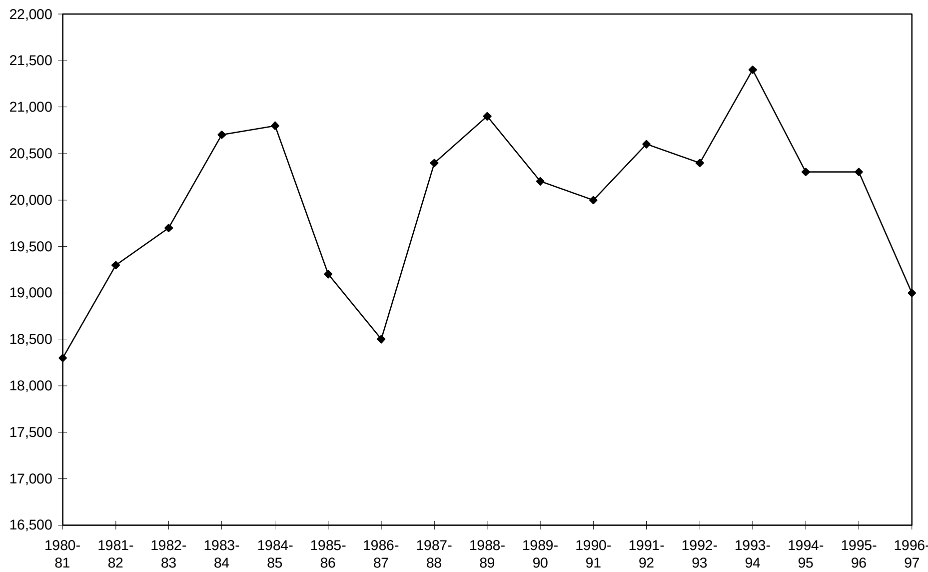

Source: [44]

**Figure 4.E.2. Florida Eggplant Harvested Acreage**



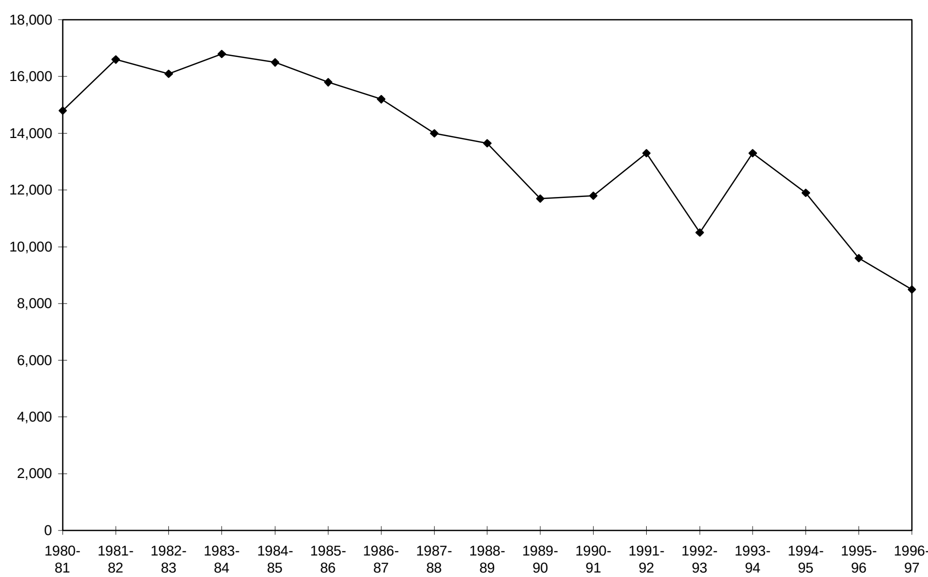

Source: [44]

**Figure 4.E.3. Florida Bell Pepper Harvested Acreage**



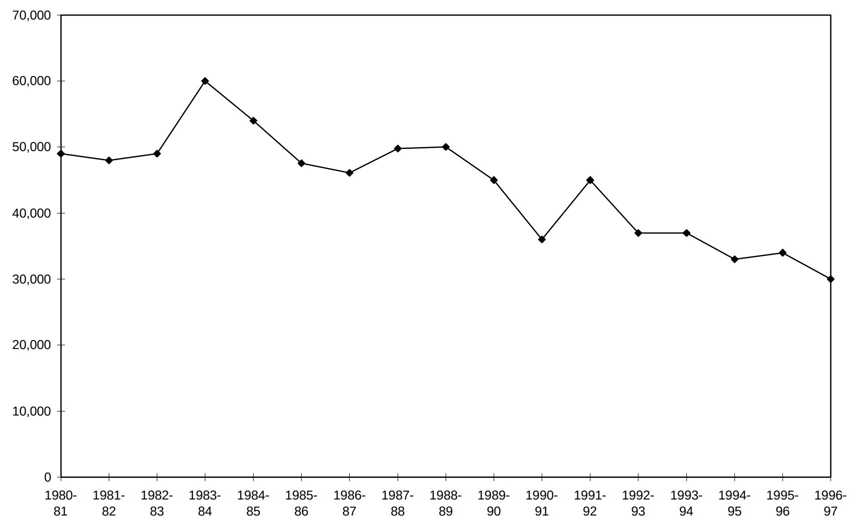

Source: [44]

**Figure 4.E.4. Florida Squash Harvested Acreage**



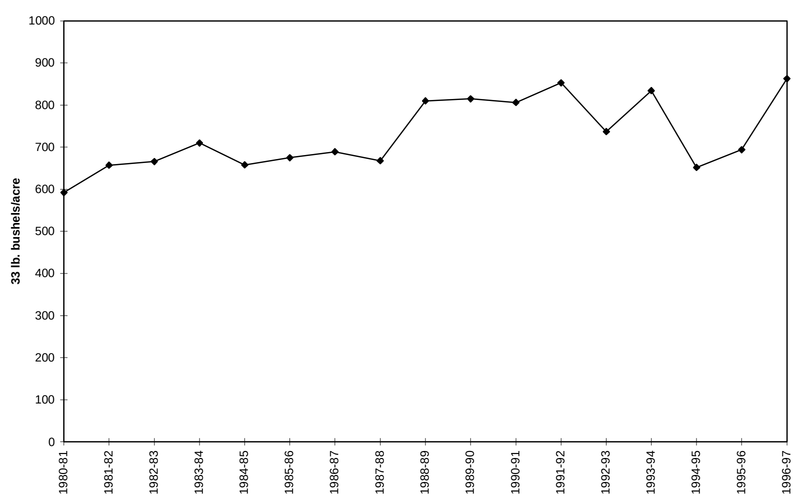

Source: [44]

**Figure 4.E.5. Florida Watermelon Harvested Acreage**



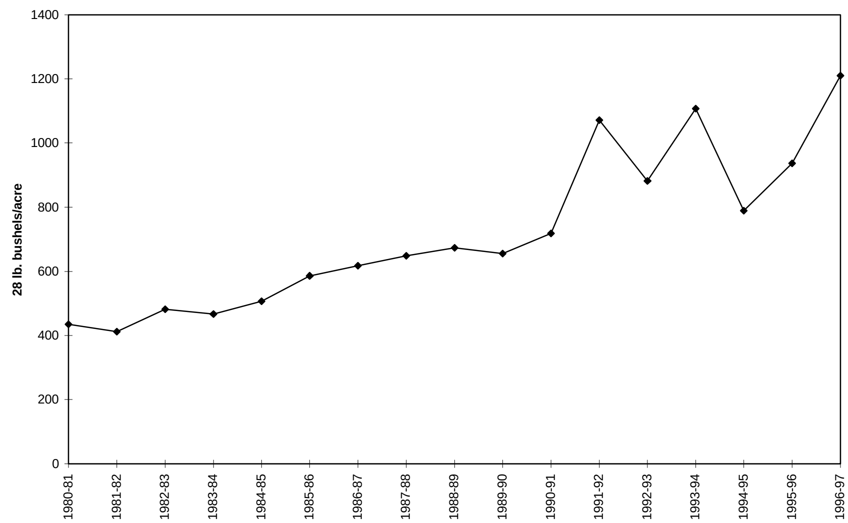

Source: [44]

**Figure 4.E.6. Florida Eggplant Yields**



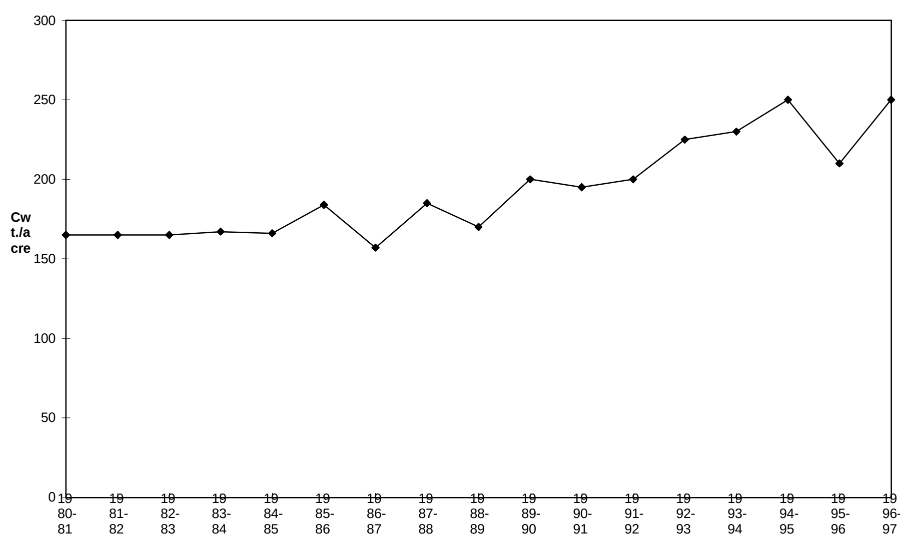

Source: [44]

Figure 4.E.7.  Florida Bell Pepper Yields




Source:  [44]

Figure 4.E.8.  Florida Watermelon Yields




Source:  [44]

**Table 4.E.1. Effects of fumigants and mulches on marketable yields of 'Pimiento L' pepper in Alabama**

| | | Mulch | | | |
|---|---|---|---|---|---|
| | | None | Styrofan | Plastic | Average |
| Treatment | Rate | Marketable Fruit (1,000 kg/ha) | | | |
| Metam Sodium | 1114 l/ha | 16.8 | 17.9 | 17.9 | 17.5 [a] |
| Metam Sodium | 2228 l/ha | 12.8 | 15.0 | 14.6 | 14.1 [c] |
| MBC 67-33 | 392 kg/ha | na | 14.1 | 15.7 | 14.9 [bc] |
| MBC 98-2 | 450 kg/ha | na | 15.6 | 16.4 | 16.0 [b] |
| None | | 11.2 | 12.9 | 13.0 | 12.4 [d] |
| Average | | 13.6 [b] | 15.1 [a] | 15.5 [a] | 14.8 |

Note: Averages followed by the same letter do not differ, 5% level, LSD.
Source: [32]

**Table 4.E.2. Results from Large Scale Field Demonstration Studies of Solarization in Fall Florida Pepper Production**

| Treatment | Year | Yield Relative to Methyl Bromide |
|---|---|---|
| Solarization + Biosolids Compost | 1996 | 93% |
| Solarization | 1997 | 106% |
| Solarization + Biosolids Compost | 1997 | 106% |

Source: [35]

**Table 4.E.3. Estimated Impacts of Methyl Bromide Ban on Other Crops from NAPIAP Report**

| | | | | | | Without Imports | | With Imports | |
|---|---|---|---|---|---|---|---|---|---|
| **Commodity** | **State** | **Acres Treated** | **Yield Loss (tons)** [1] | **Change in Control Cost** | **Change in Net Revenue** | **Change in Consumer Cost**[2] | **Total Impact** | **Change in Consumer Cost**[2] | **Total Impact** |
| | | | | **Million Dollars** | | | | | |
| Cucumbers | Florida | | 189,150 | | | | | | |
| **Cucumber Total** | | | | **0.000** | **72.1** | | **-72.1** | | **-72.1** |
| Eggplant | Florida | 2,050 | 26,200 | | | | | | |
| **Eggplant Total** | | | | **-0.408** | **12.2** | | **-11.8** | | **-11.8** |
| Melons | California | 559 | 4,366 | | | | | | |
| | Florida | 10,600 | 84,800 | | | | | | |
| | Georgia | 1,800 | 6,568,200[6,8]<br>15,325,380[7,8] | | | | | | |
| | North Carolina | 380 | 369,428[6,8]<br>861,999[7,8] | | | | | | |
| | South Carolina | 990 | 3,150 | | | | | | |
| **Melon Total** | | | | **-1.200**[4]<br>**-1.121**[5] | **29.7** | | **-28.5**[4]<br>**-28.6**[5] | | **-28.5**[4]<br>**-28.6**[5] |
| Peppers | California | 594 | 7,425[2] | | | | | | |
| | Florida | 19,635 | 191,244[3,4]<br>201,965[5] | | | | | | |
| | Georgia | 1000 | 22,950 | | | | | | |
| | North Carolina | 739 | 1,732[4,6]<br>4,040[4,7]<br>2,800[5,6] | | | | | | |
| **Pepper Total** | | | | **3.585**[4]<br>**1.471**[5] | **127.1** | | **-130.7**[4,6]<br>**-135.3**[5,6] | | **-130.7**[4,6]<br>**-135.3**[5,6] |

**Table 4.E.3. continued.**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Sweet Potatoes | California | 45 | 118.3 | | | | | | |
| **Sweet Potato Total** | | | | **0.007** | **0.1** | **-0.2** | **0.3** | **-0.2** | **0.3** |

[1] Yield losses assuming other fumigants available.
[2] Losses for cucumbers, eggplant, melons and peppers were estimated using constant market prices. Therefore, no estimates of consumer losses were made for these crops.
[2] For acres of crop rotation for 3 to 5 years. Additional loss includes double cropping carrots for 3 to 4 years.
[3] 152,995 with Vorlex and 38,249 with Vapam.
[4] With Vorlex as an alternative.
[5] Without Vorlex as an alternative.
[6] Yield loss in first year.
[7] Yield loss over time.
[8] Yield loss in number of fruit.
Source: [46]

**Table 4.E.4. Cost Change Assumptions for Other Crops from University of Florida Study**

| | Region | | |
|---|---|---|---|
| **Crop System** | **Palm Beach** | **Southwest** | **West Central** |
| Tomato-Cucumber | 27 | -61 | 224 |
| Tomato-Squash | | 0 | 226 |
| Tomato-Watermelon | | -36 | 228 |
| Pepper | 349 | Not given | |
| Fall Pepper | | | 251 |
| Spring Pepper | | | -41 |
| Pepper-Cucumber | -26 | 1511 | |
| Pepper-Squash | | | 78 |
| Pepper-Watermelon | | 286 | 65 |
| Eggplant | 144 | | |

Source: [47]

**Table 4.E.5. University of Florida Study Impacts on Other Crops**

| Crop | Yield Loss | FOB Revenue Loss |
|---|---|---|
| Cucumbers[1] | 40% everywhere except 50% in Palm Beach | 25,311 |
| Eggplant | 35% everywhere | 25,197 |
| Peppers | 15% everywhere except 35% in Palm Beach | 79,164 |
| Squash[1] | 20% everywhere | 1,058 |
| Watermelon[1] | 10% in Southwest 20% in West Central | 18,896 |

[1] Yield losses for cucumbers, squash and watermelon for second crops in double crop systems.

Source: [47]

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## F. Postharvest Uses

Methyl bromide is used as a postharvest treatment for various reasons. Its primary use is for international and domestic phytosanitary treatments to allow shipment of commodities between or within countries while minimizing the risk of introducing pests into the importing area. In many instances, methyl bromide fumigation is required as a condition of entry. In other cases, it may be used only if a pest of concern is detected upon inspection. Methyl bromide may be one of a number of treatments that an importing country or state would accept, applied when timing or cost considerations favor its use. However, methyl bromide is the primary fumigant used internationally for phytosanitary treatments since ethylene dibromide (EDB) use was prohibited in the 1980s. Methyl bromide fumigation may also be requested by importers, even in the absence of a regulatory requirement, in order to ensure marketability of the product.

An important issue underlying the use of methyl bromide for quarantine and preshipment applications and feasibility of potential alternatives is the standard to which treatments are held. The current criterion for insect quarantine treatments in many countries is probit 9, i.e., 99.9968% mortality, which is based on providing security against tropical fruit fly species, some of which may reach high levels of infestation in artificially infested fruit. The high levels of infestation that may be used in an experimental setting are not believed to occur in marketed fruit. For other quarantined insects, such as codling moth, which infest commodities at very low levels, this standard may be extremely conservative when potential for survival and reproduction is considered. Probit 9 is routinely used without consideration of other factors such as infestation level, survival, or shipment sizes that would affect risk of introduction. In addition, most quarantine treatments are based solely on mortality even when research data document low infestation rates, ability to reproduce, or both. In an evaluation of the probability of a potential mating pair of codling moths occurring in a shipment of walnuts, cherries or nectarines, based on infestation levels, volumes shipped, as well as mortality required, if any, to maintain survival below one mating pair with 95% confidence, only in-shell walnuts would require a disinfestation treatment providing a very high level of control [43]. Cherries would require no treatment. and nectarines would require treatment for shipments larger than 1000 kg [43]. Systems approaches to quarantine include development of more quantitative biology data, modification of shipment volume, arrival times, and the distribution of the commodity upon arrival. All of these data suggest that quarantine treatment should be based on survival and that in a number of situations, treatment is not needed at all [43] [42]. However, they must be used if required by the importing country.

It is also important to understand that importing countries determine the acceptability of quarantine and preshipment treatments. Even after alternative treatments are developed and proven to be effective, it may take many years for the treatment to be approved by the destination country.

A second category of postharvest methyl bromide use is to satisfy U.S. Food and Drug Administration (FDA) sanitation requirements, as set forth in the Food, Drug and Cosmetics Act. In general, the use of methyl bromide to meet FDA standards of maximum levels of insect parts or mold contamination are relevant to some dried fruits, such as raisins and dates. Processors use methyl bromide to eliminate the pest or pathogen of concern to ensure marketability of their product. In these cases, methyl bromide treatment is not specifically required by FDA, but is used for its fast action, effectiveness and low cost.

Finally, methyl bromide may be used to ensure product quality, even if it is not required by any domestic or international regulations. In such cases, methyl bromide fumigation is used to disinfest a commodity of a pest that is causing damage that would lower the value of the crop. One example of this category of methyl bromide use is the treatment of walnuts destined for the domestic market.

In some cases, methyl bromide may be used to satisfy more than one of the afore-mentioned categories. For instance, date processors use methyl bromide to rid their product of mold in order to meet FDA requirements, as well as to meet the phytosanitary requirements of importing countries. However, it is also used to ensure product quality and would be used in the absence of these regulatory requirements.

Capital costs are likely to be a limiting factor in the acceptability of alternative postharvest treatments. Investments in facilities with the capacity to treat large quantities of produce in a short amount of time during a harvest period that may last only several weeks and that may lay idle for the rest of the year may not prove to be cost-effective.

Irradiation is a potential post-harvest alternative for many of the commodities to be discussed. Given the uncertain nature of per-unit irradiation costs, which depend on the design scale of facilities and throughput among other factors, irradiation is considered as an alternative treatment only for commodities that could be treated at the existing facility in Florida.

### 1. <u>Fresh Commodities</u>

For fresh commodities, methyl bromide is used exclusively to meet regulatory requirements and/or quarantine restrictions or to satisfy importers who request fumigation in the absence of a regulatory requirement. Methyl bromide causes damage to many fresh products, which has limited its use as a routine treatment. Notably, Hawaiian growers have been limited in developing export markets by a lack of alternative phytosanitary treatments that would not cause substantial damage to fresh produce. Mango and papaya production has been pursued recently due to the development of several high-temperature treatments that have been accepted by USDA Animal and Plant Health Inspection Service and cause only minimal product damage.

Due to the relative sensitivity of fresh commodities to any postharvest treatment, the available alternatives are necessarily limited. The shorter shelf life of many fresh commodities with the notable exception of apples, which may be stored for months, limits the available options to those with a rapid treatment time. However, it should be noted that some of the alternative treatments for some commodities could improve fruit quality or extend storage times.

*Apples*

Over 700 thousand tons of apples were exported from the U.S. to destinations around the world in 1997. However, only exports to Japan currently require methyl bromide fumigation as a condition of import. In calendar year 1997, no apple exports were made to Japan [106]. Table 4.F.1 shows Washington State apple production and Japanese import data.

In 1994, Japan agreed to accept U.S. apple imports meeting several phytosanitary requirements, including treatment with methyl bromide. Red and Golden Delicious apples from Washington and Oregon are currently allowed entry to Japan if production orchards have participated in a certification program for fire blight, which includes several inspections each year and a chlorine dip postharvest treatment. Methyl bromide treatment is also required as part of a phytosanitary treatment to control codling moth larvae, to be performed following a 55-day cold-storage treatment to kill codling moth eggs. These requirements are commonly viewed as the most restrictive of any country, short of an outright ban on apple imports [50].

When Japan lifted its ban on apple imports from the U.S., exports initially surged but quickly declined to zero. The failure of U.S. apple exports to Japan is attributed to several factors. The two varieties that were accepted are not as popular with Japanese consumers as sweeter varieties. Quality of the earliest shipments was disappointing to consumers and was accompanied by publicity of residues of a fungicide that is not approved for use in Japan. High tariffs and costly phytosanitary requirements have also contributed to reduction of exports to Japan [50]. No apple growers registered acreage in the export certification program for the 1996–97 through 1998–98 seasons [77]. All exports had been from Washington State [23].

The U.S. is in negotiations with Japan for approval of imports of additional varieties, though Japan has required tests of quarantine treatments to be performed on each variety under consideration. Negotiations to resolve this issue may take several years. The U.S. began negotiations with Japan in 1972 for entry of Red and Golden Delicious apples [50]. Due to the failure of the U.S. and Japan to reach an agreement on variety-specific testing, the U.S. pursued action through a World Trade Organization (WTO) dispute panel to resolve the issue. The panel ruled that the Japanese should accept additional varieties without further testing of methyl bromide treatments [23]. While Japan has begun approving additional varieties, the varieties are those on which testing had already been done [19] [23]. Exports were expected to resume in the Fall of 1999, though only at a minor level. It is expected that exports will eventually reach 50,000 42-lb cartons per year [23]. A methyl bromide quarantine treatment was approved by Japan for apple imports from Australia in 1993 for several apple varieties (Red Delicious, Granny Smith, Royal Gala, Braeburn, Fuji and Gala) based on research that indicated no significant differences in methyl bromide sorption between these cultivars [105]. South Korea is the only other country that currently does not allow imports of U.S. apples due to concerns about the introduction of codling moth [50].

A high degree of quarantine security can be provided for codling moth on apples using a systems approach including control in the orchard and postharvest inspection. Indeed, for most importing countries, U.S. systems approaches are considered adequate protection [50]. The Washington State Department of Agriculture showed that of over 41 million apples inspected for export over a five-year period, only 33 were found infested with codling moth larvae [68].

Alternative postharvest treatments for apples are under development. Cold storage in combination with a controlled atmosphere of low oxygen and moderate carbon dioxide is a standard commercial method of storage for Northwest-grown apples. The controlled atmosphere treatment improves fruit quality over cold storage alone, but the standard controlled atmosphere levels that are used are not sufficient to control codling moth. Codling moth larvae take approximately three to four months to achieve 100% mortality in cold storage, while the addition of a controlled atmosphere enhances mortality during the first two months of storage [72]. Heat treatments followed by cold storage have shown promise for control of codling moth larvae, though certain cultivars tolerate the heat treatment better than others. Combinations of controlled atmospheres with the heat treatment allowed reduction of the duration of the heat treatment by at least 25 to 50% [71].

A combination treatment of moist heated air combined with a controlled atmosphere has been developed that improved fruit quality and should effectively control codling moth. Two treatments, with final temperatures of 44 and 46°C, achieved at a heating rate of 12°C/h, were followed by 90 days of controlled atmosphere storage, ripened and tested for several quality parameters. The red fruit is redder, the fruit is generally firmer longer and ripening and softening occurs more slowly and uniformly. The heat treatment controls storage scald, decay organisms, and allows for more direct culling [72] [65].

Irradiation at low doses, less than 900 Gy, is also a potential quarantine treatment for apples. In an evaluation of the effects of irradiation on the quality of several cultivars, fruit response varied. Loss of firmness and acid content were the major responses of apples to irradiation, with no change in external and only slight change in internal color for Gala and Granny Smith. However, the loss of firmness in apples was not of great concern. In addition, decay was reduced in irradiated apples [63].

*Blueberries*

Southeastern states begin blueberry harvest earlier than other blueberry producing states and are therefore able to capture a high-price market window. West coast states require methyl bromide fumigation of shipments from the eastern states to prevent the introduction of blueberry maggot and plum curculio. Early berries are also sent from the southeast states to some Asian countries, and although these countries do not require any phytosanitary treatments, foreign buyers are requesting methyl bromide fumigation [14].

Table 4.F.2 displays estimates of fresh blueberry production and domestic shipments requiring methyl bromide treatments.

Research into the use of irradiation on blueberries as a post-harvest treatment has been successful, in part due to the ability of the fruit to tolerate much higher doses than are required to sterilize the blueberry maggot and plum curculio without causing the fruit to suffer substantial harm [31] [57] [49]. Blueberries can tolerate up to 750 Gy of gamma radiation without exhibiting adverse effects to their quality [62]. The response of varieties grown in Florida, Climax and Sharpblue, and those grown in Georgia, Brightwell and Tifblue, to irradiation treatment and storage have been found to be generally consistent [116]. The generic dose of 150 Gy that has been proposed by USDA for tephritid flies of *Anastrepha* would provide quarantine security against blueberry maggot in blueberries [90].

The development of other quarantine treatments for blueberry has been less successful. The short shelf life of blueberries limits adoption of treatments with long treatment times. Research into the use of controlled atmospheres on the blueberry maggot, using high levels of carbon dioxide for 48 hours, killed 48% of blueberry maggots with a slight beneficial retention of fruit firmness over storage [12]. Heat treatments have been reported to cause excessive damage to blueberries, rendering them unmarketable.

*Grapefruit*

Citrus from Florida and Texas is subject to quarantine for Caribbean fruit fly and Mexican fruit fly, respectively, when shipping to other citrus producing states and some foreign countries. Japan is a major importing country that requires a quarantine treatment for both species. Both states have developed fly free protocols in recent years to control infestations and reduce reliance on chemical fumigants as postharvest treatments. Postharvest fumigation with methyl bromide is a component of each of these programs for use in cases where demand for pest-free fruit would not be satisfied with fruit from the pest-free areas. Because treatment with methyl bromide causes some damage to citrus, it is preferable to avoid fumigation if possible.

Mexican fruit fly becomes established in the Lower Rio Grande citrus production area of Texas each year, either from being newly introduced from Mexico or from undetectable populations that survive through the summer months. The Texas program was the first to certify pest free areas, which came in reaction to the anticipated withdrawal of EDB, the preferred fumigant at the time. The program consisted of several measures to assess pest risk and suppress infestation, including trapping and the release of sterile flies. The certification procedure went into effect in 1981 and was refined over the following few years in order to validate the program's reliability at providing quarantine security. The resulting program includes the use of McPhail traps, malathion bait spray on an as-needed basis, and year-round dispersal of sterile flies [81].

Caribbean fruit fly was reported in Florida in 1965 in large numbers, at which time no attempts were made to eradicate the pest since citrus was not considered a host. When it became apparent that citrus is a host of Caribbean fruit fly in Florida, quarantine treatments were developed to meet the requirements of several importing states and countries. EDB was the preferred treatment until its use was suspended. A methyl bromide treatment was developed as an alternative to EDB use. Florida began shipments from certified pest-free areas during the 1982–83 season. The program consisted of a minimum acreage requirement and a buffer between production areas and any residential area where preferred host plants were located. Initial participation in the program was only 2,200 acres, and the program was discontinued in 1984 due to the detection of citrus canker in Florida [81].

The use of EDB was canceled for domestic shipments in 1984, but its use was allowed for exports through the 1987–88 growing season. A modified fly-free protocol was established in Florida for shipping fresh grapefruit from pest-free areas and was approved by Japan in 1986. The program has been modified further since then and currently consists of minimum acreage requirements, buffers, trapping, malathion bait spray programs, and consideration of seasonal differences in host status of grapefruit [81]. Participation in Florida's fly-free program has grown since its inception. The program's success is credited in reducing fumigant usage as a post-harvest citrus treatment. Figure 4.F.1 shows trends in the amount of citrus fumigated in relation to total tonnage harvested, indicating a general decline in the percentage of fruit being fumigated since the program began. A freeze in California during the 1990–91 season resulted in larger-than-normal shipments from Florida that year.

Several factors may affect future expansion of the Texas and Florida fly-free programs. The future availability of malathion is uncertain due to anticipated regulatory review under the Food Quality Protection Act. Substitutes for malathion, such as Abamectin and Spinosad, are under investigation for use as part of the fly-free program in Florida [34] [46]. The Florida program may also eventually include sterile fly releases, as the Texas program does, to assist in suppressing wild fly populations. The release of parasitic wasps is also a potential component of the program [81]. The use of gibberellic acid, a natural plant growth regulator, may be beneficial in extending the natural resistance of Florida citrus fruit to Caribbean fruit fly and may allow the extension of the less restrictive early season certification requirements [29]. Urban encroachment may limit the expansion of the Florida fly-free program due to the buffers required between production areas and residential areas where preferred host plants are located [80].

Complete eradication of Caribbean fruit fly from Florida may also be possible, which would eliminate the need for quarantine treatments altogether. Such an effort would likely include a method to substantially decrease fly populations, such as a malathion spray program, followed by sterile fly releases at ratios to the wild population that would be high enough to insure eradication [29]. However, the implementation of a program to eradicate Caribbean fruit fly from Florida is considered to be at least 10 years away [80].

Several alternative quarantine treatments for both Mexican fruit fly and Caribbean fruit fly are available or under development. USDA Animal and Plant Health Inspection Service retains jurisdiction over controlling the spread of Mexican fruit fly from Texas to other citrus producing states and is responsible for approving the fly-free program and quarantine treatments. In addition, importing countries may also require quarantine treatment. Currently, approximately 90% of methyl bromide–treated citrus from Texas is destined for domestic market, with the remaining 10% being shipped to Mexico [32].

For Texas grapefruit sent to other citrus production states, APHIS has approved vapor heat, stepped-increase high-temperature forced-air and cold treatments. Vapor heat treatments and cold treatments both cause unacceptable damage to fruit, and cold treatment requires an extended treatment time, which entails storage costs [60]. High-temperature forced-air treatments have been developed that do not alter fruit quality, although these treatments have not been performed on a commercial scale [97]. The high-temperature forced-air treatment has also been demonstrated to inhibit the development of green mold on grapefruit, which would extend shelf life [99]. To further reduce the potential for deterioration of fruit quality from high-temperature forced-air treatments, the combination of a low-oxygen controlled atmosphere with high-temperature treatments are being investigated and have been shown to reduce treatment time [96]. Combining controlled atmospheres with refrigeration has also been investigated to alleviate chilling injury caused by cold treatments [98] and has been shown to slow development of green mold in stored grapefruit compared to refrigeration alone [76].

The control of Caribbean fruit fly on Florida citrus is not under APHIS jurisdiction. Quarantine treatments and the fly-free protocol are subject to approval by importing states and countries. Japan is a primary importing country and accepts and prefers fruit from the fly-free areas but also accepts heat-treated, cold-treated and methyl bromide–fumigated fruit. California and Texas accept fruit from the fly-free areas and methyl bromide–treated fruit. Arizona, however, only accepts fruit treated with methyl bromide.

For Florida grapefruit, the development of alternative treatments acceptable to importing states and countries is underway. Hot-water immersion and vapor heat treatments have been investigated. Hot-water-treated fruit was found to cause unacceptable damage at times required to provide quarantine security. Following hot-water immersion treatment with refrigeration may alleviate fruit damage [91]. Vapor heat treatments were found to cause more grapefruit peel injury than hot-water immersion, although vapor-heated fruit had better pulp texture. Hot-water treatment resulted in a higher incidence of aging symptoms and decay than vapor-heated fruit, though both treatments resulted in less aging symptoms than the control [62]. A hot-air treatment has been developed against Caribbean fruit fly immatures in Marsh white Florida-grown grapefruit that does not cause fruit damage. Any latent heat damage might be reduced by hydrocooling fruit immediately after heat treatment [90]. A lengthier treatment in moist air was found to be less damaging than a shorter hot-water treatment, although both were found to increase susceptibility to green mold. Fruit treated with moist air had a longer shelf life. Fungicides may be applied to reduce decay and improve shelf life following treatments that result in increased decay [58].

Irradiation has been found to be effective for use on grapefruit, although the window between the dosage required to kill the flies and the dosage at which fruit damage occurs is narrow. Recently, researchers have explored the possibility of combining vapor heat or fungicide treatments with irradiation to ameliorate fruit damage [64] [66].

Initial research results on the use of methyl iodide on Caribbean fruit fly larvae have shown its effectiveness. Tests of the effects of methyl iodide on grapefruit quality did not indicate any fruit damage. Testing is continuing to establish potential quarantine treatments [93].

*Other Citrus*

The Texas and Florida fly-free certification programs also include oranges and tangerines. The effectiveness and potential phytotoxic effects of quarantine treatments on oranges and tangerines differ from that for grapefruit. Methyl bromide is an approved treatment for tangerines against Mexican fruit fly, although fumigation of tangerines was not reported by APHIS for 1996 or 1997 [32]. APHIS has approved cold-storage and vapor heat quarantine treatments for oranges and tangerines against Mexican fruit fly, but these treatments are not currently used. High-temperature forced-air treatments for Dancy tangerines and Valencia oranges have been tested and confirmed as effective quarantine treatments against Mexican fruit fly, although these treatments have not yet been approved [60]. Fruit quality after these treatments has been acceptable [94, 95]. A high-temperature forced-air treatment for navel oranges from Florida is also under development [91].

Table 4.F.3 displays estimates of fresh citrus production and domestic shipments requiring methyl bromide fumigation.

*Peaches and Nectarines*

Peach and nectarine exports destined for British Columbia and Mexico are required to be fumigated with methyl bromide for the oriental fruit moth. Exports of peaches and nectarines to Mexico alone were estimated to be worth over $4 million in 1996 [35]. In addition, nectarines bound for Japan are required to be fumigated with methyl bromide. For 1996, these exports were valued at $143,700 [35]. Table 4.F.4 shows Washington State peach and nectarine exports to British Columbia. Table 4.F.5 shows U.S. peach and nectarine exports requiring methyl bromide fumigation.

California and Washington are the primary suppliers of fruit for these export markets. Alternative treatments are limited by the short shelf life of peaches and nectarines, as well as the sensitivity of these fruit to postharvest treatments. Experiments with hot-water immersion and hot-water with NaCl immersion all resulted in fruit damage that rendered fruit unmarketable, although the addition of NaCl reduced the amount of damage sustained by the fruit [75].

Initial tests of a forced-air heat treatment showed that heat-treated fruit had few marked differences from the nonheated controls, which suggests that California nectarines are fairly tolerant of forced-air heat treatment [75]. Further testing on additional cultivars of nectarines and peaches indicated that fruit treated with a high-temperature forced-air regime and subsequently stored at 5°C, resulted in accelerated internal breakdown for cultivars susceptible to this disorder [47].

A systems approach has been proposed to Canada for control of Oriental fruit moth in stone fruit destined for British Columbia, for which approval is pending [125]. A pilot program began in July 1999 through which peach, nectarine and apricot growers in California, Idaho and Washington may ship to British Columbia using two methods other than fumigation to eliminate the Oriental fruit fly. Under the program, growers can use mating disruption or phenology to track the date when the fly hatches to determine the best time to treat with insecticides. Field controls and strict packinghouse inspections assure that shipments are pest free [129].

*Strawberries*

Strawberry exports to Japan are routinely fumigated with methyl bromide to satisfy importers. This is not a regulatory requirement. Over 14 million lb of strawberries were exported to Japan in 1996 [5].

*Sweet Cherries*

Sweet cherry exports to Japan, South Korea and Australia are required to be fumigated with methyl bromide as a condition of entry to control codling moth and western cherry fruit fly. Washington, Oregon and California produce sweet cherries for export to these markets. Japan began accepting fruit from Oregon and Washington in 1978 and from California in 1987. Japan accounts for the vast majority of sweet cherry exports. Typically, the highest quality fruit is selected for export, for which they receive higher prices than on the domestic market [59]. Australia started accepting shipments in 1996 but only from San Joaquin County, California. In 1998, Australia began accepting shipments from anywhere in California. The Australian market is expected to grow in the coming years [117]. Australia does not currently accept cherries from Oregon or Washington because of the presence of cherry fruit fly in those states. California does not have the cherry fruit fly. The Northwest cherry industry plans on pursuing the acceptance by Australia of imports with methyl bromide treatment or a systems approach [23].

The Washington Department of Agriculture currently requires all cherries shipped out of state to be inspected for the cherry fruit fly. At the most, 5% of shipments might be found to be infested in a bad year. Those loads would then be fumigated with methyl bromide prior to shipment. California has an additional protocol for shipments from Washington State, requiring that 50 lb of fruit from every load be crushed and put into a brown sugar solution to check for emergence of larvae. The brown sugar solution makes the larvae show up against the dark color and also causes the larvae to move, which makes them easier to detect. Overall, there is no regular fumigation of shipments to other states; it is done only if inspection detects cherry fruit fly [86].

The need for any postharvest quarantine treatment for these exports is debatable. Between 1978, when exports of sweet cherries to Japan and South Korea were begun, and 1997, inspections have found only nine codling moth larvae [33]. No western cherry fruit fly larvae were found between 1978 and 1994 [68]. It has been through the use of a systems approach, including pest control in the field and postharvest inspections and culling, that infestation of fruit intended for export has been minimized. Systems approaches for cherries are now being used for most importing countries and are being proposed to Japan and Korea [33].

Alternative quarantine treatments are also under development. A major limitation to alternative treatments is the short shelf life of cherries. Exports to Japan are shipped by air, and the time from harvest to shipment may be as short as 24 to 48 hours [109]. Temperature treatments, alone and in combination with controlled atmospheres, have been investigated. Cold treatments require in excess of three months for control of codling moth. Controlled atmospheres in cold storage was no better than cold storage alone, and controlled atmosphere treatments at 70 to 75°C required one to three weeks at a minimum for codling moth control [67].

Heat treatments achieve a more rapid kill of codling moth but can potentially cause unacceptable fruit damage. Heat treatments followed by cold storage increased mortality of codling moth [74]. Alternatively, the addition of a controlled atmosphere can reduce total treatment time substantially. Combination treatments using vapor heat and controlled atmospheres resulted in 100% mortality of codling moth and acceptable fruit quality [74]. Hot forced-air + controlled atmosphere treatments have been shown to provide control of both codling moth and western cherry fruit fly [70]. The treatment of fruit with giberrelic acid before heat treatment resulted in improved fruit quality over heat treatment alone [67]. Storage life of heat + controlled atmosphere–treated fruit was extended by packaging in modified atmosphere packaging [70].

Irradiation has also proven to be an effective quarantine treatment that results in acceptable levels of fruit quality. At radiation levels necessary for quarantine control of codling moth (500 Gy), quality losses are anticipated to be acceptable [18] [20] [21] [22]. In comparison to fruit damage resulting from methyl bromide treatment, irradiated fruit was comparable. Neither treatment was found to result in damage to a degree where acceptability would be in doubt [21]. Irradiation results in some firmness loss in comparison to methyl bromide treatment, but irradiation does not result in a loss of fruit and stem color, while methyl bromide does [22].

In an assessment of overall quality, no differences between fruit treated with methyl bromide, irradiation or two combination heat and controlled atmosphere treatments were detected [74].

The use of microwave heating to control codling moth has also been investigated. Initial work using a 915-MHz microwave resulted in 100% mortality following a 20-second exposure followed by a hold of two minutes prior to hydrocooling [73]. However, treatment times necessary for near 100% kill resulted in unacceptable fruit quality [74].

Tables 4.F.8–4.F.10 delineate cherry exports from California and the Northwest that require methyl bromide treatment. Figure 4.F.2 displays a trend analysis of cherry exports to Japan and South Korea from California, Oregon and Washington.

*Other Fresh Commodities*

Small quantities of plums, apricots and prunes are currently exported from California and Washington to British Columbia and are required to be fumigated with methyl bromide before shipment.  (See Table 4.F.11.)  No research results into alternative treatments for these commodities were located.

2. Dried Fruits and Nuts

Methyl bromide is used on dried fruits and nuts at any of several stages, either routinely or when timing or environmental conditions are favorable.  For several of these crops, methyl bromide is used to disinfest the crop just after harvest.  It may be used again during the storage of a commodity, if the crop is kept in storage for an extended period before processing.  Finally, it is frequently used to disinfest commodities at the time of processing, either to insure cleanliness of product as it enters processing facilities or to disinfest the final packaged product.

Fumigation of dried fruit and nuts is performed primarily to ensure product quality, as insect populations left unchecked will degrade product to the point where its value is lowered or it becomes unsaleable.  In addition, fumigation allows processors to meet FDA requirements, where applicable.  Some countries also require methyl bromide fumigation of imports to meet phytosanitary regulations.

An important aspect of potential alternatives is the ease with which they might be incorporated into current processing practices.  There are likely to be additional costs involved with redesigning production systems.  For this reason, alternative fumigants are likely to be relied upon in the short term while industry develops and invests in other alternative technologies, such as irradiation, controlled atmosphere or temperature treatments.

Phosphine is the most likely alternative for several of the dried fruit and nut crops, despite the longer time required for effective treatment.  Phosphine is used currently for some crops at various stages of processing, in some cases replacing former methyl bromide uses.  However, phosphine is currently under regulatory review by the EPA due to worker safety concerns, and its future availability is uncertain.  Current proposals include reducing exposure standards, requiring buffers around residential areas, and notification of local residents and adjoining commercial and industrial sites prior to fumigating [127]. These restrictions would curtail current use practices, especially in busy port areas [38]. Alternative fumigants, such as sulfuryl fluoride, carbonyl sulfide and methyl iodide, have been shown in initial tests to be effective against several pests of stored products [115] [126], but none are available currently and are not likely to be for several years.

Irradiation has been studied for its potential as an alternative treatment for dried fruit and nuts and was found to be effective in disinfesting almonds, walnuts, raisins and prunes of codling moth, indianmeal moth, navel orangeworm and dried fruit beetle.  The most promising points for application of irradiation in the processing of these commodities were found to be upon receipt at large processing plants or for preshipment disinfestation of finished good.  Current FDA regulations do not allow commodities to be irradiated more than once, which would limit its applicability for commodities in storage. Seasonality of treatments and the trade-offs between locating numerous small irradiators at processing plants compared to the increased handling costs involved with fewer, centrally located facilities must all be considered when large capital expenditures are involved.

*Almonds*

Almond processors were more reliant on methyl bromide fumigation in the past than they are today.  Most postharvest fumigation is done using hydrogen phosphide [124].  During the 1991–92 crop year, processors representing 10% of the crop reported using methyl bromide frequently [122].  One processor reports switching to phosphine in the early 1980s because it was cheaper, safer and easier to handle than methyl bromide.  With phosphine treatments, almonds are fumigated in the bins used for storage with a plastic liner.  When the crops are large, fumigation is done out on the ground in piles covered with a tarp [123].

*Dates*

Dates are routinely fumigated with methyl bromide to ensure product quality and to meet the requirements of importing countries.  Methyl bromide controls mold and insects, and its use facilitates meeting FDA regulations as set forth in the Food, Drug and Cosmetics Act, which limit the allowable portion of fruit contaminated with mold and insects. Exports to New Zealand are required to be fumigated with methyl bromide as a condition of entry.  These exports amounted to 205,836 lb worth $373,900 in 1996 [106].  Nearly all dates are currently fumigated with methyl bromide.  California is the only state with significant date production [107].  Date gardens are located in Imperial and Riverside counties, in the Coachella and Imperial Valleys of Southern California [10].

Methyl bromide is used to control insects and other arthropods present after dates are harvested and as needed during storage to control storage pests.  Several insect pests are known field pests in date producing areas.  Nitidulid beetles, including the dried fruit beetle, are abundant in the date growing area of Southern California and have the potential to infest a significant portion of each developing date crop.  Beetle populations thrive throughout the year in fallen dates present on the ground under the trees, and the adults move from this population reservoir into the new crop as it ripens on the trees. Crop damage is most severe during years with above-average rainfall.  Nitidulids are most attracted to dates that are soured, fermented, or mechnically damaged and are able to carry fruit-degrading microorganisms into the crop [4].

In addition to beetles, several moth species may also infest dates, including the carob moth, raisin moth and the indianmeal moth [4, 13, 53].  Indianmeal moth larvae feed on ripe dates in the bunches and on the ground, as well as in the packinghouse.  They enter through any break in the surface of the calyx end of the fruit or bore into intact fruit.  As the larvae feed, they spin a web in which masses of frass are retained, and a web is also formed over the entrance. The raisin moth infests fruit in the bunch and after harvest. Larvae of the raisin moth feed in the ripening dates. This damage renders the fruit unsaleable. The raisin moth and the indianmeal moth account for a large percentage of the so-called hidden culls, which cause a reduction in fruit grade in the packinghouse [13].

The sawtoothed grain beetle, the indianmeal moth and the raisin moth differ from the nitidulid beetles in that they continue breeding in the packinghouse and in the packaged product. The nitidulid beetles are usually associated with dates of high moisture content and spoilage, whereas the other three insects can develop also in unspoiled fruit of low moisture content [110]. The dried fruit beetle can pass through a complete life cycle in fifteen days, which makes its control in stored fruit especially important [111].

Malathion dust applied about three weeks prior to the first date pick is recommended for the combined control of the indianmeal moth, raisin moth and nitidulid beetles [4] [13]. Fumigation of the crop upon arrival at the packing plant effectively controls infestation by beetles and moths. If dates are to be kept in storage for a prolonged period of time, subsequent fumigations may be necessary.

Methyl bromide is almost exclusively used on dates in the U.S. [13, 45], and has been used widely since the mid-1940s [111]. Previously, carbon disulfide, hydrogen cyanide and a mixture of ethylene oxide and carbon dioxide had been used. Phosphine treatments have been investigated and shown to be effective [13, 51]. However, phosphine treatments take much longer than methyl bromide treatments, which would require current packing processes to be altered and would required more harvesting containers and storage space [45]. In addition, phosphine is less effective at low temperatures. Dates are harvested from the beginning of October through mid-December, and the cool temperatures that prevail at that time of year would require even longer phosphine treatments.

Researchers in Israel have investigated controlled atmosphere treatments for dates in storage. The insect population was effectively controlled and reinfestation prevented [16].

*Figs*

Figs are fumigated to eliminate insect infestation present when the crop is harvested and during storage. Fumigation allows producers to meet FDA requirements on the maximum contamination levels due to presence of insect parts and mold. California is the only state with any substantial fig production [107]. Primary growing areas are located in Madera, Merced and Fresno Counties [10].

Figs for drying make up the vast majority of production, about 98% of the total. Dried figs are allowed to fall to the ground where they are gathered every five to ten days. While the figs are on the ground, they are especially susceptible to infestation because they have an open eye. Nearly all of the fruit is fumigated with methyl bromide immediately after it is gathered from the orchard to eliminate pest infestation. Fruit may be reinfested during sorting and grading. Depending on how long the fruit will remain in storage, it may be fumigated one or several more times. Harvest begins in September and lasts as long as the trees continue to bear fruit. A substantial portion of their market is for the holidays, which makes the duration of fumigation treatments an important issue [48].

Many years ago, the primary insect in fig orchards was drosophila, but as the industry has moved northward due to urbanization, the driedfruit beetle has become the number one pest. During years of high temperatures, drosophila and dried fruit beetle populations remain at a low level. Dried fruit beetles feed on ripening and overripe fruit and may introduce secondary organisms to the fruit. Diazinon and malathion are available to control insects in the orchard, but insecticides alone will not keep dried fruit beetle under control because it is impossible to get the materials inside the figs. Continual harvest, not leaving fruit on the ground for extended periods, will interrupt the completion of driedfruit beetle life cycles in fig orchards and thereby eliminate this as a source of population increase [28]. Field sanitation is also important to avoid massive infestations the next year [48].

Phosphine is the most likely alternative to methyl bromide for use on figs. Because some fruit is fumigated on the ranch before it is shipped to a packer, methods requiring special facilities would not be readily adopted to replace the first fumigation just after harvest. Phosphine takes significantly longer than methyl bromide to completely control insects in a load of fruit. It can take up to seven to ten days for an effective treatment. The extended treatment time would require growers to gather fruit from the orchards more frequently. Also, more or larger treatment chambers would need to be built to process the same quantity of fruit. Figs headed for the holiday market may not be processed in time to meet the market window. For figs destined for the processing market, which is not seasonal, phosphine treatments would be more easily incorporated into current practices [48].

Organic fig producers freeze their product, but the facilities needed to do so are very costly. Trials with a controlled atmosphere treatment yielded live insects after 40 days [48].

*<u>Peanuts</u>*

Peanuts are treated in order to meet FDA requirements of maximum levels of insect infestation, insect parts and mold. Methyl bromide use in the U.S. peanut industry is very small, less than 3% of the crop annually. Phosphine is the preferred fumigant because some peanut product manufacturers believe that methyl bromide imparts an undesirable flavor to peanuts. There are certain situations where the use of methyl bromide is important, especially where low temperatures prevent the successful use of phosphine. Carbon dioxide has been shown through research to be a possible fumigant for stored peanut products. However, experience is sparse and equipment for carbon dioxide fumigation is not available to most operations. Because it is odorless, workers may be exposed unknowingly to lethal concentrations [6].

*Prunes*

California is the predominant prune producing state, producing nearly 99% of the total U.S. crop [107] and approximately 70% of the world prune supply [1]. Major prune growing counties are Sutter, Yuba, Butte, Tehama and Glenn [10]. Methyl bromide is used to fumigate stored prunes or during processing after storage. About 10% of the crop is exported to countries requiring fumigation.

Prunes are harvested fresh from the tree in the fall using mechanical shakers that drop fruit onto fabric catch-frames. Conveyor belts transfer them to positions where forced air can separate the trash from the fruit [1]. At this point, there is minimal insect infestation because the fruit is harvested fresh.

After harvest, fruit is dried using a process that heats the fruit to temperatures that are sufficient to kill any infesting pests. While fruit is left for variable moisture levels to equilibrate after dehydration, fruit may become infested with storage pest insects. To eliminate any infestation in the fruit as well as in the processing plant, many operations close down the entire plant with the fruit stored inside and fumigate the structure and fruit at the same time. This fumigation may take place over the Thanksgiving weekend in order to avoid losing any processing time. During the winter, the indianmeal moth, the primary pest in stored prunes, is not active. Processing and packaging is steady year round, not seasonal as for some other commodities. As fruit are taken out of storage for processing, they may be fumigated with methyl bromide, or a space treatment of diclorvos may be used. Stored fruit may be refumigated in late June or early July. Some fruit will remain in storage for up to two years, depending on crop and market conditions, and is refumigated periodically.

Little research was found on alternatives to methyl bromide for use in prunes, but it is expected that phosphine, cold storage or controlled atmosphere treatments would be possible. Phosphine use in the processing plant would be limited by corrosivity, which could damage plant equipment. Cold storage would not disinfest prunes, but may be used to keep product clean and arrest insect development while in storage. Controlled atmospheres may be used for initial disinfestation or in storage facilities [39]. In irradiation trials, no significant differences in quality were attributable to irradiation or irradiation plus storage [27].

*Raisins*

About half of the raisins produced in California are fumigated with methyl bromide, while the other half is processed using phosphine. Fumigation is used to disinfest raisins after harvest and throughout storage. FDA maintains standards of maximum contamination of mold on natural and golden raisins and insects for golden raisins. California is the only state with significant raisin production [107]. Fresno is the leading raisin grape producing county, followed by Madera and Tulare [10].

Raisins are sun dried on trays laid on the ground in the row middles. Dried fruit beetle may infest the fruit while they dry. High moisture content of fruit favors their development and periods of high humidity at harvest generally are conducive to greater damage of berries. Chemical control of the dried fruit beetle in the vineyard has not been developed; control is accomplished primarily in the packinghouse [53]. Organic producers mechanically dehydrate grapes to avoid infestation during the drying process. Field infestation of indianmeal moth is not as common as infestation in storage, but most crops stored more than 30 to 60 days become infested. Infested raisins are contaminated by excrement, cast skins, webbing, cocoons, and living or dead larvae. Indianmeal moth is also primarily controlled in the packinghouse [54]. Raisin moth, while known to feed on ripening grapes, chiefly affects stored raisins, especially those in farm storage before they are delivered to the packinghouses. They do not completely consume the raisin but move about, leaving masses of excreta and webbing. During its development, one larva can damage about twenty Thompson seedless or nine Muscat raisins. Raisin moths can be controlled by sanitary cultural practices as well as by fumigation. Reinfestation of raisins in the packinghouse is negligible [55]. Sawtoothed grain beetle larvae and adults attack the commodities but do not deposit webbing. Control of this pest takes place primarily in the packinghouse [56].

Raisin growers may stockpile their product before making delivery to the processor. In some cases, growers may store raisins for several months, during which time the raisins may become infested with indianmeal moth or *Oryzaephilus*. Deliveries to the processor normally begin in September and reach a peak in mid-October. Some growers may deliver as late as January or February. Because processors are unable to process and market the huge volumes of product received during peak deliveries and in order for them to serve the market on a year round basis, they must store raisins for weeks to months [104]. Bins used for storage are 1.2 x 1.2 x 0.6 m and hold about 1000 lb of raisins. For outdoor yard storage, bins are normally placed in large stacks and covered with laminated paper. Stacks 10 bins wide and 8 bins high of variable length are considered standard for the industry. The stacks are covered with a double layer of plastic-coated, tar-laminated paper, which is held in place by vertical slats nailed to a wooden framework built over the bins [101].

Large processors are no longer using methyl bromide as part of their production process for raisins. After harvest, raisins are stored in large stacks of wooden bins covered by tarps. The stacks are routinely fumigated with phosphine by all producers due to its superior penetration properties in the absence of recirculation fans. When the raisins are taken out of storage, the stacks are opened by removing the tarps in order to move fruit into the plant. While the stacks are open, they are subject to reinfestation. Fruit is fumigated to clean the fruit before packaging. Large producers have the facilities to fumigate smaller quantities of fruit coming out of the stacks with phosphine, while smaller producers, with limited facilities, require methyl bromide, which allows them to fumigate a greater quantity of fruit in a smaller facility.

It may be possible for small producers to alter stack configuration, making them small enough that the entire quantity of fruit from a stack could be processed before infestation reached levels that would require fumigation. This would require greater space requirements in the yards where the stacks are located. These producers could also construct the additional facilities needed to handle fumigation with phosphine for fruit as it is brought in from the stacks [37].

Researchers have investigated a disinfestation treatment using controlled atmospheres for control of raisin moth, followed by either a treatment using the indianmeal moth granulosis virus, controlled atmosphere treatment or a low-temperature treatment. The initial disinfestation treatment was effective, and no damage from indianmeal moth was found in any of the treatments. Raisin quality was maintained throughout most of the test, although high moisture levels found in the low-temperature treatment caused some concern [40].

Controlled atmospheres may be established and maintained in yard stacks or in small chambers [79]. A low-oxygen atmosphere successfully controlled several pests of raisin in experiments in small polyethylene-covered stacks and in commercial-size outdoor stacked raisin storages covered with paper laminate [100]. In a 1984 cost comparison of the use of generated low-oxygen atmosphere or phosphine in yard stacks and methyl bromide fumigation in concrete chambers, all for a six-month storage with monthly treatment, the controlled atmosphere treatment was $10.64/metric ton, while phosphine was $10.76 and methyl bromide treatment cost $8.39. The costs of the controlled atmosphere generator, which operated by burning natural gas with air, would decrease if the heat was recovered for use in steam generation or water heating for other uses in the facility [101]. The use of controlled atmospheres for disinfestation of finished goods may be improved by using heat to shorten treatment time [79]. However, the use of heat on dried fruit may cause difficulties related to disequilibration of moisture content of the fruit [39].

Refrigeration may be used to protect raisins and prunes from reinfestation while bins are accessible for purposes of sorting, grading and blending. Refrigeration would be a necessary component of a physical insect control program [79].

Irradiation treatments were found to cause deterioration over time, but no obvious correlation with radiation levels was detected [27].

*Walnuts*

The walnut industry in California relies on methyl bromide to disinfest walnuts as they come out of the field, to disinfest nuts that become infested during processing and as a periodic treatment for nuts held in storage. Some importing countries also require methyl bromide fumigation as a condition of entry. California produces over 99% of the total U.S. walnut crop [107]. Major producing counties are San Joaquin, Stanislaus, Butte, Tulare and Sutter [10]. Table 4.F.13 displays estimates of walnut exports to countries requiring methyl bromide fumigation.

The rapid and effective treatment afforded by methyl bromide is extremely valuable to the walnut industry for which the ability to meet a market in Western Europe for the December 8 St. Nicholas holiday is critical. The quantity of product sold on the European holiday market affects domestic prices for the balance of the crop, which are sensitive to oversupply. Walnut harvest peaks in early October and nuts are transported by ship to Europe, which takes three to four weeks. Walnuts bound for this holiday market must be on board ship by November 1. Methyl bromide treatment is not specifically required, but is used to meet the requirement of having no live insects. Any infestation in a shipment would also deteriorate the quality of the product. Packers are able to receive, fumigate and ship walnuts in one or two days using methyl bromide. Any delay in the process may cause deterioration in product quality if harvest is delayed, resulting increased infestation. Processors rush to move all commodity into some kind of bulk storage facility immediately after harvest where it can be fumigated [79].

The California walnut industry has developed markets, both export and domestic, that are reliant on high quality standards. Shipment of fresh, top grade nuts at holiday time allows the industry a competitive advantage over other potential suppliers.

The rest of the crop that is not time sensitive is fumigated upon receipt to prevent further insect damage to the crop and placed in refrigerated storage, where it may be refumigated periodically. These walnuts will be fumigated again at the time of processing.

Methyl bromide is used to control codling moth, navel orangeworm and indianmeal moth. Walnut husk fly is a lesser pest on California walnuts. Codling moth and navel orangeworm are field pests, which are a concern right after harvest, while indianmeal moth is a storage pest that may reinfest walnuts while in storage. Codling moth causes economic losses mainly in orchards planted with early season cultivars such as Payne, Ashley and Chico. Navel orangeworm infests sound nutmeats of the new crop after husk split and is most often a pest of those cultivars that are also susceptible to codling moth and blight. The walnut husk fly is a mid- to late-season pest. It occurs in all walnut-growing areas in California except in certain areas of the central and southern San Joaquin Valley [108]. In comparison to dried fruits, walnuts are less frequently reinfested during storage [79].

Several alternative postharvest treatments have been investigated for use on walnuts. Phosphine is the most likely alternative in the short term. The longer treatment time would necessitate an earlier cutoff date for shipments to Europe. Additionally, the longer treatment time would require the construction of fumigation facilities to handle a much larger quantity of walnuts at any one time. Siebert, et al., conducted an economic analysis of the impact that the earlier cutoff date would cause for the walnut industry [102]. Using a cutoff date of October 24, they found that growers who could meet the market window would experience gains due to higher prices received, while the rest of the crop would suffer losses. Table 4.F.14 shows the calculations of revenues associated with switching to phosphine. These calculations, however, do not take into account the cost of constructing additional facilities. The feasibility of constructing additional facilities has been doubted by industry representatives [52].

Phosphine is more easily adopted for replacement of methyl bromide use for walnuts kept in storage. Industry began fumigating the stored crop with phosphine during the 1998–1999 season. However, it is anticipated that the final fumigation of product coming out of storage will be more difficult to replace with phosphine [52].

Phosphine is believed to impart an off-flavor to walnuts. The off-flavors are believed to be a problem primarily with shelled walnuts but may also affect in-shell nuts [109].

Controlled atmospheres have proved effective in disinfesting walnuts of navel orangeworm and indianmeal moth. Low-temperature treatment keep indianmeal moth populations at acceptable levels [39]. In a comparison of the indianmeal moth granulosis virus, low temperatures and controlled atmospheres, all following initial disinfestation with controlled atmospheres, efficacy of the initial disinfestation treatment was over 99%. All three protective treatments were able to protect the walnuts by keeping moth populations and damage at low levels under relatively high pest pressure. Results from industry standard quality analysis showed that none of the treatments had any negative effect on the quality parameters measures and were well within acceptable limits [40] [113].

Controlled atmosphere disinfestation of walnuts would require approximately 10 days in order to allow time to fill, seal, purge, maintain and aerate the storage space. Potential problems with implementing controlled atmosphere treatments include the integrity of existing storage bins to maintain an altered atmospheric composition. Otherwise, the existing facilities may be too large to establish the atmosphere quickly enough to treat the product in a timely fashion. With the increased treatment time over methyl bromide treatment, total capacity of facilities for treatment may be too small [79].

High temperatures are promising for disinfesting in-shell walnuts of codling moth with greatly reduced treatment times when combined with low-oxygen or high-carbon dioxide atmospheres. Further research, including large-scale testing, is needed to determine the effects of these treatments on sensory and chemical quality of nutmeats [103]. Walnuts are believed to be sensitive to heat treatments, which may cause significant quality deterioration.

Irradiation has been tested for the control of codling moth. The dose required for quarantine security was 188 Gy based on emergence of any adults from treated larvae [9]. Higher levels of irradiation cause additional oxidation during storage [27]. The treatment points that are considered to be feasible for irradiation are upon initial receipt or preprocessing for in-shell walnuts and before or after packing for shelled walnuts [79].

Genes encoding insecticidal crystal protein fragments (ICPFs) isolated from *Bacillus thuringiensis* that are effective against lepidopteran insects have been inserted into the walnut genome. High levels of ICPFs can be produced in walnut. The level of control provided by these genetically altered walnuts against production, quarantine and stored-product pests in commercial walnut, vegetative or reproductive tissue is yet to be determined in the field [109].

In tests of efficacy against navelorangeworm, codling moth, sawtooth grain beetle, driedfruit beetle, cigarette beetle and confused flour beetle, carbonyl sulfide, methyl iodide and sulfuryl fluoride were demonstrated to be toxic at relatively short exposure times [115]. However, none of these three fumigants are registered for use on food products currently and are not expected to available for at least several years.

3. Other Durable Commodities

*Cotton*

Cotton exported to several destination countries is required to be fumigated with methyl bromide. Though the portion of the crop that requires fumigation is small, the value of the exports is large in comparison to other exports requiring methyl bromide fumigation. Most of the exported cotton is grown in California and Arizona, though other states such as Texas and Mississippi also export cotton [38] [61]. Tables 4.F.15 and 4.F.16 delineate U.S. cotton exports to countries requiring methyl bromide treatments. Figure 4.F.3 displays the trend in U.S. cotton exports to countries requiring methyl bromide treatments.

The volume of exports to countries requiring methyl bromide fumigation has been variable due to several factors. In 1995, Pakistan had a crop failure and had to import cotton to keep their textile mills running. Since 1995, a small amount of high-quality pima cotton has been sold to Pakistan. Egypt recently changed its policy on cotton imports, effectively allowing imports from more countries than they had until the mid-1990s. Before Egypt changed its requirements for cotton imports, the U.S. was the only country that could meet their requirements. Egypt produces superpremium cotton and imports lower quality upland cotton. Most of the cotton that was being shipped to Egypt was from Arizona. In the last couple of years, neighboring countries such as Syria have begun to ship to Egypt, and U.S. exports have declined [61].

The likely alternative treatment to methyl bromide for cotton is aluminum phosphide, although treatment times are longer and the chemical may be more expensive [38].

*Oak Logs*

The wood processing industry in Europe is strongly dependent on the export of North American hardwood resources. Oak wood in particular is demanded, as European forests are not able to supply the market with the qualities, quantities, and dimensions needed, i.e., for veneering. For decades, the high-value oak stands located mainly in the northern and eastern parts of the United States have been providing the overseas markets, chiefly in the European Union, with oak wood in the rough. In the 1970s, quarantine regulations significantly restricting the oak wood trade were imposed, because the authorities of the European Union feared the introduction of oak wilt disease caused by the fungus *Ceratocystis fagacearum*. In the U.S., the disease was first recorded in the 1940s and has since been found in 21 states. There is apprehension that the introduction of the fungus could pose a serious threat to the health of European oak forests.

North American oak wood imported by the European Union is subject to quarantine procedures in order to prevent the introduction of the oak wilt fungus to Europe. The quarantine requires debarking and removal of sapwood for oak wood in the rough and for oak sawlogs. Furthermore, the wood has to be kiln dried to a moisture content of less than 20%, or it must be submitted to a heat treatment. These requirements reduce wood quality of oak wood to such an extent that the veneer industry would not be able to process that timber. Therefore, temporary exceptions from the directive were permitted, and the only satisfactory and currently internationally accepted method for disinfecting oak wood is fumigation with methyl bromide [44].

Mexico also requires the treatment of oak logs with methyl bromide as a condition of import [35].

Two chemical treatments have been investigated as alternative fumigants to methyl bromide for use on oak log exports to Europe: sulfuryl fluoride (Vikane) and methyl iodide. The fungitoxicity of sulfuryl fluoride was first reported in 1995 [114]. Sulfuryl fluoride killed oak wilt fungus in the sapwood regions of the naturally infected log sections at a concentration x time (CT) value similar to those required for methyl bromide [83]. Sulfuryl fluoride effectively eradicated oak wilt fungus in sapwood adjacent to ends of 2.4-m- (7.9 ft) long logs sealed to prevent longitudinal entry at the proximal endgrain and would therefore be expected to also be similarly effective in logs of 5 m (16.4 ft) length as are common in commercial trade. The oak wilt fungus can be killed throughout the sapwood depth in large red oak logs from naturally infected trees after fumigation with sulfuryl fluoride [84]. Sulfuryl fluoride is not yet registered for use on oak logs, nor has it been accepted as a quarantine treatment by the European Union. Sulfuryl fluoride is also considerably more expensive than methyl bromide, although this is not anticipated to hinder adoption for oak wood fumigation [84].

Methyl iodide tested outdoors under a tarp on commercial-size logs was less effective than methyl bromide in prevention of stain in red oak at similar CT values [85]. Methyl iodide is not registered for any applications.

Steam has also been investigated but found to be approximately 35 times more costly than current gas fumigation and may not be desirable due to the potential damaging result of heating to wood quality for some species [85].

*Rice*

Rice exports to Honduras are required to be fumigated with methyl bromide as a condition of entry [35]. In fiscal year (FY) 1996, over 38 million kg of rice were exported to Honduras, worth over $13 million. See Table 4.F.17.

*Sorghum*

Sorghum exports to South Africa are required to be fumigated as a condition of export. In FY 1996, about two million lb of sorghum worth $107,900 were exported to South Africa [35].

The Mexican rice borer, *Eoreuma loftini*, is a stalk-boring insect that occurs in Texas and Mexico. This insect attacks sorghum. The Sugarcane borer, *Diatraea saccharalis*, is also a stalk-boring insect of sugarcane, sorghum, corn, rice and wild grasses occurring in Southeast U.S. from Texas to Florida. Both of these insects are quarantined by much of the rest of the world. The alternative quarantine treatments for sugarcane borer are a cold treatment at –10°C for 48 h, immersion in water heated to 52°C for 20 min and immersion in ambient 25°C water for 72 h. There are no quarantine treatments against the Mexican rice borer. Initial work using irradiation on these two pests has been performed. A dose of 300 Gy seems sufficient to prevent reproduction of Mexican rice borers irradiated as late pupae; the sugarcane borer was less tolerant [15].

*Tobacco*

Tobacco exports to Chile are required to be fumigated with methyl bromide as a condition of entry [35]. See Table 4.F.18.

It may be possible to use phosphine products to fumigate tobacco as an alternative treatment to methyl bromide [69].

*Other Wood Products*

The U.S. has become one of the world's largest exporters of wood and wood products. There exist a number of plant pests native to the U.S. forests, such as the nematodes occasionally found in southern pines, which are not found in most overseas forests [89].

There are no formal requirements of importing countries that U.S. wood exports, other than oak logs mentioned previously, be fumigated with methyl bromide [35].

A method has been investigated that consists of heat treating with steam or hot water in the holds of a ship while in transit, to kill any plant pests present in the wood or wood products, while preserving the fresh-cut characteristics of the pieces [89].

## 4. Previous Studies

In the NAPIAP assessment, the impact of a methyl bromide ban for postharvest uses examined uses for exports, imports and interstate shipments of Florida citrus. The scope of the current study does not include imports. The analysis for Florida citrus estimates a loss associated with the diversion of fruit to nonpremium processing and culling, as shown in Table 4.F.19. For exports, commodities were identified for which methyl bromide treatment was required. (See Table 4.F.20.) No further analysis of impacts for exports was performed [82].

In the 1993 University of California report, the impact of canceling methyl bromide was considered for California-produced commodities. The analysis is limited to evaluation of impact on two industries, cherries and walnuts, as shown in Table 4.F.21. For cherry exporters, it was assumed that there was no alternative treatment available and that all cherries would be diverted to the domestic market. Growers would lose the price premium for high-quality exports, which was estimated at over four times the domestic price. Exports in 1991 totaled 2,492 tons. Using a demand elasticity of -2.0, it was estimated that domestic cherry prices would have to fall from $0.40 to 0.38/lb to clear the market [78].

In the analysis of impacts on the walnut industry, it was assumed that 25% of the in-shell walnuts would not meet the cutoff date for shipments to the European holiday market and would be diverted to the domestic market. Using a domestic demand elasticity of -0.7 and a foreign demand elasticity of -2.0, export prices were estimated to rise from $1,800 to $2,025 per in-shell ton, while domestic prices were predicted to fall from $1,720 to $1,413 per in-shell equivalent ton [78].

In the University of Florida report, the impact of a methyl bromide ban on the Florida citrus industry was analyzed. Assuming there were no alternative postharvest treatments for citrus shipped to other citrus producing states, the effects of diverting shipments to other domestic and export markets were calculated. Impacts on the processing market for grapefruit juice were also considered. A spatial equilibrium model with endogenous supply was used to predict price changes and new plantings, as well as potential yield losses from reduced grove care in the case of prices below costs of production. Revenue losses were calculated for a 12 year period, discounted to present values using a 4% interest rate, then annualized [41]. Results of that analysis are presented in Table 4.F.22.

In a recent study of several postharvest alternatives from Washington State University, analyses of impacts on apples, cherries, stone fruit, almonds and walnuts were presented. Two types of calculations were performed. First, farm level price changes were estimated using demand elasticities and assuming the loss of export markets and subsequent diversion of exports onto the domestic market. The results of this analysis are provided in Table 4.F.23. In the cases of cherries and walnuts, the calculated price adjustment resulted in a predicted negative price. Therefore, price estimates were not included in the results.

Next, an analysis of the costs of several alternatives was presented. See Table 4.F.24. Methyl bromide fumigation costs include costs to construct facilities and operating costs. Alternative treatment costs were calculated by developing treatment schedules specifically for each commodity, depending on harvest dates, marketing seasons, storage time and size and number of facilities. For apples, three alternatives were considered, gamma irradiation, cold storage and controlled atmosphere storage. For apples, the benchmark methyl bromide treatment and all other treatment scenarios include the costs of cold storage, including construction and operating costs. Only one alternative treatment was considered for cherries, which were assumed to have access to a port-owned irradiator. Similarly, stone fruit were also assumed to have only gamma irradiation at a port-owned facility as an alternative. Both almonds and walnuts were assumed to have three options as alternatives to methyl bromide treatment, phosphine fumigation, gamma irradiation and controlled atmosphere treatment. Processor-owned irradiation facility scenarios were considered for both nut crops. Walnut treatment times were considered in relation to the European holiday market window, and all treatments were found to meet the export shipment time.[118].

5. Postharvest Impacts

A description of the assumptions underlying the impact calculations for postharvest uses of methyl bromide is given below. It should be noted that retrofitting costs involved with switching to phosphine treatments are not included in the impact calculations presented here, due to the difficulty in assessing the costs of converting existing facilities and constructing additional facilities. Impacts are summarized in Table 4.F.26.

*Apples*

Due to the ongoing negotiations with Japan on the status of apple exports, for the purposes of this report, cost calculations are provided for alternative treatments but are not considered as losses and are not included in the impact calculations below. Methyl bromide treatment costs are based on the Washington State University study, including only operating costs, as facilities already exist and the fixed costs are considered sunk for the purposes of the current cost comparison [118].

*Apricots*

There are no alternative treatments for fresh apricots shipped to British Columbia. Methyl bromide treatment costs are based on the stone fruit fumigation costs presented in the Washington State University study [118]. Only variable costs are considered here. Losses related to losing the export market to British Columbia were calculated assuming that the fruit would be diverted to the domestic market, using an elasticity of -0.23, similar to the elasticity for peaches and nectarines used in the Washington State study [118]. Impact calculations are presented in Table 4.F.25.

*Blueberries*

Blueberries in the southeastern states are assumed to be fumigated with methyl bromide currently in their state of origin at a cost of $240 per truckload, or $0.022/lb, assuming that 1000 11-lb cartons are in each fumigated truckload. It is difficult to estimate fumigation costs for blueberries since there are chambers of different sizes,and sometimes fruit is fumigated in a chamber or container that may be less than half full [119]. Therefore, these costs are an estimate and average costs may vary. All blueberries are assumed to be irradiated at the facility in Mulberry, Florida. Participants at the Florida workshop suggested that the facility would charge $500 to 800 per load for irradiation treatment, including loading and unloading. Costs were calculated assuming an irradiation charge of $650 per load, or $0.059/lb. Berries from Arkansas and Georgia were assumed to be trucked to the Florida facility for irradiation, incurring roundtrip transportation costs of $0.065 per ton per mile [120]. Distances used for transportation costs were calculated using a mapping program, assuming Little Rock as the shipping point for Arkansas and Macon as the shipping point for Georgia.

*Cotton*

The cost of methyl bromide fumigation of cotton varies depending on the destination and the requirements of the port where the fumigation is taking place. For shipments to Pakistan, it is less expensive because they use a lower concentration of methyl bromide, whereas for cotton shipped to Peru or Egypt, fumigation may cost twice as much. Ports may have different requirements as to whether a shipment has to be removed from the shipping container before fumigation. A fumigation company in Southern California charges $3.15 per bale to treat shipments to Pakistan and $7.85 per bale for shipments to Peru and Egypt. Here, it is assumed that the average treatment cost is $5.50 per bale. A bale is assumed to weigh 480 lb. Phosphine fumigation is expected to cost about the same as methyl bromide fumigation, although it takes longer [38].

*Dates*

The costs of methyl bromide and phosphine fumigation of dates were assumed to be similar to those for raisins. (See following section on raisins.) These costs include only variable costs, i.e., fumigant, labor and other operating costs, and do not include the costs of constructing any additional facilities that might be needed due to the longer treatment times needed for phosphine fumigation.

*Figs*

The costs of methyl bromide and phosphine fumigation of figs were assumed to be similar to those for raisins. (See following section on raisins.) These costs include only variable costs and do not include the costs of constructing any additional facilities that might be needed due to the longer treatment times needed for phosphine fumigation.

*Citrus*

Methyl bromide fumigation costs for citrus are based on those charged by the Florida Department of Plant Industry, which charges $240 per load for methyl bromide fumigation. Assuming a load holds 1,000 cartons and each carton weighs 40 lb, the cost of methyl bromide is approximately $0.006/lb. Several treatments are considered as alternative treatments for citrus: irradiation, high-temperature forced-air and cold treatments. In Florida, citrus may be treated at the irradiation facility in Mulberry, where it is expected that treatment would cost between $500–800 per load. Using $650 per load as an average cost, irradiation costs for Florida citrus would be approximately $0.01625/lb.

Texas citrus is assumed to use a high-temperature forced-air treatment at a cost ten times more than methyl bromide treatment costs.

*Oak Logs*

Methyl bromide fumigation of oak logs is estimated to cost between $1 to 3 per 1000 board feet [85]. Sulfuryl fluoride is approximately 7 to 9 times more expensive than methyl bromide [121]. Costs assumed for the impact calculations below are $2 per 1000 board feet for methyl bromide and $16 per 1000 board feet for sulfuryl fluoride.

*Peaches/Nectarines*

There are no alternative treatments for peach and nectarine exports requiring methyl bromide fumigation. Methyl bromide treatment costs are based on the stone fruit fumigation costs presented in the Washington State University study [118]. Only variable costs are considered here. Loss calculations for peaches and nectarines were made assuming that exports would be diverted to the domestic market and that the domestic price would decrease, using an elasticity of -0.23, as in the Washington State study [118]. Impact calculations are presented in Table 4.F.25.

*Plums/Prunes (Fresh)*

There are no alternative treatments for fresh plum and prune currently requiring methyl bromide fumigation. Methyl bromide treatment costs are based on the stone fruit fumigation costs presented in the Washington State University study [119]. Only variable costs are considered here. Losses were calculated assuming exports were diverted to the domestic market, using an elasticity of -0.39 [118]. Impact calculations are presented in Table 4.F.25.

*Prunes*

Methyl bromide and phosphine fumigation costs for prunes are based on labor and other operating costs from the Washington State University study [118]. Average labor costs of $3.31 per ton and other operating costs of $3.97 per ton are used here. The average of labor and operating costs from the four walnut scenarios in that study was used. Fumigant costs per ton of prunes were calculated assuming methyl bromide costs $1.30/lb [118], the specific volume of prunes fumigated in a warehouse is 80 $ft^3$/ton, and the concentration of methyl bromide needed is 1.5 lb/1000 $ft^3$ [79]. For phosphine fumigation, it was assumed that pellets cost $0.86 per 100 pellets and that 200 pellets were required per 1000 $ft^3$.

*Raisins*

Methyl bromide and phosphine fumigation costs for raisins are calculated similarly to those for prunes, with a different specific volume assumed. The specific volume of 128 $ft^3$/ton for raisins is used here [79].

*Rice*

A Southern California fumigation company charges $45 per container of 39,000 lb to fumigate rice exports with methyl bromide. Methyl bromide fumigation costs are assumed to be the same for exports to Honduras, approximately $0.00115/lb. Phosphine is assumed to be the alternative treatment, at a cost similar to methyl bromide fumigation [38].

*Strawberries*

There are no alternative treatments for strawberry exports requiring methyl bromide fumigation. Methyl bromide treatment costs are based on the stone fruit fumigation costs presented in the Washington State University study [118]. Only variable costs are considered here. Similarly to the loss calculations for stone fruit besides cherries, losses were calculated assuming that exports would be diverted to the domestic market, using an elasticity of -3.92. Impact calculations are presented in Table 4.F.25.

*Sweet Cherries*

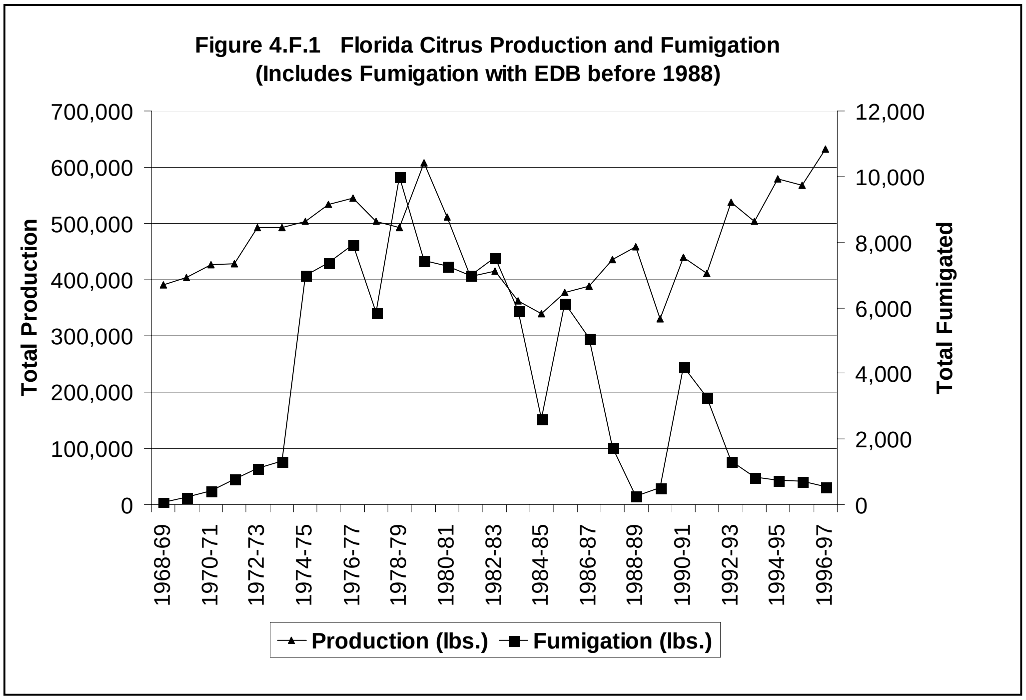
Sweet cherries are assumed to use a combination treatment of heat plus controlled atmospheres. Costs of this treatment are assumed to be ten times greater than methyl bromide treatment costs.

*Tobacco*

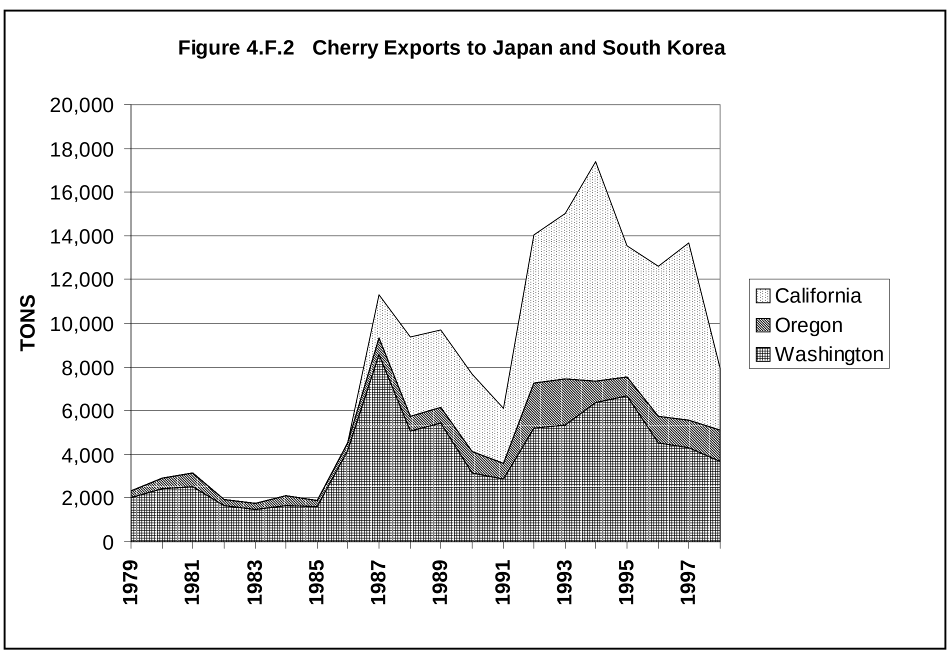
Tobacco fumigation costs were obtained from a fumigation company in LaPorte, Texas. Although application rates may vary, the standard treatment is performed using a concentration of 3 lb/1000 $ft^3$. For a 40-ft container holding 45,000 lb of tobacco, they charge $550 [128].

*Walnuts*

Walnut methyl bromide and phosphine treatment costs are based on work presented in the Washington State University study [118]. The average variable costs from the four walnut facility scenarios are used, assuming an average cost per ton of $4.90 for methyl bromide fumigation and $7.69 for phosphine.

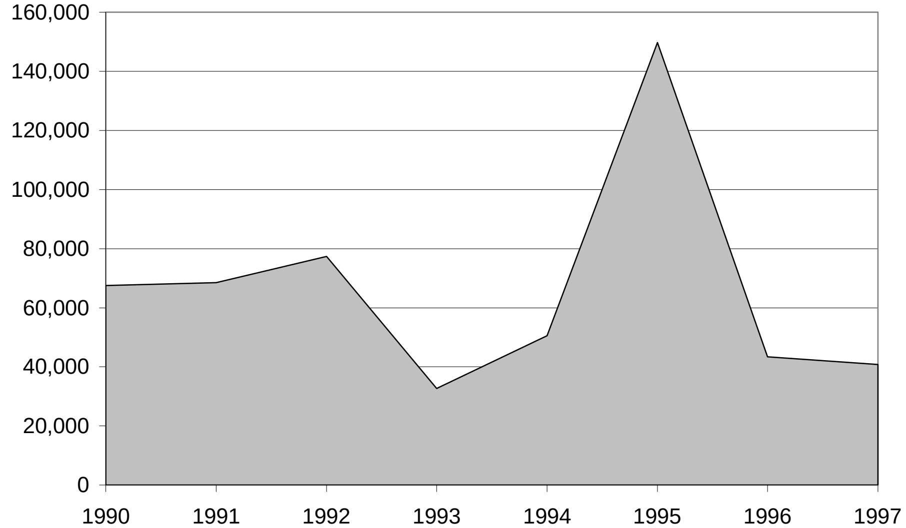



Source: [26]




Note: California exports to South Korea included only in 1994–97 data.
Sources: [11] [36]

**Figure 4.F.3 Cotton Exports to Countries Requiring Methyl Bromide Treatment (tons)**




Source: [106]

**Table 4.F.1 Washington State Fresh Market Apple Production and Exports to Japan**

| Year | Total Production (1,000 lbs.) | Total Crop Value ($1,000) | Quantity Exported (lbs.) | Percent Exported | Value of Exports ($1,000)[1] |
|---|---|---|---|---|---|
| 1994-95 | 3,500,000 | 903,000 | 18,732,486 | 0.54% | 4,833 |
| 1995-96 | 4,100,000 | 807,700 | 1,858,478 | 0.05% | 366 |
| 1996-97 | 3,600,000 | 766,800 | 233,688 | 0.01% | 50 |

[1] Value of exports calculated as percent exported multiplied by total crop value.
Sources: Total production and crop value from [24]. Exports from [50].

**Table 4.F.2 Fresh Blueberry Production and Domestic Shipments Requiring Methyl Bromide Treatments**

| State | Year | Total Production (1,000 lbs.) | Total Crop Value ($1,000) | Quantity Treated (lbs.) | Percent Treated | Value of Treated Commodity ($1,000)[1] |
|---|---|---|---|---|---|---|
| Arkansas | 1997 | 1,350 | 1,445 | 172,656 | 12.79% | 185 |
| Florida | 1995 | 2,000 | 4,600 | 191,290 | 9.56% | 440 |
| | 1996 | 1,800 | 4,590 | 201,784 | 11.21% | 515 |
| | 1997 | 1,600 | 4,720 | 11,616 | 0.73% | 34 |
| Georgia | 1995 | 5,000 | 4,800 | 375,000 | 7.5% | 360 |
| | 1996 | 2,000 | 2,420 | 150,000 | 7.5% | 182 |
| | 1997 | 4,000 | 4,560 | 375,000 | 7.5% | 342 |

[1] Value of exports calculated as percent exported multiplied by total crop value.
Sources: Total production and crop value from [24]. Arkansas and Florida blueberry fumigation data from [8] and [26], respectively. Percent of Georgia blueberries shipped to west coast states estimate from [14] and used to calculate quantity treated.

**Table 4.F.3 Fresh Citrus Production and Domestic Shipments Requiring Methyl Bromide Fumigation**

| Crop | State | Year | Total Production (1,000 lbs.) | Total Crop Value ($1,000) | Quantity Treated (lbs.) | Percent Treated | Value of Treated Commodity ($1,000)[1] |
|---|---|---|---|---|---|---|---|
| Grapefruit | Florida | 1994-95 | 1,890,315 | 128,851 | 13,726,040 | 0.73% | 936 |
| | | 1995-96 | 1,941,655 | 127,403 | 12,161,560 | 0.63% | 798 |
| | | 1996-97 | 1,975,145 | 130,528 | 13,435,600 | 0.68% | 888 |
| | Texas | 1995-96 | 241,760 | 18,797 | 4,884,210 | 2.02% | 380 |
| | | 1996-97 | 297,440 | 19,705 | 17,314,623 | 5.82% | 1,147 |
| Oranges | Florida | 1994-95 | 939,690 | 62,730 | 8,383,998 | 0.89% | 560 |
| | | 1995-96 | 897,210 | 74,841 | 11,743,914 | 1.31% | 980 |
| | | 1996-97 | 969,570 | 69,157 | 5,689,866 | 0.59% | 406 |
| | Texas | 1995-96 | 66,980 | 6,859 | 542,690 | 0.81% | 56 |
| | | 1996-97 | 81,260 | 6,081 | 1,923,847 | 2.37% | 144 |
| Tangerines | Florida | 1994-95 | 252,890 | 49,779 | 7,652,882 | 3.03% | 1,506 |
| | | 1995-96 | 298,680 | 63,980 | 4,250,894 | 1.42% | 911 |
| | | 1996-97 | 356,915 | 59,924 | 3,647,991 | 1.02% | 612 |

[1] Value of exports calculated as percent exported multiplied by total crop value.

Sources: Production and value data from [25]. Quantity treated for Florida and Texas from [26] and [32] respectively. Total Texas citrus fumigation assumed to be 90% grapefruit and 10% oranges.

**Table 4.F.4 Washington State Peach and Nectarine Exports to British Columbia**

| Commodity | Year | Quantity (1,000 lbs.) |
|---|---|---|
| Nectarine | 1998 | 1,171 |
| Peach | 1996 | 188 |
| | 1997 | 888 |
| | 1998 | 1,145 |

Source: Peach exports from [2]. Nectarine statistics from [7], assuming all fumigated stone fruits destined for British Columbia.

**Table 4.F.5 U.S. Peach/Nectarine Exports to Destinations Requiring Methyl Bromide Fumigation**

| Destination | Year | Quantity (1,000 lbs.) | Value ($1,000) |
|---|---|---|---|
| British Columbia[1] | 1998 | 2,316 | 1 |
| Mexico | 1994-95 | 28,385 | 5,719 |
| | 1995-96 | 17,971 | 4,160 |
| | 1996-97 | 33,665 | 7,451 |
| | 1997-98 | 34,734 | 7,589 |
| Japan | 1994-95 | 25 | 3 |
| | 1995-96 | 326 | 144 |
| | 1996-97 | 378 | 178 |
| | 1997-98 | 111 | 72 |

[1] Nectarine exports from Washington State only included in figures for British Columbia. Value of calculated assuming a price of $0.22/lb. [24].

Source: U.S. peach/nectarine export data from [106].

**Table 4.F.8 California Fresh Sweet Cherry Exports to Countries Requiring Methyl Bromide Fumigation**

| | Destination | | | |
|---|---|---|---|---|
| **Year** | **Australia** | **Japan** | **South Korea** | **Total** |
| | 1,000 lbs. | | | |
| **1987** | | 3,960 | | 3,960 |
| **1988** | | 7,308 | | 7,308 |
| **1989** | | 7,062 | | 7,062 |
| **1990** | | 7,067 | | 7,067 |
| **1991** | | 4,984 | | 4,984 |
| **1992** | | 13,464 | | 13,464 |
| **1993** | | 15,137 | | 15,137 |
| **1994** | | 20,050 | 47 | 20,097 |
| **1995** | | 11,941 | 16 | 11,957 |
| **1996** | 233 | 13,708 | 39 | 13,980 |
| **1997** | 454 | 16,181 | 59 | 16,694 |
| **1998** | | 5,683 | | 5,683 |

Note: Data for California exports to South Korea not available for years prior to 1994. South Korea and Australia import data not available for 1998.
Source: [11]

**Table 4.F.9 Northwest Cherry Exports to Japan and South Korea by Production Area**

| | Production Area | | | |
|---|---|---|---|---|
| **Year** | **Wenatchee** | **Yakima** | **Mid-Columbia** | **Total** |
| | 1,000 lbs. | | | |
| **1979** | 1,515 | 2,511 | 632 | 4,657 |
| **1980** | 2,588 | 2,261 | 967 | 5,816 |
| **1981** | 3,149 | 1,901 | 1,230 | 6,280 |
| **1982** | 1,403 | 1,952 | 525 | 3,880 |
| **1983** | 1,625 | 1,358 | 472 | 3,455 |
| **1984** | 2,426 | 873 | 911 | 4,210 |
| **1985** | 2,827 | 382 | 549 | 3,759 |
| **1986** | 6,843 | 1,476 | 771 | 9,090 |
| **1987** | 12,823 | 4,312 | 1,508 | 18,644 |
| **1988** | 9,332 | 764 | 1,375 | 11,472 |
| **1989** | 9,570 | 1,248 | 1,486 | 12,303 |
| **1990** | 5,760 | 560 | 1,962 | 8,282 |
| **1991** | 5,266 | 490 | 1,456 | 7,211 |
| **1992** | 9,036 | 1,358 | 4,171 | 14,565 |
| **1993** | 8,853 | 1,802 | 4,226 | 14,882 |
| **1994** | 11,114 | 1,606 | 2,020 | 14,740 |
| **1995** | 11,676 | 1,709 | 1,708 | 15,093 |
| **1996** | 6,381 | 2,666 | 2,407 | 11,454 |
| **1997** | 5,954 | 2,626 | 2,549 | 11,129 |
| **1998** | 4,717 | 2,618 | 2,878 | 10,213 |

Source: [36]

**Table 4.F.10 Fresh Sweet Cherry Production and Exports Requiring Methyl Bromide Fumigation**

| **Origin** | **Year** | **Total Utilized Production (1,000 lbs.)** | **Total Crop Value ($1,000)** | **Percent Treated with MB** | **Value of Treated Commodity[1] ($)** |
|---|---|---|---|---|---|
| California | 1995 | 22,000 | 37,510 | 53.49% | 20,066 |
| | 1996 | 32,000 | 40,640 | 43.02% | 17,485 |
| | 1997 | 63,200 | 49,612 | 24.26% | 12,037 |
| Oregon | 1995 | 11,000 | 8,305 | 15.53% | 1,289 |
| | 1996 | 22,000 | 17,490 | 10.94% | 1,914 |
| | 1997 | 30,000 | 25,650 | 8.49% | 2,177 |
| Washington | 1995 | 86,000 | 92,020 | 15.56% | 14,322 |
| | 1996 | 98,000 | 105,350 | 9.23% | 9,725 |
| | 1997 | 130,000 | 112,450 | 6.60% | 7,421 |

[1] Value of treated commodity calculated as total crop value multiplied by percent treated.
Source: Sweet cherry production and value data from [24].

**Table 4.F.11 Washington State Fresh Fruit Fumigation in 1998**

| Commodity | Quantity Treated with MB (lbs.) |
|---|---|
| Apricots | 134,400 |
| Plums/Prunes | 297,600 |

Source: [7]

**Table 4.F12 California Dried Fruit and Nut Production and Fumigation**

| Commodity | Year | Total Production (1,000 lbs.) | Total Crop Value ($1,000) | Percent Treated with MB | Value of Treated Commodity[1] ($1,000) |
|---|---|---|---|---|---|
| Dates | 1994 | 46,000 | 17,250 | 95% | 16,388 |
| | 1995 | 45,400 | 17,706 | 95% | 16,821 |
| | 1996 | 52,000 | 18,460 | 95% | 17,537 |
| Figs[2] | 1994 | 36,400 | 21,840 | 95% | 20,748 |
| | 1995 | 32,400 | 14,450 | 95% | 13,728 |
| | 1996 | 27,200 | 10,921 | 95% | 10,375 |
| Prunes[3] | 1994 | 386,000 | 210,370 | 100% | 210,370 |
| | 1995 | 362,000 | 188,240 | 100% | 188,240 |
| | 1996 | 440,000 | 198,000 | 100% | 198,000 |
| Raisins | 1994 | 837,200 | 547,002 | 50% | 273,501 |
| | 1995 | 612,800 | 526,297 | 50% | 263,149 |
| | 1996 | 620,000 | 582,234 | 50% | 291,117 |
| Walnuts[4] | 1994 | 464,000 | 238,960 | 100% | 238,960 |
| | 1995 | 468,000 | 327,600 | 100% | 327,600 |
| | 1996 | 416,000 | 322,400 | 100% | 322,400 |

[1] Value of treated commodity calculated as total crop value multiplied by percent treated.
[2] Fig production reported for processing fruit on dried basis.
[3] Prune production reported on dried basis.
[4] Walnut production reported on in-shell basis.
Source: Production and value data from [17]

**Table 4.F.13 Walnut Exports to Countries Requiring Methyl Bromide Fumigation as Condition of Entry (lbs.)[1]**

| | 1994/95 | 1995/96 | 1996/97 | 1997/98 |
|---|---|---|---|---|
| **Japan** | 921,850 | 355,000 | 423,700 | 240,000 |
| **New Zealand** | 47,600 | 21,600 | 15,595 | 26,500 |
| **South Africa** | 15,500 | 9,000 | 24,800 | 20,000 |
| **South Korea** | 560,698 | 209,400 | 312,140 | 218,100 |

[1] In-shell walnut export to Japan and shelled walnut exports to New Zealand, South Africa and South Korea are required to be fumigated with methyl bromide.
Source: [112]

**Table 4.F.14 Simulated economic impacts of longer treatment times for walnut exports on revenues.**

| | **Crop available for export market** | | **Crop sold on domestic market[1]** | **Total** |
|---|---|---|---|---|
| | **Before Oct. 24** | **Oct. 24-31** | | |
| All California walnuts | 27.8% | 5.53% | 66.67% | 100% |
| | | | | |
| Revenues: | $1,000 | | | |
| | | | | |
| Methyl Bromide | 101,679 | 20,336[2] | 233,183 | 355,197 |
| Phosphine | 144,101 | 14,372[3] | 186,830 | 345,302 |
| Change | 42,422 | -5,964 | -46,353 | -9,895 |
| | | | | |
| % Change | 41.7% | -29.3% | 19.9% | -2.8% |

Notes: Harvest cutoff date is October 31 for export when fumigating with methyl bromide; cutoff date is October 24 when fumigating with phosphine. 1992 Price and Crop Value Statistics used as base. Standard deviation of change in returns to early export quality walnuts is $14.5 million.

[1] All shelled product categorized as domestic sales for purpose of comparison.

[2] Based on export market prices because these walnuts meet the cutoff date for export.

[3] Based on domestic market prices because these walnuts miss the cutoff date for export.

Source: [102]

**Table 4.F.15 Cotton Exports Requiring Methyl Bromide Fumigation by Destination (tons)**

| **Year** | **Pakistan** | **Egypt** | **Guatemala** | **Sri Lanka** | **South Africa** |
|---|---|---|---|---|---|
| 1990 | 603 | 65,864 | 694 | 55 | 315 |
| 1991 | 432 | 67,920 | 209 | 0 | 0 |
| 1992 | 1,365 | 73,459 | 1,980 | 419 | 84 |
| 1993 | 906 | 18,736 | 11,818 | 1,000 | 219 |
| 1994 | 25,324 | 4,711 | 16,399 | 3,716 | 354 |
| 1995 | 77,308 | 45,495 | 22,720 | 3,827 | 429 |
| 1996 | 5,464 | 11,424 | 24,765 | 1,750 | 43 |
| 1997 | 12,305 | 0 | 27,031 | 1,452 | 0 |

Source: [106]

**Table 4.F.16 Cotton Production and Exports to Countries Requiring Methyl Bromide Fumigation**

| Year | Total Production (1,000 lbs.) | Total Crop Value ($1,000) | Percent Exported to Countries Requiring MB Treatment | Value of Treated Exports ($1,000) |
|---|---|---|---|---|
| 1995 | 8,591,904 | 6,574,612 | 3.39% | 249,153 |
| 1996 | 9,092,160 | 6,408,144 | 0.92% | 72,020 |
| 1997 | 9,108,960 | 6,142,346 | 0.59% | 42,522 |

Sources: Production and value from [107], export quantity and value from [106]

**Table 4.F.17 Rice Production and Exports to Honduras**

| Year | Total Production (1,000 lbs.) | Total Crop Value ($1,000) | Percent Exported to Honduras | Value of Exports to Honduras ($1,000) |
|---|---|---|---|---|
| 1995 | 17,387,100 | 1,587,236 | 0.57% | 9,851 |
| 1996 | 17,132,100 | 1,687,407 | 0.44% | 12,409 |
| 1997 | 17,889,600 | 1,728,687 | 0.37% | 13,269 |

Sources: Production and value from [107], export quantity and value from [106]

**Table 4.F.18 Tobacco Production and Exports to Chile**

| Year | Total Production (1,000 lbs.) | Total Crop Value ($1,000) | Percent Exported to Chile | Value of Exports to Chile ($1,000) |
|---|---|---|---|---|
| 1995 | 1,268,538 | 2,305,192 | 0.01% | 219 |
| 1996 | 1,517,351 | 2,851,548 | 0.02% | 2,303 |
| 1997 | 1,678,821 | 3,039,217 | 0.02% | 1,844 |

Sources: Production and value from [107], export quantity and value from [106]

**Table 4.F.19 The Use of Methyl Bromide on Post Harvest Fumigation of Trucked Citrus in Florida, 1989-90 (avg.) from NAPIAP Report**

| Tons Treated with MB | Application Rate (lbs./truck) | Treatment Cost Including Application ($/truck) | Yield Loss w/o MB (tons) |
|---|---|---|---|
| 79,571 or 4,080 trucks | 25 lbs./19.8 tons (truck) | 120 | Fresh market loss of 76,000 tons with a value of $25 million |

Source: [82]

**Table 4.F.20 Value of U.S. Exports Requiring Methyl Bromide Treatment from NAPIAP Report**

| Commodity | Receiving Countries Requiring Methyl Bromide Fumigation | Value in Current Dollars | | | |
|---|---|---|---|---|---|
| | | **10/88-9/89** | **10/89-9/90** | **10/90-9/91** | **10/91-9/92** |
| **Cherries** | **Japan** | 40,348,631 | 37,427,665 | 33,539,321 | 62,289,838 |
| | **Korea** | 438,880 | 541,179 | 254,004 | 400,365 |
| **Cotton** | **Egypt** | 58,075,307 | 96,645,575 | 88,092,061 | 124,583,434 |
| | **Bangladesh** | 22,647,922 | 36,608,512 | 18,697,863 | 9,374,163 |
| | **Pakistan** | 1,017,715 | 2,564,283 | 814,625 | 1,674,853 |
| | **El Salvador** | 4,176,585 | 808,490 | 6,410,249 | 4,801,400 |
| | **Guatemala** | 87,537 | 368,456 | 1,192,656 | 1,289,769 |
| | **Peru** | 0 | 0 | 18,624 | 1,209,557 |
| **Oak Logs** | **EEC** | 42,499,429 | 33,089,406 | 29,000,722 | 26,093,441 |
| | **Mexico** | 1,725,767 | 2,054,316 | 1,537,604 | 3,186,199 |
| | **Austria** | 902,003 | 259,002 | 64,964 | 49,065 |
| **Peaches/ Nectarines** | **Japan** | 577,266 | 265,925 | 26,682 | 0 |
| | **Mexico** | 0 | 0 | 6,619,648 | 4,951,910 |
| **Strawberries** | **Australia** | 2,306,224 | 931,584 | 1,685,327 | 1,335,784 |
| **Walnuts In Shell** | **Japan** | 2,121,013 | 1,791,851 | 1,004,640 | 1,683,555 |
| **Total** | | **176,924,279** | **213,356,244** | **188,958,990** | **242,923,333** |

Source: [82]

**Table 4.F.21 Post Harvest Impacts from 1993 and 1996 UC Reports**

| Commodity | Revenue Loss Estimate from 1993 Report ($ million) | Revenue Loss Estimate from 1996 Report ($ million) |
|---|---|---|
| **Cherries** | 7.3 | 4.2 |
| **Peaches/Nectarines** | Not Estimated | 11.6 |
| **Walnuts** | 36.8 | 9.9 |
| **Total** | **44.1** | **25.7** |

Source: [30] and [78]

**Table 4.F.22 Estimated Changes in FOB Revenues from University of Florida Report**

| | **Annualized FOB Revenue Change** |
|---|---|
| **Fresh White Seedless Grapefruit** | -347,153 |
| **Fresh Red Seedless Grapefruit** | -10,634,761 |
| **Grapefruit Juice** | 257,117 |
| **Fresh Oranges** | -1,330,528 |
| **Fresh Tangelos** | -384,512 |
| **Fresh Tangerines** | -946,055 |
| **TOTAL** | -13,385,892 |

Source: [41]

**Table 4.F.23 Price Adjustment Estimates Resulting from Loss of Export Markets Requiring Methyl Bromide Fumigation from Washington State University Study**

| **Commodity** | **Initial Price ($/ton)** | **Quantity Diverted to Domestic Market (tons)** | **New Price ($/ton)** |
|---|---|---|---|
| Apples | 340.00 | 10,550 | 332.86 |
| Cherries | 1,260.00 | 19,375 | Not calculated[1] |
| Peach/Nectarine | 408.00 | 18,359 | 360.10 |
| Plums | 950.00 | 2,889 | 862.60 |
| Almonds[2] | 2,500.00 | 28,400 | 660.00 |
| Walnuts[2] | 2,369.00 | 29,907 | Not calculated[1] |

[1] Prices for cherries and walnuts not calculated due to greater than 100% predicted price decrease.
[2] Almond and walnut figures on shelled basis.
Source: [118]

**Table 4.F.24 Estimated Cost of Post Harvest Alternatives from Washington State University Study**

| | | Treatment Costs | | | | | |
|---|---|---|---|---|---|---|---|
| **Commodity** | **Quantity Treated (tons)** | **Methyl Bromide** | **Phosphine** | **Gamma Irradiation (Port Owned)** | **Gamma Irradiation (Processor Owned)** | **Controlled Atmosphere** | **Cold Storage** |
| | | **$/ton** | | | | | |
| Apples | 11,813 | 32.01[1] | | 60.47[1] | 130.00[1] | 39.12[1] | 29.74[1] |
| Cherries | 4,446 | 9.04 | | 32.00 | | | |
| Nectarine, Peach and Plum | 17,570 | 3.98 | | 32.00 | 56.14 | | |
| Almonds[2] | 100,000 | 5.03 | 5.47 | | 15.05 | 9.93 | |
| | 50,000 | 5.01 | 5.88 | | 24.12 | 9.13 | |
| Walnuts[2] | 100,000 | 4.79 | 5.98 | | 10.89 | 7.15 | |
| | 50,000 | 6.19 | 15.71 | | 78.63 | 19.85 | |

[1] All apple treatment scenarios include costs of cold storage, except the controlled atmosphere treatment.
[2] Almond and walnut figures on shelled basis. Almond and walnut treatment cost calculations given for large and small processing facilities.
Source: [118]

**Table 4.F.25. Price Adjustments Resulting from Diversions of Exports to Domestic Market**

| Commodity | Initial Price ($/ton) | Quantity Diverted to Domestic Market (tons) | Resulting Price ($) | Producers' Loss ($) | Consumers' Gain ($) | Net Impact ($) |
|---|---|---|---|---|---|---|
| Apricots | 768.66 | 67.2 | 754.77 | 225,515 | 225,049 | -467 |
| Peaches/Nectarines | 519.36 | 15,689 | 466.11 | 36,262,802 | 35,845,087 | -417,715 |
| Plums/Prunes | 424.10 | 149 | 423.21 | 161,940 | 161,874 | -66 |
| Strawberries | 1,307.34 | 7,758 | 1,302.77 | 2,622,655 | 1,604,918 | -17,738 |

**Table 4.F.26. Post Harvest Impacts**

| Commodity and Origin | Reason for Treatment[1] | Quantity Treated (lbs.) | Value of Treated Commodity ($1,000) | MB Treatment Cost ($/lb.) | Alternative Treatment | Alternative Treatment Cost ($/lb.) | Impact ($) |
|---|---|---|---|---|---|---|---|
| Apples | | | | | | | |
| Washington | FQ | 0 | 0 | 0.001145 | | | 0 |
| Apricots | | | | | | | |
| Washington | FQ | 134,400 | 55 | 0.001795 | None | | 467 |
| Blueberries | | | | | | | |
| Arkansas | DQ | 172,656 | 185 | 0.0218 | Irradiation | 0.125 | 17,818 |
| Florida | DQ | 134,897 | 330 | 0.0218 | Irradiation | 0.059 | 5,018 |
| Georgia | DQ | 300,000 | 970 | 0.0218 | Irradiation | 0.085 | 18,960 |
| Cotton | FQ | 142,802,000 | 121,232 | 0.0115 | Phosphine | 0.0115 | 0 |
| Dates | FDA, PQ | 45,204,164 | 16,838 | 0.0020 | Phosphine | 0.0038 | 81,367 |
| | FQ | 205,836 | 77 | 0.0020 | Phosphine | 0.0038 | 371 |
| Figs | FDA | 30,400,000 | 14,950 | 0.0020 | Phosphine | 0.0038 | 54,720 |
| Grapefruit | | | | | | | |
| Florida | DQ | 13,107,733 | 874 | 0.006 | Irradiation | 0.0163 | 135,010 |
| Texas | DQ | 11,099,417 | 764 | 0.006 | Heat | .06 | 599,369 |
| Oranges | | | | | | | |
| Florida | DQ | 8,605,926 | 657 | 0.006 | Irradiation | 0.0163 | 88,641 |
| Texas | DQ | 1,233,269 | 100 | 0.006 | Heat | .06 | 66,597 |
| Tangerines | | | | | | | |
| Florida | DQ | 5,183,922 | 1,017 | 0.006 | Irradiation | 0.0163 | 53,594 |
| Peaches and Nectarines | FQ | 31,378,000 | 6,532 | 0.001795 | None | | 417,715 |
| Oak logs[2] | FQ | 25,033 | 12,422 | 0.8475 | Sulfuryl Fluoride | 6.78 | 148,508 |
| Plums and Prunes | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| (Fresh) | | | | | | | |
| Washington | FQ | 297,600 | 63[3] | 0.001795 | None | | 66 |
| Prunes (Dried) | PQ | 356,400,000 | 178,983 | 0.00199 | Phosphine | 0.00371 | 613,008 |
| | FQ | 39,600,000 | 19,887 | 0.00199 | | 0.00371 | 68,112 |
| Raisins | FDA, PQ | 345,000,000 | 275,922 | 0.00204 | Phosphine | 0.00375 | 589,950 |
| Rice | FQ | 79,930,000 | 11,843 | 0.00115 | Phosphine | 0.00115 | 0 |
| Strawberries (Fresh) | PS | 14,515,086 | 23,930 | 0.001795 | None | | 17,738 |
| Sweet Cherries | | | | | | | |
| California | FQ | 13,623,096 | 16,529 | 0.00288 | Heat + CA | 0.0288 | 353,111 |
| Oregon | FQ | 2,220,353 | 1,793 | 0.00288 | Heat + CA | 0.0288 | 57,552 |
| Washington | FQ | 10,337,147 | 10,489 | 0.00288 | Heat + CA | 0.0288 | 267,939 |
| Tobacco | FQ | 223,000 | 1,455 | 0.01222 | Phosphine | 0.01222 | 0 |
| Walnuts | PQ | 448,708,055 | 295,908 | 0.00245 | Phosphine | 0.0038 | 605,716 |
| | FQ | 625,278 | 412 | 0.00245 | Phosphine | 0.0038 | 844 |

[1] FQ-Foreign Quarantine; DQ-Domestic Quarantine; PS-Pre-Shipment Treatment; PQ-Product Quality; FDA-FDA standards.

[2] Oak log quantities reported in $m^3$.

[3] Plum and prune value of treated fruit from Washington State valued using a price of $0.21/lb [24].

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## 5. **Alternative Specific Analyses – Preplant Uses**

### A. Chemical Alternatives

*1,3-Dichloropropene (Telone II)*

Though its primary activity is against nematodes ,1,3-D controls nematodes, viruses, bacteria, soil insects and fungi [1]. For many methyl bromide–using crops, 1,3-D alone or in combination with other materials is considered the best available alternative to methyl bromide. It is often formulated in combination with varying rates of chloropicrin (Telone C-17, Telone C-35), which increases the spectrum of efficacy, especially against fungal pathogens. Liquid 1,3-D rapidly volatilizes into a gas when injected into the soil and permeates the soil mass. It reaches nematodes and fungi by moving through air spaces in the soil and dissolving into the film of water that surrounds soil particles [1]. The amount of soil moisture directly influences the movement of 1,3-D through the soil air space. While there must be sufficient moisture in the soil to increase its efficacy against nematodes and decrease emissions, movement will be retarded and effectiveness of the treatment will be reduced if soil moisture levels are too high [1].

Dissipation of 1,3-D from treated soils takes longer than methyl bromide, and this is expected to lead to planting delays due to potential phytotoxicity issues. Cool temperatures slow dissipation of 1,3-D from soil. It is recommended that soil temperatures be between 40°F and 80°F at the depth of injection [1]. In Florida, planting is expected to be delayed by between four and seven days, with longer waiting periods if soils are cool [2]. For late-harvested perennial crops in California, trees or vines may not be removed in time to treat the fields with 1,3-D, without waiting until the next year. If the fields cannot be prepared for treatment before the weather turns cold and wet, growers will have to leave their fields fallow for a year before being able to replant [10].

In combination with chloropicrin, 1,3-D is considered the best alternative to methyl bromide for vegetable crops in Florida and the other southeastern states. However, there are several limitations to its adoption. The primary obstacle is the PPE requirements for field workers during application of 1,3-D. Current requirements include a full-face respirator, coveralls, chemical-resistant gloves, chemical-resistant footwear and a chemical-resistant apron for direct-contact activities [3]. Florida vegetable growers apply fumigants in the row, covering the beds with plastic tarps at the time of application. This requires approximately one dozen workers to be in a field at the time of fumigation, performing manual labor such as digging trenches. All of these workers would be required to wear the PPE for application of 1,3-D. The cost of this equipment has been estimated and is presented in Table 5.A.1. Besides the expense of this equipment, the hot, humid conditions at the time of fumigation for the fall crop are such that wearing this type of equipment is expected to be a burden that workers will refuse to bear. It is possible that these PPE requirements could be changed to be similar to those required for workers using methyl bromide. Dow has submitted a study to the EPA that is believed to demonstrate the lack of carcinogenicity of Telone and could be the basis for changing the PPE requirements. However, the EPA has yet to issue a decision on this issue [4].

**Table 5.A.1 Costs of Personal Protective Equipment Required for Telone C-17**

| **Item** | **Cost** |
|---|---:|
| NIOSH Full Face Respirator | $73.56 |
| Two Organic Vapor Cartridges (changed daily) | $6.95 |
| Chemical Resistant Coveralls | $4.00-11.50[1] |
| Chemical Resistant Gloves (Neoprene) | $2.40 |
| Chemical Resistant Footwear (Neoprene) | $9.50 |
| **Total Per Person** | **$101.41** |

[1] Tyvek coveralls estimated to cost $4.00; laminated barrier type coveralls (Saranex) estimated to cost $11.50.
Source: [19]

To avoid the problems with PPE requirements, 1,3-D may be applied as an untarped broadcast treatment, which would reduce the number of workers required to be in the field at the time of application. It is unclear whether efficacy would be diminished using this sort of application method. Researchers have expressed concern that the top soil layer may not be effectively treated in an untarped fumigation, as the fumigant would dissipate from this layer too quickly [5]. However, Florida soils currently are wetted before bed formation and fumigation, in order hold the bed shape. With broadcast fumigation, it would not be necessary to wet the soils to the same degree, and treatment may be more effective as a result of increased fumigant movement through the soil [4].

In California, the PPE requirements are not anticipated to pose the same problems as for growers in Florida. Most fumigation is currently either untarped or broadcast fumigated, with very few workers in the field who would be required to wear the special protective gear, compared to standard practices in Florida.

Use of 1,3-D is restricted in Florida to use on soils with a relatively shallow hard pan or soil layer, which is estimated at 95% of tomato acreage [2]. Because growing areas in Dade County lack such a hard pan, the manufacturer has voluntarily prohibited use of Telone in that part of the state.

Adoption of 1,3-D as an alternative to methyl bromide is also limited by restrictions specific to California. Ambient air quality concerns, after detection at several orders of magnitude over air quality standards, led to cancellation of 1,3-D registration in California in 1990 [6], but restricted uses have been reinstated since that time [7]. These restrictions are intended to address the air quality concerns that led to its cancellation. The most limiting restriction in California is expected to be the township caps, which set the maximum amount of 1,3-D that may be applied within 36-square-mile areas referred to as townships. The cap is variable depending on application depth and the time of year when applications are made [7]. Because of the caps, it is expected that there will be growers in certain areas who will be unable to use 1,3-D to the extent that they would prefer.  An estimate of the impact that the township restrictions will have on California growers follows.  Work is ongoing to evaluate the effectiveness of drip application methods that might decrease volatilization [9].  However, drip application of Telone is not allowed under current restrictions [8].

Also, in California, the maximum application rate for 1,3-D is 24 gal/acre for tarped fumigation and 35 gal for untarped fumigation.  For perennial crops, the maximum application rate may not provide effective control [10].  In addition, there is a 300-ft buffer zone around occupied structures [7], which is more restrictive than the current buffer zone requirements for methyl bromide fumigation.  The methyl bromide buffer zones vary between 100 and 300 ft depending on application methods and areas.

Telone is generally less expensive than methyl bromide at usual application rates for both materials.  Telone C-17 costs approximately $13.00/gal [19].  Under California regulations, a licensed custom application company must apply 1,3-D.  To re-coup the costs of re-registering Telone in California, the manufacturer has increased the price in that state.  The cost of custom application of Telone + chloropicrin are the same as for methyl bromide/chloropcirin, between $1000 and 1400 per acre for tarped broadcast fumigation.  For nontarped fumigation using Telone II, applied at depths greater than 18 in., Tri-Cal charges $14.50/gal of product up to 35 gal/acre and $40 per acre for application costs.  For nontarped bed fumigation, costs include $15.50/gal of product and $35 per acre for application costs with application rates of 10 gal/field acre [11]. Growers who modify their production methods from broadcast fumigation to bed fumigation may be able to decrease their fumigation-related expenses.

In December 1994, 1,3-D use was reinstated with several restrictions [1].  The California Department of Pesticide Regulation issued suggested permit guidelines to the County Agricultural Commissioners, specifying the amount and manner in which Telone products were to be used.  The guidelines have been modified since reintroduction of Telone.  The latest guidelines, issued in November of 1997, limit the total amount of 1,3-

D that may be applied within 36-square-mile area delineations, referred to as townships [7]. The limit is variable depending on depth and timing of applications within each township. The applicable section of the guidelines follows:

> XI. Township/Range Cap:
> The pest control business shall assure that the maximum township/range cap is not exceeded. The maximum amount of 1,3-D active ingredient applied per calendar year per township/range (36 square mile area), shall be no more than:
> A. 47,500 pounds of active ingredient of 1,3-D when <u>**any**</u> applications are made at depths less than 18 inches, but also including <u>**any**</u> applications made at depths 18 inches or deeper during January or December; **or**
> B. 71,250 pounds of active ingredient of 1,3-D when <u>**any**</u> applications are made at depths 18 inches or deeper from January 1 through December 31; **or**
> C. 90,250 pounds of active ingredient of 1,3-D when <u>**all**</u> applications are made at 18 inches or deeper from February 1 through November 30. For partial township/range blocks (divided by county or state borders), the number of pounds of active ingredient of 1,3-D allowed per calendar year must be approximately proportional to the size of the block.
> Source: [7]

The township restrictions for 1,3-D in California are anticipated to be binding when methyl bromide is no longer available. Currently, the township caps have already limited the amount of carrot acreage in Kern County that is treated with 1,3-D [8] [21] [22].

The township restrictions are just one part of the guidelines, which specify several other modified use practices designed to minimize levels of 1,3-D in ambient air. The guidelines also specify a 300-foot buffer zone requirement around occupied structures, which is greater than the current buffer zone requirements for methyl bromide–treated areas. These buffer zones are also expected to have a significant impact on the amount of acreage that 1,3-D could be used to treat.

The following is an analysis of the impact of the 1,3-D township limits on crops in California under a ban on methyl bromide. Although the buffer zones will also limit the acreage that is currently fumigated with methyl bromide that could be fumigated with 1,3-

D, these restrictions are not considered here due to the site-specific nature of the restriction.

Using the 1995 California Pesticide Use Database, total 1,3-D demand by township was calculated. This was done by adding 1,3-D use reported in 1995 with estimates of 1,3-D demand in areas that were fumigated with methyl bromide. For acreage treated with methyl bromide, 1,3-D application rates and depths were assumed as presented in Table 5.A.2. The analysis is performed both assuming that strawberry growers will choose to use 1,3-D and that they will not use 1,3-D, based on information that suggests that other materials may be more effective. A discussion of alternatives for California strawberries growers is provided elsewhere in this report.

**Table 5.A.2 Application Rate Assumptions Used in Telone Township Restriction Analysis**

| Crop | Type of Fumigation | Formulation | Product Rate (gal./A)[1] | 1,3-D Rate (lbs./A)[1] | Application Depth |
|---|---|---|---:|---:|---:|
| **Almond** | Broadcast | Telone II | 35 | 332 | >18” |
| **Carrots** | Bed[2] | Telone II | 8.5 | 81 | <18” |
| | Broadcast[2] | Telone II | 12 | 114 | <18” |
| **Grapes** | Broadcast | Telone II | 35 | 332 | >18” |
| **Lettuce** | Bed | Telone II | 8 | 76 | <18” |
| | Bed | Telone C-35 | 11.3 | 76 | <18” |
| **Nursery** | Broadcast | Telone C-35 | 35 | 235 | <18” |
| **Peach** | Broadcast | Telone II | 35 | 332 | >18” |
| **Peppers** | Bed | Telone C-35 | 11.3 | 76 | <18” |
| **Strawberry** | Broadcast | Telone C-35 | 35 | 235 | <18” |
| **Sweet Potato** | Broadcast | Telone II | 20 | 190 | <18” |
| **Tomato** | Bed | Telone II | 8 | 76 | <18” |
| **Walnut** | Broadcast | Telone II | 35 | 332 | >18” |
| **Watermelons** | Bed | Telone II | 12 | 114 | <18” |

[1] Application rates given per field acre.

[2] Half of the carrot acreage is assumed to be bed fumigated, the other half broadcast fumigated.

Source: [11]

Several adjustments were made to the 1995 California Pesticide Use Database for the purposes of this analysis, as in the methyl bromide use estimates presented elsewhere in this report. First, it is generally known that treated acreage is overstated for methyl bromide use in perennial crops due to reporting of spot treatments on less than one acre as full-acre treatments. In order to reduce the overstatement, all records where the application rate was less than 50 lb/acre were deleted. In addition, all records where application rates were greater than 1000 lb/acre were considered to be misreported and were also deleted.

Another adjustment was made to account for the substantial amount of methyl bromide use that is reported as unspecified as to which crop was to be planted on that acreage. Over 2 ½ million lb of methyl bromide use is reported as unspecified in the database, accounting for approximately 9000 treated acres. County Agricultural Commissioners in the counties with a large amount of unspecified use were contacted for further information on which crops were being fumigated. All unspecified uses in Siskiyou County were assumed to be for strawberry nurseries. The breakdown of unspecified uses in Fresno, Madera and Tulare Counties, which together account for over 2.1 million lb of the unspecified methyl bromide use, is given in Table 5.A.3. Unspecified use in other counties is not considered.

**Table 5.A.3 Estimated Breakdown of Unspecified Methyl Bromide Fumigated Acreage**

| Crop | Fresno[1] | Madera[2] | Tulare[3] |
|---|---:|---:|---:|
| Almonds | | 486 | |
| Grapes | 829 | 898 | 1,046 |
| Nectarines | 1,244 | | 407 |
| Plum/Prune | 829 | 88 | 279 |
| Peach | 414 | | 128 |
| Strawberries | | | 349 |
| Misc. | | | 116 |
| **Total Unspecified Acreage** | **3,316** | **1,472** | **2,325** |

[1] The Fresno County Agricultural Commissioner's office estimated that 25% of unspecified use was for grapes, 38% for nectarines, 25% plums and 12.5% peaches [23].
[2] The Madera County Agricultural Commissioner's office estimated that the majority of unspecified use was for grapes with the remaining uses on almonds and other crops. The estimates for Madera are based on acreage planted to perennial crops from acreage surveys [24] [26] [27] [28] [29].
[3] The Tulare County Agricultural Commissioner's office estimated that 45% of unspecified fumigation was for grapes, 15% for strawberries, 35% of unspecified fumigation was for tree fruit, with 5% miscellaneous uses. It is assumed that half of the tree fruit acreage was nectarines, one third was plums/prunes and the remaining acreage was in peaches [25].

The number of townships in each county for which calculated 1,3-D demand exceeds the township limits is presented in Tables 5.A.4 and 5.A.5, with separate analyses including and not including strawberries as 1,3-D users.

**Table 5.A.4 California Counties where 1,3-D Demand is Anticipated to Exceed Township Restrictions with Strawberries as 1,3-D Users**

| County | Estimated 1,3-D Demand (lbs.) | Demand in Excess of Township Caps (lbs.) | Number of Townships Exceeding Township Caps |
|---|---|---|---|
| **Fresno** | 1,231,065 | 298,263 | 5 |
| **Kern** | 1,302,612 | 468,922 | 8 |
| **Madera** | 474,265 | 352,654 | 1 |
| **Merced** | 881,142 | 406,145 | 7 |
| **Monterey** | 2,244,540 | 1,414,086 | 13 |
| **Napa** | 244,424 | 130,157 | 1 |
| **Orange** | 428,278 | 160,316 | 3 |
| **Riverside** | 265,933 | 71,706 | 2 |
| **San Diego** | 266,106 | 57,593 | 1 |
| **San Joaquin** | 846,336 | 202,211 | 7 |
| **Santa Barbara** | 625,660 | 377,726 | 2 |
| **Santa Cruz** | 645,398 | 400,271 | 5 |
| **Shasta** | 139,580 | 62,821 | 1 |
| **Siskiyou** | 182,193 | 42,426 | 2 |
| **Sonoma** | 378,813 | 2,656 | 1 |
| **Stanislaus** | 937,036 | 198,920 | 5 |
| **Sutter** | 357,763 | 119,927 | 1 |
| **Tulare** | 745,866 | 128,872 | 1 |
| **Ventura** | 980,190 | 682,840 | 5 |
| **TOTALS** | **13,177,200** | **5,578,512** | **71** |

**Table 5.A.5 California Counties where 1,3-D Demand is Anticipated to Exceed Township Restrictions with Strawberries Assumed to Not Use 1,3-D**

| County | Estimated 1,3-D Demand (lbs.) | Demand in Excess of Township Caps (lbs.) | Number of Townships Exceeding Township Caps |
|---|---|---|---|
| **Fresno** | 1,222,088 | 298,263 | 5 |
| **Kern** | 1,300,798 | 468,922 | 8 |
| **Madera** | 473,513 | 352,654 | 1 |
| **Merced** | 821,762 | 384,611 | 6 |
| **Monterey** | 551,018 | 92,403 | 4 |
| **Napa** | 243,954 | 130,157 | 1 |
| **Riverside** | 259,832 | 71,706 | 2 |
| **San Joaquin** | 843,140 | 202,211 | 7 |
| **Shasta** | 139,580 | 62,821 | 1 |
| **Siskiyou** | 134,782 | 21,931 | 1 |
| **Sonoma** | 377,873 | 2,656 | 1 |
| **Stanislaus** | 925,041 | 190,079 | 4 |
| **Sutter** | 356,047 | 119,927 | 1 |
| **Tulare** | 745,866 | 128,872 | 1 |
| **TOTALS** | **8,395,294** | **2,527,213** | **43** |

*Chloropicrin*

Chloropicrin controls fungi, nematodes, bacteria, insects and weeds, although it does not control weeds or nematodes as well as methyl bromide. It is used primarily for its fungicidal properties. Methyl bromide formulations for preplant fumigation include chloropicrin at varying proportions. At a low concentration, it is included as a warning agent to signal presence of methyl bromide, which is odorless. At higher concentrations, it is used to broaden the spectrum of pest control of methyl bromide fumigation. Chloropicrin and methyl bromide are believed to act synergistically, resulting in larger yield increases when used together than could be accounted for by the use of each separately. Chloropicrin is also commonly formulated with 1,3-D to broaden the spectrum of pest control using this fumigant.

Either alone or in combination with other materials, chloropicrin is expected to be part of pest control practices when methyl bromide is no longer available.  As mentioned previously, a combination of 1,3-D and chloropicrin is expected to be adopted for many of the vegetables crops in the Southeast.  For California strawberry growers, research has demonstrated consistently higher yields in plots treated with a high rate of chloropicrin than with other alternative fumigants [17].

However, public complaints are anticipated if chloropicrin is adopted widely.  In California, public hearings have been held regarding methyl bromide fumigation due to complaints by nearby residents.  These complaints are believed to stem at least partially from the odor associated with the chloropicrin portion of the formulation.  In anticipation of increased usage, the agricultural commissioners in two major strawberry producing counties of California, Monterey and Santa Cruz, have issued interim guidelines for use of chloropicrin, limiting the application rate to 200 lb/acre in most areas and 125 lb/acre in methyl bromide residential buffer zones [12] [13].  These rates are much lower than the rates at which researchers had obtained their best yields for strawberry production. Recent research efforts have included plots treated with low rates of chloropicrin in combination with metam sodium [14] [15] [16].

There are some concerns about the longer waiting period required when using chloropicrin compared with those required for methyl bromide fumigation.  Chloropicrin requires a minimum of 14 days between treatment and planting.  Methyl bromide requires a minimum of 9 days between treatment and transplanting.  The longer waiting periods are required in order to minimize potential phytotoxicity problems associated with slower dispersion of chloropicrin from the soil [2].  Cool soil temperatures may further delay dissipation of chloropicrin and result in crop damage due to prolonged phytotoxic effects.

Chloropicrin is generally more expensive than methyl bromide, though at low rates, per-acre fumigant costs may be lower using chloropicrin.  Chloropicrin is applied using the same equipment and methods as methyl bromide, so labor and machinery costs will be similar. Chloropicrin costs approximately $2.55/lb [18].

*Metam Sodium (Vapam, Busan, Sectagon II)*

Metam sodium is used to control nematodes, fungi, soil insects and weeds. It decomposes to methyl isothiocyanate (MITC), the biocidal ingredient, when applied to moist soil. Diseases such as those caused by *Fusarium* and *Verticillium* spp. are not controlled by metam sodium [6]. For use in perennial crops, metam sodium does not penetrate roots from a previous crop as well as methyl bromide [6]. Metam sodium has a history of providing unreliable pest control if not used carefully. If soil temperatures are too high and soil moisture is low, conversion to MITC is increased, and the chemical may diffuse out of the soil too quickly, not allowing for an accumulation of the chemical in the soil and effective control. If the soils are too wet and temperatures are cool, the rate of decomposition to MITC is decreased, which limits the effectiveness and slows dissipation of the material, resulting in delayed planting.

Metam sodium is likely to be adopted as an alternative to methyl bromide either alone or in combination with other materials. For growers in areas that will not have access to 1,3-D, such as Dade County, metam sodium is expected to be the best available alternative. It is less expensive than 1,3-D and chloropicrin at standard application rates, so other growers may choose metam sodium over other alternatives for the cost savings. In addition, metam sodium may also be used in combination with other materials such as chloropicrin or 1,3-D.

Metam sodium appears to move as a fumigant only 8 to 10 cm from the point of injection. Researchers have investigated alternative application methods. Application through drip irrigation systems or surface application followed by rotovation may provide more effective control than injection as a fumigant. For use in orchards, a portable soil drenching device has been developed, which uses dripper emitters [10]. Other chemigation methods of application, such as through microsprinklers, are also under development [9]. Metam sodium moves with water and reaches only those pests that come into contact with the wetted area. Improved control may require increased application rates or application of large quantities of water, which increases concerns about groundwater contamination [6]. Longer waiting periods are required before planting and may extend to between 14 and 50 days depending on soil conditions and rate of application. The EPA has classified metam sodium as a known teratogen, probable human carcinogen, and potential leacher leading to groundwater concerns [2].

If metam sodium is surface applied, application will require the use of a boom sprayer and a disc, as well as the labor required to run this equipment. Metam sodium costs approximately $4.10/gal [18].

*Dazomet (Basamid)*

Dazomet controls nematodes, fungi and weeds. The granular formulation of dazomet, Basamid, reacts with soil moisture to produce MITC, the same biocidal agent in metam sodium. Soil moisture plays a crucial role in activating Basamid and increasing the susceptibility of the target pests. If comprehensive incorporation and/or complete activation do not occur, results will be variable and phytotoxicity can be prolonged. Soil type, as it influences soil moisture, has a profound impact upon rewetting and the subsequent breakdown of Dazomet to the gas phase [30]. In cool climates Dazomet needs a 60 day reentry waiting period [6]. Groundwater contamination is also of concern for the same reasons cited for metam sodium [6].

Basamid has been included in many of the methyl bromide research trials to date. Researchers report difficulty with applying the fine granules, which are easily dispersed by wind during application. Overall experience with the material has been variable, and researchers have expressed doubts that growers will choose to use a material with erratic performance on high-value crops. Recent large-scale trials combining Basamid and

Telone C-35 treatment yielded positive results. However, the application methods used for Basamid are not permitted under current label restrictions [33]. Basamid is not currently labeled for food crops and does not currently have an experimental use permit. However, the manufacturer, BASF, submitted a registration package to the EPA in June 1997 for tomatoes, peppers and strawberries [31].

Basamid is surface applied and incorporated. The application costs associated with the use of Basamid include the use of a broadcast spreader, a disc and the labor to run this equipment. Basamid costs approximately $2.90/lb [32].

*Vorlex*

Vorlex, a formulation of 1,3-D and MITC, was voluntarily cancelled by the registrant in the early 90s. At that time, it was considered the next best alternative to methyl bromide for many crops, especially vegetables crops in the southeast states. AgrEvo recently submitted a petition to the EPA to renew registration of the product. Depending on the outcome of their current petition, they will decide whether to pursue registration. At this time, they believe the data they have submitted will be sufficient, and that they may receive a conditional section 3 registration in the coming months [89].

*Methyl Iodide*

Methyl iodide is in the experimental stages and is not registered for use on agricultural crops in the U.S. or elsewhere. Research has demonstrated its effectiveness against a broad range of pests, including fungi, nematodes, and weeds [34] [35] [36] [37] [38]. Debate continues on the carcinogenicity of methyl iodide. Methyl iodide is rapidly destroyed by UV light and is therefore unlikely to be involved in stratospheric ozone depletion [39].

Methyl iodide may be applied using the same equipment and methods as methyl bromide, so labor and machinery costs would be similar [39]. Methyl iodide has been available to researchers at the University of California at Riverside for $12 to 14/lb. This cost would be expected to decline if methyl iodide were produced in large quantities [39].

*Enzone*

Enzone is a new compound that may control nematodes, soilborne diseases and insects but may not be as effective as methyl bromide for weed control. The active ingredient of Enzone is sodium tetrathiocarbonate, which releases the biocide carbon disulfide. Enzone can be pre- or postplant applied to vines that are at least one year old. It is short-lived and frequent applications may be needed. Enzone is best applied with water [6]. Enzone is registered in California for several perennial crops [40].

*Herbicides*

Methyl bromide is an effective herbicide, controlling many annual weeds. In Florida and other southeastern states, in particular, the control of yellow and purple nutsedge is critical. Methyl bromide use has reduced hand weeding costs and, in California, has allowed the use of clear plastic mulches by strawberry growers, which promotes earlier yields. None of the potential fumigant alternatives to methyl bromide have been shown to be as effective at controlling weeds. It is anticipated that herbicide use will increase when methyl bromide is no longer available. Following, several herbicides are described which may be part of a methyl bromide alternative.

*Pebulate (Tillam):* The herbicide pebulate is currently labeled for tobacco, tomato and sugarbeets. Research has been done using pebulate in combination with various fumigant treatments on tomatoes, finding that it provides good control of nutsedge. Pebulate is a liquid that is surface applied prior to bed formation, requiring the use of a boom sprayer and a disc, as well as the labor required to run this equipment. Pebulate costs approximately $7.93/lb of active ingredient [41].

*Napropamide (Devrinol):* Napropamide, an herbicide, is labeled for tomatoes, peppers, eggplants and strawberries. However, only posttransplant use is registered for strawberries, and preplant use in eggplants requires the use of transplants instead of seeding [43]. Napropamide is available in both granular and liquid formulations. If a granular formulation is used, application costs would include the use of a broadcast spreader and labor. A liquid formulation would require the use of a spray boom and labor. Napropamide costs approximately $17.00/lb of active ingredient [41].

*Trifluralin (Treflan):* Trifluralin is an herbicide labeled for preplant incorporated use on tomatoes and peppers. Trifluralin is available in both granular and liquid formulations. If a granular formulation is used, application costs would include the use of a broadcast spreader and labor. A liquid formulation would require the use of a spray boom and labor. Trifluralin costs approximately $9.53/lb of active ingredient [41].

*Bensulide (Prefar), Naptalam (Alanap):* Bensulide and Naptalam are herbicides that are labeled for watermelon. They may be used separately or in combination for a broader spectrum of activity. Bensulide and Naptalam are formulated as liquids. Application costs include the use of a spray boom and labor. Bensulide costs $42.75/gal [41]. Naptalam costs $11.00/lb of active ingredient [41].

*Oryzalin:* Oryzalin is an herbicide that is labeled for ornamental crops. Application costs include the use of a spray boom and labor. Oryzalin costs $63.60/gal or $15.90/lb of active ingredient [41].

*Metolachlor:* Metolachlor is an herbicide that is labeled for ornamental crops. Application costs include the use of a spray boom and labor. Metolachlor costs approximately $8.52/lb of active ingredient [41].

*Rimsulfuron (Shade-out)*: Rimsulfuron is registered on potatoes, at a different rate and under a different name (Matrix). Rimsulfuron was registered recently through the methyl bromide fast track for use on tomatoes in California (between the rows of plants only). Research in Florida has just been completed, but the rate at which Rimsulfuron is registered in other crops is not high enough to control nutsedge [75].

## B. Nonchemical Alternatives

### *Solarization*

Soil solarization is a procedure that uses transparent film to trap solar energy in the soil. When extended over a six to eight week period, heat generated in the soil by the trapped solar energy can lead to the suppression of several key soilborne pests [46]. Effectiveness depends on soil moisture and texture; air temperature; season; length of day; intensity of sunlight; wind speed and duration; and type, color, and thickness of plastic [44]. Enhanced growth, termed the increased growth response, has been observed even in the absence of major pathogens following both solarization and fumigation [45].

Application of solarization on methyl bromide–using crops has been developed primarily in Florida. Early trials of solarization in Florida were performed in the 1980s by laying transparent film in a solid sheet over the entire area to be treated [47] [48] [49]. However, several problems with this procedure were discovered including the additional cost of plastic, which would be removed after treatment and field preparation, and pooling of water after heavy rains. These issues were addressed with further development of the system, using plastic only over the beds in strip solarization, which would then remain in place as mulch during the growing season [50].

Solarization can be incorporated into commercial production practices with minimal disruption to field procedures. In Florida, production fields are not cropped during the summer months, the ideal period for solarization treatment. Raised beds are prepared and covered using standard production practices, except that clear, LDPE plastic is used instead of white or colored films. The only additional requirement is that the film must be painted white before planting to cool the soil [46]. Soil temperatures achieved in solarization treatments range from 134ºF at the surface to 101ºF at a depth of 10 in. Mixed populations of yellow and purple nutsedge have been controlled in North Florida by solarizing raised beds prior to planting. Tubers germinate producing vegetative shoots that are burned back by the high temperatures at the soil's surface. Eventually, as the process repeats itself, the depleted food reserves in the tubers leave them unable to compete when the crop is planted. Less success has been obtained with fungal and bacterial pathogens. Lack of direct suppression may be the result of the higher thermal tolerances of fungi and bacteria [46].

The application of soil solarization in Florida is limited to fall production systems [50]. Recent trials were performed where solarization was performed during the cool season. While soil temperatures were increased by the treatment, lethal temperatures were not achieved for several weeds that are commonly controlled by summer solarization treatments [51]. Approximately 40% of Florida tomatoes are planted in the fall [52]. Most of the Florida solarization research has been performed on tomato production systems. While production practices for other crops are similar, researchers urge caution when evaluating the applicability of the treatment to other crops.

Soil solarization alone does not provide effective control of plant parasitic nematodes and, when used in a nematode infested field, should be combined with an effective nematicide. Weed suppression to the point of eliminating the weeds' effect on yield is adequate in most situations, but weed growth underneath the plastic mulch is not eliminated [54]. The use of double layers of plastic has been proposed in order to minimize the time required for an effective solarization treatment [53].

For Southeast vegetable production, solarization costs are less than methyl bromide fumigation. Using clear LDPE, the only additional procedure required is painting the plastic white to terminate the solarization period. The cost of clear LDPE is approximately $175 to 180 per acre compared to $225 to 300 for white-on-black coextruded LDPE [44] [55]. White paint is estimated to cost $135 per hectare ($55 per acre) [55]. Additional labor is required to paint the plastic.

*Resistance and Grafting*

Resistant varieties may be available for some crops or in rootstocks that are used for grafting. Most genes are effective against only a single pathogen and sometimes only one race of a pathogen, which may enhance the development of new pathotypes. This effect may be reduced by crop rotation, alternating with the use of tolerant varieties or integration of other control options. Research is focused on breeding in broad-spectrum resistance [6]. Plant breeding may take 5 to 15 years [56]. The level of resistance describes the effect of the host on reproductive capabilities of a pest. Ideally, resistant cultivars are bred for both resistance (suppressed reproduction) and tolerance (infection will have little impact on plant growth and crop yield). Resistant cultivars might have lower yield and quality than susceptible varieties, and choosing cultivars with specific resistance requires knowledge by growers as to which specific pests are present in the field [2]. Resistant cultivars benefit from fumigation. Significant yield losses were observed when a resistant variety of tomato was planted into soils with high populations of root-knot nematode [59]. Rootstocks that are resistant to nematodes are beneficial once a vineyard or orchard is established but do not solve the replant problem, as growth will be poor without fumigation [57] [58]. Rootstock acceptability is based on many factors including rootstock performance in the nursery and graft compatibility between the rootstock and the fruit bearing portion of the tree [60].

The cost of resistant hybrids is estimated at $50 to 75/lb of seed (for each acre) for cucurbits and $500 to $1000/lb for tomatoes and eggplants [44]. Peach without resistance cost approximately $251 per acre, but peach on resistant rootstock (Guardian) costs approximately $333 per acre. For grapes, the cost is $292 to 650 per acre for nongrafted grapes and $1575 to 4000 per acre for grapes grafted to resistant rootstock [2].

*Cover Crops*

Cover crops are noncommercial crops that are turned into the soil as green or dry residues. Many cover crops are legumes such as clovers, vetches, alfalfa, etc., that improve both the fertility and tilth of soil by increasing organic matter. Cover crops have also provided beneficial weed control in some instances [88]. Living mulches, grown at the same time as the cash crop, can suppress weeds, reduce tillage and control insect pests without affecting yields [63]. Leguminous cover crops (also called "green manures") are increasingly used in orchards and vineyards to suppress weeds and improve habitats for natural enemies of soilborne and foliar pests [61]. Studies in Florida and Alabama have shown that several tropical perennial legumes effectively reduce some plant-parasitic nematodes, even after a single cropping cycle. Exclusion of weeds that host nematodes and problems encountered with stand establishment of some cover crops must be resolved if this approach is to be used reliably [62].

*Crop Rotation*

Crop rotation is a historic method of crop production that reduces soil pest problems by removing susceptible plants from an infested area for a period of time long enough to reduce pest populations to tolerable levels. An investigation into the effect of a rotation of broccoli and the incorporation of crop residue into the field on *Verticillium dahliae* found significant reductions in disease incidence and severity between the broccoli treated plots and the nonbroccoli plots [64]. Crop rotation as a control strategy may be limited by the presence of long-lasting viable stages of microorganisms, such as microsclerotia, or the ability of the microorganisms to subsist as a saprophyte in competition with the soil flora and fauna. Capital field improvements such as irrigation systems, water permitting requirements, and the availability of suitable land also limit adoption of crop rotation as a pest control strategy. Once a grower has invested in an irrigation system for a piece of land, the grower is less likely to rotate to a lower value crop.

*Fallow*

Taking land out of production reduces habitat and food for the pests associated with a particular crop. Under some conditions, fallowing has been equivalent or superior to cover cropping or crop rotation as a means of nematode population suppression. Fallowing has unfavorable effects on soil organic matter and soil structure and can increase the potential for soil erosion. Fallow conditions should be managed to minimize weed growth. Because of the wide host range of many nematode species, uncontrolled weed growth during the fallowing period can also mitigate its suppressive effect on nematode population. Frequent tillage is generally required to maintain clean fallow soil conditions [65]. Four years of dry fallowing prior to replanting orchard sites is generally adequate to avoid most of the replant problem for perennial crops [57].

*Soil Amendments*

The addition of organic matter to soils can improve soil water-holding capacity, infiltration, aeration, permeability, soil aggregation and micro nutrient level and support soil microbial activity. The kind of organic matter and its state of decomposition and/or microbial colonization determine the effects on root diseases [6]. The addition of organic amendments may improve crop growth by increasing tolerance to nematodes [69]. However, the effects of some compost materials on yields have been inconsistent in research trials [70]. Effects may also be long term, occurring after several years of adding soil amendments [71]. The high rates required for nematode control by most organic amendments (up to several tons per acre), the rates of oxidation due to high soil temperature and moisture conditions, their high costs, and their marginally defined efficacy are major limitations that have constrained expanded use of these materials [62]. The raw materials from which composts are prepared, the process and conditions under which they are produced, its maturity or stability, the microflora colonizing composts after peak heating and timing of and procedures used during composting all have an effect on the potential for composts to control plant diseases. These factors must be monitored to realize beneficial effects consistently [72]. Composted materials are becoming more reliable as classification systems are developed. Municipalities should have an interest in supplying farmers with sludge to save landfilling costs, a savings that could be passed on to growers [73]. Researchers are studying the effects of incorporating brassica residues on soilborne diseases, related to the release of MITC during decomposition, the same active ingredient in metam sodium and dazomet. In areas where crops such as broccoli are grown, the field may be mowed after harvest to chop the crop residue and allow it to dry before it is incorporated into the soil [74].

Different types of soil amendments are applied at different rates. For composted yard waste, 100 tons per acre may be appropriate, while sludge applied at 10 to 20 tons per acre has provided good plant growth [66]. The costs associated with various types of soil amendments depend on the weight of materials, transportation and application methods. Some organic farmers use chicken manure, which is applied at approximately 5 tons per acre. Composted yard waste from a facility in Jacksonville costs $11.70/ton [67]. Chicken manure costs approximately $15 to 20/ton [68]. No figures are available for municipal sludge. Transportation costs are estimates at $0.80 to 1.00 per mile per load with a maximum capacity of 22 tons. Costs to spread materials on fields are estimated at $6 to 7/ton [68].

*Flooding*

Flooding is a potential alternative in flat, low-lying areas rich in mineral soils where there are seasonally high water tables and abundant water supplies. Alternating anaerobic and aerobic conditions through periodic flooding can decrease nematode populations, while longer periods of flooding can control weeds. High temperatures during flooding generally improves effectiveness and decreases amount of time necessary to flood. Alternating flooding with disking may eliminate problems with pathogens that persist on plant debris or on the soil surface by turning them deep into soils [76]. Flooding is particularly effective when organic matter is incorporated into the soil prior to addition of water, producing anaerobic microbial by-products that suppress pathogens and nematodes [61]. While nematode densities in soil may be reduced after 2 to 3 months of flooding, longer periods of time may be required to eliminate nematode eggs. In an early trial in California, eggs of root-knot nematodes remained viable for 2 to 22.5 months after flooding was initiated. Results obtained by flooding vary with aeration, season, soil type, level of the water table, presence of toxic by-products, and other environmental conditions. Also, it is important to remember that water can be an important agent for passive dispersal of plant pathogens, introducing new pest problems into the field or transporting ones from the field to other areas [45].

Assuming an area is amenable to flooding, costs include the capital costs required to prepare the area for flooding, including construction of ponds and ditches, leveling fields, drains, and barriers. The costs of flooding are estimated at $64 to 140 per acre, including capital, labor and materials [76]. The use of flooding would be expected to be limited by availability and cost of water in some areas.

*Hot Water*

Aqua Heat has developed a system that uses a 25 million BTU diesel-fired mobile boiler, heating 250 to 300 gal of water per minute continuously to temperatures of 200 to 230°F.

The system sprays and injects heated water into the soil then mixes it into the soil during preplant tillage. The volume of water required depends on soil type, ambient soil temperature and depth of soil to be treated, but estimates are that 25,000 to 50,000 gal/acre would be needed for effective nematode control [32]. Some estimate that up to 100,000 gal of water per acre would be needed to raise soil temperatures high enough to provide effective pest control [2]. A commercial hot water system is planned for later this year [77] and is expected to be able to treat 10 acres per day, compared to 40 to 50 acres a day when fumigating with methyl bromide [2]. The first machine will be made available in California, where rose plant and strawberry growers have expressed interest in using the system [77]. There is a potential for negative environmental impacts due to use of large amounts of fossil fuels and water. The system has potential to change soil structure, which can lead to erosion, compact soil, and shift pest populations towards more heat-tolerant organisms [2]. Hot-water treatments may lead to water logging or "soupy" field conditions, rendering the treated area nonnavigable [78] [45]. The use of hot water for soil sterilization would also be hindered where there are water shortages [45].

Estimates are that hot-water treatments would be performed by commercial applicators at a total cost of between $1000 to $1500 per acre. These costs will vary depending on soil type, temperature, moisture, and depth [32].

*Greenhouse Production*

Greenhouse production may entail the use of artificial substrates such as rockwool, rock, clay granules and flexible polyurethane foam blocks. Tomatoes, strawberries, cucumbers, peppers, eggplants and some flowers can be grown using these substrates in a system that would not be reliant on methyl bromide for pest control. Capital costs are high, and the risk of water and/or heating system failure may result in substantial losses. Artificial substrate systems may also create substantial waste streams of substrates and plastics. Infestation of soilless media is also possible if proper sanitation procedures are not followed [6]. Greenhouse production has been successfully implemented in the Netherlands for strawberries, cucumbers, eggplants and melons. Costs include high capital startup costs, but operating costs are generally lower than conventional methods. Yields are generally doubled. Returns to growers are generally increased due to the ability to adjust production in response to market conditions to take advantage of high price market windows [76].

It is estimated that greenhouse production of strawberries would cost approximately $30,536 to $44,211 per acre, and cucumbers would cost $82,199 per acre, not including capital costs. Strawberry yields were estimated at between 40,610 and 80,298 lb/acre, for single- and double-crop systems, respectively. Cucumber yields were estimated at 605,804 lb/acre [76]. Florida greenhouse tomato total capital startup and production costs are estimated at $244,122 per acre per year, yielding 153 tons [79]. Greenhouse production of cucumbers in the San Joaquin Valley using bag culture costs an estimated $4630/1000 ft$^2$ of greenhouse and is anticipated to yield 450 15-lb boxes/1000 ft$^2$ [80].

*Botanical Extracts*

Several botanical extract products that may control the same diseases and weeds as methyl bromide have been developed, and some have recently obtained registration from the EPA. Some of the extracts are derived from pepper, mustard, cinnamon, neem and cloves, for example. Laboratory testing of several products, including clove oil, neem oil, a formulation of chili extract and essential oil of mustard, and an extract of cassia tree suggest that some of these materials may provide effective control of fusarium wilt [81]. Research is ongoing to investigate the effectiveness of these materials against verticillium wilt and evaluate potential phytotoxicity [82]. Initial research results suggest that a formulation of pepper and mustard oils may provide nematode control [83].

*Steam*

Steam has excellent distribution characteristics in soil and releases large quantities of heat after condensation. Upon cooling, water at 100°C releases only one-sixth the thermal energy of steam. Many systems have been devised to steam-disinfest planting beds including grids of buried perforated pipes that are either permanent or transportable, arrays of hollow spikes for steam injection, surface application under inverted pans or reinforced sheets or mobile rakes [45]. Steam technologies may be applied in greenhouse or small-field nursery settings. Steam machines built for field use can treat 1/4 acre per workshift [53]. Negative pressure steaming, which pulls steam down through the soil profile using buried pipes, allows treatment of soils to greater depths than surface applications. Steaming has the advantage of allowing growers to replant up to three weeks sooner, as there is usually no waiting period [76]. Steam heating of ground beds did not provide uniform soil heating and allowed the survival of soilborne pathogens in some areas [84]. Disadvantages of free-flowing steam include killing too much of the microflora because of the high temperature, increase in total soluble salts, and changes to the soil structure [78].

For steam to economically replace methyl bromide, sources of cheap energy and water must be available. The costs of steaming vary with the cost of energy, water cost and soil permeability.

*Biological Control*

Biological control involves using beneficial fungi and bacteria as antagonists to suppress soil pathogens. A number of soil amendments and other products containing antagonistic fungi such as *Trichoderma* and *Gliocladium*, or bacteria such as fluorescent pseudomonads, are commercially available [61]. Of the fungi used for control of soilborne pathogens, various species of Trichoderma have received the most attention. Although Trichoderma is ubiquitous, the type of soil can affect growth, proliferation and effectiveness as a biocontrol agent. Because soil ecology is complex, and since there are year-to-year fluctuations in climate and growth conditions, treatments with microbials are sometimes inconsistent [85]. Trichoderma has been used to protect greenhouse crops such as beans, peas, cucumbers and tomatoes from *Pythium, Rhizoctonia solani* and *Sclerotium rolfsii* [53]. A commercial form of *Gliocladium* has been registered in the U.S. for controlling damping-off and root rot pathogens of ornamental and food plants in nurseries and greenhouses, and registration is expected to be extended to open field use [63].

Preliminary research is underway to investigate soilborne organisms that affect strawberry yield and to identify biological pesticides that might be used in an integrated pest management system [74]. However, there are only a few instances of observed naturally occurring biological control of *Verticillium dahliae*, the major pathogen of concern in strawberry production [74]. Biological control agents have a narrow spectrum of pest control effectiveness and should not be viewed as a stand-alone replacement of methyl bromide. It is difficult to introduce a biological control agent and have it become dominant over a comparatively large pest population [86].

*Infrared Soil Treatment*

Infrared soil treatment uses specific infrared frequencies targeted to the molecular level, making energy transfers more effective and treatment cycles shorter than with microwave energy treatments. A prototype has been constructed and used to treat soil samples supplied by the U.S. Forest Service that were infested with three fungal organisms: Fusarium, Trichoderma and Pythium. The soil was spread out on a tray with a layer of between 1/8 and 1/4 in. thick. Six soil samples were treated at different time intervals then returned to the Forest Service for analysis of fungal survivial. The results are presented in Table 5.A.6.

Forest Service personnel plan to develop a machine capable of treating field soil, in cooperation with MITECH, the company that has developed the infrared technology. The machine will be mounted on a tractor, lifting soil up onto a conveyer belt for treatment as the machine passes over the field. Treatment to a depth of 10 in. is considered feasible. A commercial unit is expected to be able to treat 1 acre per hour. Estimated machinery costs and underlying assumptions are presented in Table 5.A.7.

**Table 5.A.6 Infrared Soil Treatment Test Results**

| Time (min:sec) | Fusarium (cfu/g) | Trichoderma (cfu/g) | Pythium (cfu/g) | Energy (Kw/m$^2$) |
|---|---|---|---|---|
| No Treatment | 274.3 | 68.2 | 13.7 | 28.8 |
| 0:20 | 136.2 | 408.6 | 0 | 28.8 |
| 0:23 | 205.9 | 0 | 0 | 28.8 |
| 0:24 | 68.1 | 68.1 | 0 | 28.8 |
| 0:27 | 0 | 0 | 0 | 28.8 |
| 0:55 | 0 | 0 | 0 | 28.8 |
| 1:06 | 0 | 0 | 0 | 28.8 |

Source: [87]

**Table 5.A.7 Per Acre Costs of Infrared Soil Treatment[1]**

| **Cost of Machinery** | **$30,000** | **$50,000** | **$100,000** |
|---|---|---|---|
| Interest Rate | 10% | 10% | 10% |
| Life of Machinery (years) | 10 | 10 | 10 |
| Cost per Month | $396.45 | $660.75 | 1,321.51 |
| Cost per Year | $4,757 | $7,929 | 15,858 |
| Acres/Hour | 1 | 1 | 1 |
| Acres/Year | 500 | 500 | 500 |
| **Capital Cost per Acre** | **$9.51** | **$15.86** | **$31.72** |
| Labor Cost per Hour | 15 | 15 | 15 |
| Number of Workers | 2 | 2 | 2 |
| Acres/Hour | 1 | 1 | 1 |
| **Labor Cost per Acre** | **$30.00** | **$30.00** | **$30.00** |
| Service Cost per Year | $5,000 | $5,000 | $5,000 |
| Acres/Year | 500 | 500 | 500 |
| **Service Cost per Acre** | **$10.00** | **$10.00** | **$10.00** |
| Kilowatts per Acre | 8,547 | 8,547 | 8,547 |
| Cost of Propane Gas/Kilowatt Hour | $0.02812 | $0.02812 | $0.02812 |
| **Energy Cost per Acre** | **$240.36** | **$240.36** | **$240.36** |
| **Total Cost per Acre** | **$289.87** | **$296.21** | **$312.07** |

Source: [42]

*Hot Water Dips*

Rooted cuttings of grapes and other plants infested with insects or pathogens can be disinfested by dipping the roots in hot water. A study in Japan on grapevine stocks infested with root attacking Phylloxera sp. insects found treatments with methyl bromide (3 h) versus hot water (20 minutes) produced comparable results [61].

*Plastic Barriers*

Polyethylene sleeves can protect young vines and trees from root-attacking insects such as grape phylloxera. In the former Soviet Union, rooted grapevine cuttings grown in 50 cm-long polyethylene sleeves and planted in the fall prevented infestation by phylloxera on grafted rootstocks and delayed infestation on ungrafted vines for up to nine years after planting [61].

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## 6. Methyl Bromide Usage Estimates

A profile of methyl bromide usage by crop was assembled from publicly available surveys, reports and expert opinions from Extension Service Specialists.

Because of full-use reporting requirements in California, all uses of methyl bromide have been tabulated in a statewide report, the latest being for 1995 [1]. Table 6.1 delineates the preplant usage of methyl bromide in California by crop as published by the state of California. As can be seen, there are several large subtotals that are not disaggregated by crop, such as "uncultivated agricultural areas (All or unspec.)" and "soil application , preplant – outdoor (seedbeds, etc.)." An examination of the detailed California usage file that contains the individual application records reveals that much of the unspecified methyl bromide usage is in three counties: Fresno, Madera and Tulare. The agricultural commissioners in these three counties were contacted and provided percentage estimates of the unspecified methyl bromide usage by crop. These percentages were used to distribute the estimates of unspecified methyl bromide usage in these counties to the individual crops identified by the county commissioners. Table 6.2 delineates the redistributed methyl bromide usage estimates for these three counties, disaggregated by crop.

In addition, treated acreage for perennial crops is known to be overstated in the California database due to the reporting of spot treatments on areas smaller than an area as treatments on full acres. In order to correct this overestimate of acres treated, estimates of treated acreage for perennial crops were calculated by dropping records for which application rates were less than 50 lb/acre. The results of that calculation are shown n Table 6.3.

USDA has released assessments of the usage of all pesticides in strawberry and tomato production by state. These reports contain estimates of the usage of individual pesticide active ingredients (including methyl bromide) by state. Tables 6.4 and 6.5 delineate the methyl bromide state usage estimates from the USDA reports for tomatoes and strawberries, respectively.

The USDA National Agricultural Statistics Service regularly surveys fruit and vegetable growers (in alternate years) regarding their pesticide usage. USDA publishes reports that delineate the usage of individual active ingredients by crop and state [4] [5]. NASS reports issued for 1992, 1994 and 1996 for vegetables and 1995 for fruits include estimates of methyl bromide usage for bell peppers, carrots, cucumbers, eggplant, grapes, lettuce, peaches, prunes, strawberries, tomatoes (fresh) and watermelons. These NASS estimates are displayed in Table 6.6.

For states not included in the NASS surveys, a search was made of Extension Service surveys of pesticide use for estimates of methyl bromide usage. Surveys in Arkansas for tomatoes and strawberries included methyl bromide usage estimates [8] [11]. These estimates are included in Table 6.7, which also includes methyl bromide usage estimates from five Extension Specialists who were contacted for their expert opinion regarding methyl bromide usage patterns.

For states for which published estimates and expert opinions were not available, methyl bromide usage estimates were assigned based on the values for a neighboring state. These estimates are also presented in Table 6.7.

Table 6.8 summarizes methyl bromide usage by crop. A separate tabulation has been made for California, including the detailed crop data from Table 6.1 supplemented by the estimated distribution by crop from Table 6.2. Although there still is an unspecified methyl bromide usage amount for California in Table 6.8, it is a considerably smaller value than the value published by the State of California.

The methyl bromide usage estimates for other states include the estimates from Tables 6.4–6.7. In those cases where duplicate values exist for a single crop and state, a single value was selected from Tables 6.4–6.7.

**Table 6.1. 1995 Preplant Methyl Bromide Use in California by Use Category[1]**

| Use Category | Treated Acres | MB Use (lbs.) |
|---|---|---|
| STRAWBERRY (ALL OR UNSPEC) | 19,469 | 4,228,963 |
| UNCULTIVATED AGRICULTURAL AREAS (ALL OR UNSPEC) | 5,278 | 1,516,409 |
| GRAPES, WINE | 3,125 | 1,190,499 |
| N-OUTDR CONTAINER/FLD GRWN PLANTS | 3,190 | 1,082,099 |
| SOIL APPLICATION, PREPLANT-OUTDOOR (SEEDBEDS,ETC.) | 3,584 | 1,034,183 |
| ALMOND | 4,648 | 930,929 |
| LETTUCE, HEAD (ALL OR UNSPEC) | 3,021 | 810,315 |
| CARROTS, GENERAL | 4,469 | 795,417 |
| GRAPES | 1,453 | 491,596 |
| N-OUTDR GRWN TRNSPLNT/PRPGTV MTRL | 1,977 | 522,701 |
| PEPPERS (FRUITING VEGETABLE), (BELL,CHILI, ETC.) | 2,485 | 484,994 |
| SWEET POTATO | 2,503 | 392,992 |
| N-OUTDR GRWN CUT FLWRS OR GREENS | 1,167 | 361,530 |
| PEACH | 1,300 | 364,225 |
| WATERMELONS | 1,628 | 307,686 |
| TOMATO | 1,823 | 247,919 |
| WALNUT (ENGLISH WALNUT, PERSIAN WALNUT) | 1,000 | 260,442 |
| N-GRNHS GRWN CUT FLWRS OR GREENS | 441 | 138,456 |
| PRUNE | 527 | 146,947 |
| LETTUCE, LEAF (ALL OR UNSPEC) | 498 | 125,574 |
| ORNAMENTAL TURF (ALL OR UNSPEC) | 211 | 77,601 |
| ASPARAGUS (SPEARS, FERNS, ETC.) | 189 | 74,957 |
| CANTALOUPE | 415 | 66,518 |
| LEMON | 165 | 58,550 |
| CHERRY | 187 | 62,466 |
| BROCCOLI | 174 | 50,647 |
| PEPPERS (CHILI TYPE) (FLAVORING AND SPICE CROP) | 320 | 48,435 |
| MELONS | 253 | 43,780 |
| CAULIFLOWER | 188 | 41,440 |
| ONION (DRY, SPANISH, WHITE, YELLOW, RED, ETC.) | 222 | 39,908 |
| NECTARINE | 128 | 37,288 |
| RASPBERRY (ALL OR UNSPEC) | 103 | 25,565 |
| CELERY, GENERAL | 100 | 20,858 |
| ORANGE (ALL OR UNSPEC) | 36 | 14,242 |
| UNCULTIVATED NON-AG AREAS (ALL OR UNSPEC) | 36 | 13,743 |
| EGGPLANT (ORIENTAL EGGPLANT) | 47 | 10,862 |
| N-GRNHS GRWN PLANTS IN CONTAINERS | 35 | 10,208 |
| APPLE | 32 | 10,228 |
| BEANS, DRIED-TYPE | 20 | 8,663 |
| CITRUS FRUITS (ALL OR UNSPEC) | 19 | 7,966 |
| GRAPEFRUIT | 20 | 7,883 |

| | | |
|---|---|---|
| ONIONS (GREEN) | 21 | 5,424 |
| PLUM (INCLUDES WILD PLUMS FOR HUMAN CONSUMPTION) | 16 | 5,365 |
| RYE (ALL OR UNSPEC) | 43 | 5,345 |
| BRUSSELS SPROUTS | 16 | 3,832 |
| CHRISTMAS TREE PLANTATIONS | 13 | 3,348 |
| FUMIGATION, OTHER | 10 | 3,119 |
| BEANS (ALL OR UNSPEC) | 11 | 2,814 |
| AVOCADO (ALL OR UNSPEC) | 5 | 1,960 |
| RESEARCH COMMODITY | 6 | 1,805 |
| ALFALFA (FORAGE - FODDER) (ALFALFA HAY) | 15 | 1,648 |
| VEGETABLES (ALL OR UNSPEC) | 4 | 1,401 |
| CABBAGE | 5 | 1,260 |
| APRICOT | 16 | 960 |
| PUMPKIN | 5 | 690 |
| CORN, HUMAN CONSUMPTION | 3 | 597 |
| N-GRNHS GRWN TRNSPLNT/PRPGTV MTRL | 3 | 535 |
| KIWI FRUIT | 1 | 400 |
| GREENHOUSES (EMPTY) (ENVIRONS, BENCHES, ETC.) | 1 | 395 |
| PEAR | 0 | 369 |
| LANDSCAPE MAINTENANCE | 1 | 257 |
| SQUASH (ALL OR UNSPEC) | 2 | 235 |
| COMMODITY FUMIGATION | 2 | 223 |
| FLAVORING AND SPICE CROPS (ALL OR UNSPEC) | 1 | 49 |
| FRUITS (DRIED OR DEHYDRATED) | 0 | 23 |

[1] Preplant use assumed if treated units were reported as acres or square feet. Records with application rates greater than 1000 lb/acre not included. Records with application rates less than 50 lb/acre were assumed to be spot treatments and were adjusted to make treated acres equal to zero.

Source: [1]

**Table 6.2. Estimated Distribution of Unspecified Methyl Bromide Usage in California**

| | County | | | |
|---|---|---|---|---|
| Crop | Fresno | Madera | Tulare | Total |
| Almonds | | 139,434 | | 139,434 |
| Grapes | 250,455 | 257,743 | 320,377 | 828,575 |
| Nectarines | 380,691 | | 128,153 | 508,844 |
| Plum/Prunes | 250,455 | 25,353 | 85,435 | 361,243 |
| Peaches | 120,219 | | 35,597 | 155,816 |
| Strawberries | | | 106,793 | 106,793 |
| Other | | | 35,596 | 35,596 |
| Total | 1,001,820 | 422,530 | 711,951 | 2,136,301 |

Estimated based on percentages provided by the County Agricultural Comissioners.

**TABLE 6.3**
**Methyl Bromide Use: California Orchard Crops (1995)**

| | Acreage Treated | | Lbs/Yr | Lbs AI/A |
|---|---|---|---|---|
| | 1995 Report | Adjusted | Adjusted | Adjusted |
| Almonds | 22,822 | 4,648 | 854,085 | 184 |
| Apples | 123 | 32 | 10,202 | 318 |
| Apricots | 16 | 16 | 960 | 60 |
| Cherries | 873 | 187 | 59,616 | 319 |
| Citrus | 304 | 240 | 88,641 | 369 |
| Grapes | 4,963 | 4,608 | 1,725,410 | 374 |
| Nectarines | 152 | 128 | 37,140 | 290 |
| Peaches | 4,426 | 1,300 | 339,628 | 261 |
| Plums | 18 | 16 | 5,360 | 335 |
| Prunes | 5,256 | 527 | 125,774 | 239 |
| Walnuts | 8,580 | 1,000 | 229,788 | 230 |

The adjustment was made by examining the individual use records for 1995 and excluding records for which the application rate per treated acre was less than 50 pounds active ingredient (AI).

**Table 6.4. NAPIAP Estimates of Methyl Bromide Use in Fresh Tomato Production 1993**

| State | LB AI/A | Acres Treated % | Acres Treated # | MB use (1000 lbs.) |
|---|---|---|---|---|
| Alabama | 350 | 50 | 2,500 | 875 |
| California | 350 | 2 | 570 | 200 |
| Florida | 191 | 98 | 51,783 | 9,891 |
| Georgia | 250 | 100 | 2,940 | 735 |
| Indiana | 350 | 5 | 67 | 23 |
| Maryland | 300 | 25 | 695 | 209 |
| New Jersey | 350 | 5 | 242 | 85 |
| Ohio | 420 | 10 | 296 | 124 |
| South Carolina | 196 | 99 | 3,564 | 699 |
| Tennessee | 117 | 40 | 1,760 | 206 |
| Virginia | 350 | 90 | 2,898 | 1,014 |

Source: [2]

**Table 6.5. NAPIAP Estimates of Methyl Bromide Use in Fresh Strawberry Production 1994**

| State | Lb AI/A | Acres Treated % | Acres Treated # | MB Use (1,000 lbs.) |
|---|---|---|---|---|
| California | 318 | 91 | 20,839 | 6,627 |
| Florida | 294 | 99 | 5,366 | 1,578 |
| Michigan | 300 | 10 | 200 | 60 |
| North Carolina | 281 | 32 | 730 | 205 |
| New York | 300 | 5 | 140 | 42 |
| Ohio | 315 | 55 | 627 | 198 |
| Oregon | 300 | 10 | 594 | 178 |
| Pennsylvania | 312 | 10 | 156 | 49 |
| Washington | 316 | 5 | 78 | 25 |
| Wisconsin | 325 | 15 | 171 | 56 |

Source: [3]

Table 6.6. NASS Estimates of Methyl Bromide Use by State and Crop

| Crop | State | Year | LB AI/A | Acres Planted | Acres Treated # | MB Use (1,000 lbs.) |
|---|---|---|---|---|---|---|
| Bell Peppers | California | 1994 | 214 | 19,000 | 380 | 64 |
| | Florida | 1992 | 163 | 19,900 | 16,517 | 2,833 |
| | | 1994 | 189 | 22,100 | 18,343 | 3,477 |
| | | 1996 | 175 | 21,300 | 19,383 | 3,396 |
| | North Carolina | 1994 | 142 | 7,000 | 420 | 60 |
| Carrots | California | 1994 | 188 | 100,700 | 6,042 | 680 |
| | | 1996 | 186 | 70,400 | 2,816 | 561 |
| Cucumbers | Florida | 1992 | 180 | 17,600 | 2,288 | 418 |
| | | 1994 | 188 | 13,300 | 1,330 | 259 |
| | North Carolina | 1994 | 146 | 6,000 | 300 | 47 |
| Eggplant | Florida | 1992 | 166 | 2,500 | 725 | 120 |
| | | 1994 | 158 | 2,500 | 1,050 | 167 |
| | | 1996 | 186 | 1,700 | 1,292 | 242 |
| | New Jersey | 1992 | 134 | 1,000 | 70 | 9 |
| Grapes | California | 1995 | 358 | 796,400 | * | 342 |
| Lettuce | California | 1992 | 156 | 144,000 | 1,440 | 125 |
| Peaches | California | 1995 | 253 | 72,600 | 1,452 | 523 |
| Prunes | California | 1995 | 209 | 93,800 | 938 | 141 |
| Strawberries | California | 1992 | 164 | 23,400 | 19,890 | 4,029 |
| | | 1994 | 212 | 23,300 | 21,203 | 4,488 |
| | | 1996 | 211 | 25,200 | 23,184 | 4,859 |
| | Florida | 1992 | 196 | 4,700 | 4,277 | 845 |
| | | 1994 | 196 | 5,800 | 5,626 | 1,107 |
| | | 1996 | 207 | 6,000 | 5,940 | 1,231 |
| | North Carolina | 1992 | 170 | 2,400 | 408 | 70 |
| | | 1994 | 182 | 2,500 | 900 | 165 |
| | | 1996 | 158 | 2,400 | 1,224 | 193 |
| Tomatoes (Fresh) | California | 1994 | 117 | 36,500 | 5,110 | 628 |
| | Florida | 1992 | 163 | 49,400 | 45,942 | 7,913 |
| | | 1994 | 183 | 47,900 | 45,026 | 8,228 |
| | | 1996 | 142 | 40,000 | 37,600 | 5,346 |
| | North Carolina | 1992 | 84 | 1,600 | 496 | 42 |
| | | 1994 | 126 | 1,700 | 170 | 21 |
| | | 1996 | 121 | 1,600 | 1,120 | 136 |
| Watermelons | Florida | 1994 | 124 | 40,000 | 1,200 | 170 |
| | North Carolina | 1994 | 193 | 9,500 | 190 | 42 |
| | | 1996 | 195 | 10,400 | 312 | 67 |

Sources: [4] [5]

* less than 1%

**Table 6.7. Preplant Methyl Bromide Usage: Other States**

| | | Acres Planted | % Treated | Rate Lb AI/A | 1,000 lbs AI/y Total | Source |
|---|---|---|---|---|---|---|
| Cucumbers | Georgia | 8000 | 9 | 188 | 135 | [*] |
| Peppers | Alabama | 250 | 91 | 175 | 40 | [*] |
| | Georgia | 3700 | 91 | 175 | 589 | [*] |
| | S.Carolina | 200 | 6 | 142 | 2 | [*] |
| Tomatoes | Arkansas | 900 | 46 | 200 | 83 | [8] |
| Strawberries | Arkansas | 170 | 23 | 240 | 9 | [11] |
| | Connecticut | 300 | 5 | 200 | 3 | [*] |
| | Illinois | 500 | 15 | 325 | 24 | [*] |
| | Indiana | 700 | 10 | 200 | 14 | [*] |
| | Kentucky | 250 | 23 | 170 | 10 | [*] |
| | Maryland | 400 | 10 | 312 | 12 | [*] |
| | Massachusetts | 400 | 5 | 200 | 4 | [*] |
| | Minnesota | 700 | 15 | 352 | 37 | [*] |
| | Missouri | 250 | 23 | 170 | 10 | [*] |
| | New Jersey | 500 | 10 | 312 | 16 | [*] |
| | S. Carolina | 200 | 32 | 281 | 18 | [*] |
| | Virginia | 500 | 10 | 312 | 16 | [*] |
| | Tennessee | 650 | 33 | 281 | 60 | [6] |
| Tomatoes | Pennsylvania | 5000 | 40 | 300 | 600 | [7] |
| Peppers | Pennsylvania | 900 | 25 | 175 | 39 | [7] |
| | Louisianna | 625 | 75 | 175 | 82 | [12] |
| Tobacco | Kentucky | 268000 | 1 | 119 | 319 | [9] |
| | N.Carolina | 284000 | 1 | 119 | 338 | [10] |

* Assigned

**Table 6.8. Preplant Methyl Bromide Usage Summary by Crop (1,000 lbs AI/y)**

| | California | Other States | Total |
|---|---|---|---|
| Almonds | 1070 | - | 1,070 |
| Apples | 10 | - | 10 |
| Apricots | 1 | - | 1 |
| Asparagus | 75 | - | 75 |
| Avocados | 2 | - | 2 |
| Broccoli | 50 | - | 50 |
| Brussel Sprouts | 4 | - | 4 |
| Cantaloupes | 66 | - | 66 |
| Cau1iflower | 41 | - | 41 |
| Carrots | 795 | - | 795 |
| Cherries | 62 | - | 62 |
| Citrus | 89 | - | 89 |
| Cucumbers | - | 441 | 441 |
| Eggplant | 11 | 251 | 262 |
| Grapes | 2,511 | - | 2,511 |
| Lettuce | 936 | - | 936 |
| Nectarines | 546 | - | 546 |
| Nurseries | 2,115 | - | 2,115 |
| Onions | 45 | - | 45 |
| Peaches | 520 | - | 520 |
| Peppers | 533 | 4,208 | 4,741 |
| Plums/Prunes | 513 | - | 513 |
| Raspberries | 26 | - | 26 |
| Strawberries | 4,336 | 2,265 | 6,601 |
| Sweet Potatoes | 393 | - | 393 |
| Tobacco | - | 657 | 657 |
| Tomatoes | 248 | 10,135 | 10,383 |
| Walnuts | 260 | - | 260 |
| Watermelons | 308 | 237 | 545 |
| Other | 639 | - | 639 |
| Total | 16,205 | 18,194 | 34,399 |

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## 7. **Economic Analysis**

### A. Horticultural Economic Model

Methyl bromide is used on a wide variety of crops in the United States. As an agricultural fumigant that controls nematodes, weeds, fungi and other soilborne pathogens, methyl bromide has been incorporated as an essential component in production practices for many annual crops. Methyl bromide use on tomatoes, strawberries, peppers, watermelon, cucumber, squash and eggplant accounts for over 60% of the total U.S. preplant use, either directly or in a double crop rotation production system. These crops are grown with methyl bromide primarily by horticulturists in California and Florida with some production in South Carolina, and Georgia. Their primary competition during different periods of the year comes from three states of Mexico (Baja California, Sinaloa, and Sonora), Texas, and non–methyl bromide using regions in the California, South Carolina, North Carolina and Georgia. The ban on methyl bromide will force many U.S. growers to change their production technology. Sunding et al. estimate the losses to California agriculture to be $162 million [30]. Deepak et al. estimate that Florida revenues for seven crops will decline 54%, from $1.144 billion to $524 million [31]. Growers will save some costs as well; consequently, the overall net losses would be lower. Deepak et al. found that most of the lost revenue in Florida will be gained by Mexico, whose revenue is projected to increase by 65% [31].

The annual horticultural market,[1] including those regions that are methyl bromide users (California, Florida, South Carolina, and Georgia) as well as their direct competitors (Mexico, Texas), are modeled as a spatial partial-equilibrium problem. The calculations include baseline equilibrium production, monthly shipments between production areas and markets, and monthly consumption in each

[1]Perennial crops are treated in another section of this report.

representative market (Atlanta, Chicago, New York and Los Angeles) in each month given current technology. Equilibrium crop prices for each market for each month are also computed. A ban on methyl bromide is introduced, resulting in a shift of production technology, which changes the cost of growing the crop and the expected monthly yield. A determination has been made of the one best alternative technology by crop and by region. These alternatives are presented in Table 7.1 for the crops that currently use methyl bromide.[2] The changes in costs are presented in Table 7.2 and the changes in yields in Table 7.3. Alternative technologies were determined through published scholarly journal articles, as well as interviews with growers, scientists, and farm advisors. The best alternative technology is defined as the one with the lowest per-unit cost (highest yield per acre for the lowest cost per acre). Using the new costs and yields, the changes in crop production, shipments and consumption levels are calculated for each region and market. Data for individual growers are not available, precluding an economic regression approach. Therefore, a simulation approach has been utilized.

The model uses data on each region's crops, yields, constraints, and marketing windows to determine in which region or regions and using which production systems growers will achieve the most profit from producing each crop in each month up to the point where the growers have used all the available land. The model has growers choosing which of the four demand market areas to ship their crops to, given the different market prices and the transportation costs to each market. For example, the Chicago market may offer a higher price per ton for Florida eggplant than the Atlanta market, but the price difference must be sufficient to cover the increased transportation costs. The market price is a function of the level of shipments that enter a particular market in a particular month.

Crop production follows a putty-clay model with fixed proportions technology or, as it is often called, a linear response and plateau (LRP) formulation to generate supply by region. This type of supply curve is depicted in Figure 7.1. For a given cost in a given region, a grower can achieve a given yield per

[2]The determination of these alternatives has been discussed in detail in the individual crop sections of this report.

acre. For example, in Region 1 of Figure 7.1, the grower spends $200 per ton and can produce up to 125 tons. The grower in Region 2 must spend $320 per ton and can produce up to 80 tons. This results in the plateau appearance of the supply curve. (Each horizontal segment of the supply curve reflects one region's production.) Berck and Helfand demonstrate that the LRP or von Liebig model performs well [32]. The von Liebig functional form assumes that the plant responds linearly to the addition of a limiting input until a different input becomes limiting. Although this function does not allow perfect substitution between inputs, i.e., the plant needs a combination of inputs to grow, it has been shown that a smooth crop production function can be derived from the LRP form by aggregating the effects of heterogenous inputs. Lanzer and Paris have also demonstrated the validity of the fixed proportions assumption for fertilizers [33]. The costs of production were derived from budgets developed by the states for the relevant regions for the 1993–96 crop years. More details are presented in the Empirical Specification section.

Yields are determined for production using methyl bromide and then for production using one of the alternative technologies. The yields are assumed to be nonstochastic. While per-acre yields for fruit and vegetables vary from year to year, several technologies are included that are not being used currently in most regions; thus it was not possible to obtain time-series data on the yields.

A regionally disaggregated model is used. The costs to producers of the methyl bromide ban may vary among regions. This heterogeneity implies a need to use regionally disaggregated models in which the regions correspond to the geographic and other differences that exist. Pesticide use patterns vary across regions in response to both economic and environmental conditions, such as pest problems or climatic conditions. The costs and effectiveness of the technologies are allowed to vary by region so that one region may use more methyl bromide than another or may apply methyl bromide using a different technology.

The model seeks to maximize producers' returns and consumers' benefits while taking into account the constraint on the amount of land available in each region and that the amount sold to consumers cannot be greater than the amount supplied. The model can be represented by the following maximization equation:

$$
\begin{aligned}
Max \quad & \sum_{i=1}^{I}\sum_{k=1}^{K}\sum_{t=1}^{T}(a_{ikt}Q_{ikt} - 1/2 b_{ikt}Q_{ikt}^{2}) - \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{h=1}^{H} l_{ijh}\cdot pc_{ijh} - \\
& \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{t=1}^{T} Y_{ijt}\cdot hc_{ij} - \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{t=1}^{T} X_{ijkt}\cdot tc_{ijk} \\
s.t. \quad & L_{ij}(1+.10) \geq \sum_{h=1}^{H} l_{ijh} \\
& Y_{ijt} \leq \sum_{h=1}^{H} l_{ijh}\cdot y_{ijht} \\
& Y_{ijt} \geq \sum_{k=1}^{K} X_{ijkt} \\
& Q_{ikt} \leq \sum_{j=1}^{J} X_{ijkt} \\
& Y_{ijt}, X_{ijkt}, Q_{ikt}, l_{ijh} \geq 0.
\end{aligned} \qquad \textbf{(2)}
$$

The model computes the equilibrium levels of supply for each crop in each region in each month, $Y_{ijt}$, the quantity shipped of each crop from each region to each market in each month, $X_{ijkt}$, the quantity consumed in each market of each crop in each month, $Q_{ikt}$, as well as the number of acres in each crop in each region in each production system, $l_{ijh}$.

We use the following indices:

Regions: $j = 1, \ldots J_1$: index the 13 production regions in the United States.
$j = J_1 + 1, \ldots J_{tot}$ : index the two production regions in Mexico.
Crops: $i = 1 \ldots I$ : index the seven crops being considered.
Markets: $k = 1 \ldots K$: index the four market centers.
Production systems: $h = 1 \ldots H$: index the 23 production systems.
Time: $t=1, \ldots T$: index the 12 months when the crop may be sold.

*Demand*

The demand for these crops is divided into four different markets. The inverse demand curve is represented for the markets as $P_{ikt} = a_{ikt} - b_{ikt} Q_{ikt}$ where $P_{ikt}$ is the wholesale price per ton for crop $i$ in market $k$ in month $t$, $Q_{ikt}$ is the quantity of tons of crop $i$ that is sold in market $k$ in month $t$, $a_{ikt}$ is the demand curve's intercept, $b_{ikt}$ represents the slope of the demand function. This formulation assumes that the slope of the demand function is constant over all quantities. An example of the demand curve is presented in Figure 7.1. The assumption is made that each region's production is a perfect substitute for that of any other region. The model assumes that the price of each commodity is a function of its own quantity alone; that is, $Q_{ikt}$ is the total quantity demanded as a function of $P_{ikt}$, the per-unit price for the $i^{th}$ crop in the $k^{th}$ market in the $t^{th}$ month, and the price is not affected by other crop prices and quantities that may be sold in that market in that month. If this simplification was not assumed, the integrability problem addressed by McCarl and Spreen [35] and Peters and Spreen [36] would become an issue.

*Supply*

Crops are produced with fixed proportion production functions, assuming that all producers in a particular region use the same production technology and, therefore, will have the same yields and costs. In addition, production systems have been included that allow producers to plant double crops, such as tomatoes followed by cucumbers, on their acreage. The yield, $y_{ijht}$, is the per-acre yield in crop $i$ in month $t$ in region $j$ for production system $h$. The planted acreage, $l_{ijh}$, is the number of acres planted in a particular crop in a region in a production system and the maximum possible acreage for each crop in each region is set as a percentage of $L_{ij}$. The actual monthly production then, $l_{ijh} * y_{ijht}$, is the number of acres planted in crop $i$ in region $j$ in production system $h$, multiplied by the per-acre monthly yield. The total production regardless of production system is represented by $Y_{ijt}$, the yield per acre of crop $i$ in region $j$, multiplied by the number of acres planted in that crop in that region added up over all possible production systems $h$.

The preharvest cost per acre of crop $i$ in region $j$ for production system $h$ equals $pc_{ijh}$, and the preharvest production costs for all acreage planted for a particular crop is $pc_{ijh}* l_{ijh}$. The other costs, including harvesting, packing, hauling, grading, cooling, tariffs, etc., equal $hc_{ij}$, which is the per-ton cost per crop per region. Because harvest costs do not vary by month, the total harvest and postharvest costs are represented by $hc_{ij}* Y_{ijt}$ for crop $i$ in region $j$ in month $t$. The final cost incurred, $tc_{ijk}$, is the transportation cost per ton from the region $j$ to the demand market $k$. Then, because transportation costs also do not vary by month, $X_{ijkt}$, the total shipments of crop $i$ from region $j$ to market $k$ in month $t$, the total cost of transport per month equals $tc_{ijk.}*X_{ijkt}$ for crop $i$ from region $j$ to market $k$ in month $t$.

*Constraints*

To compute the baseline and then the impact of a methyl bromide ban, the model employs two land constraints. First, the model is constrained so that all planted acreage does not exceed the land available for that crop in that region by 10 % for the baseline. This constraint is binding in only one case (California Central Coast Tomatoes). (See Table 7.14.) When we computed the impact of a methyl bromide ban, we relaxed the constraint so that any region can increase its acreage in a crop by 50 % of the three-year average of the reported harvested acres.

In some areas, land is very scarce, is of limited fertility, or has a high opportunity cost (for example, it can be sold for residential development), and this constraint may actually be too lax, i.e., in the short run growers cannot expand acreage by 50 %. In others, this constraint can represent the potential need for pre- and postharvest resources such as cooling facilities, labor or expertise on growing the crop.

Also, there is competition from horticultural growers who do not use methyl bromide and will see relative profitability increase. Restructuring of the horticultural sector in Mexico, as well as the elimination of many trade barriers with Mexico and other countries, has been challenging U.S. horticultural growers in recent years. These other countries may be able to enter the market, which might keep existing regions from expanding.

Land constraints are imposed for the following reasons: California growers confront pressure from other crops, residential development, and the need to have rights to water for irrigation which are often attached to the deed for a piece of land. Florida growers also face residential development pressure. In addition, they have been challenged with environmental regulations, especially in Dade County due to water quality concerns with regard to the Everglades. Therefore, some land previously available for agriculture has been removed from production.

In Mexico, Baja California has very limited arable land upon which to expand, mainly due to limited water availability and a ban on establishing new groundwater wells. In fact, some of the land currently in production faces problems with salinity in the groundwater, which is very detrimental to strawberries. Sinaloa, on the other hand, has a great deal of available land, which in the last decade under Mexican government programs, many Sinaloa growers have planted in grains. These programs and the connected subsidies are being discontinued or greatly reduced. In addition, legislative changes have made it possible for land in community ownership to be rented or sold, which has made more land available for horticultural production. Thus in the long run, Sinaloa growers may be able to expand acreage into vegetable production by more than 50 %.

The other standard constraints are also imposed. That is, $Y_{ijt}$, the quantity available to sell, from any region in any month, cannot exceed the sum of all the acreage in each crop multiplied by the yield per acre in that month in that region; $X_{ijkt}$, the quantity of crop $i$ shipped from region $j$ in month $t$ to all markets, cannot exceed the amount available to sell, $Y_{ijt}$. $Q_{ikt}$, the quantity demanded of crop $i$ in market $k$ in month $t$, cannot exceed the amount shipped from all production regions during that month, $X_{ijkt}$. All variables are assumed to be nonnegative.

## B. Empirical Specification

The analysis of the annual horticultural market includes seven crops: fresh market tomatoes, strawberries, peppers, watermelon, cucumbers, squash and eggplant. Some growers of these crops use methyl bromide as a preplant fumigant to control nematodes, weeds and soilborne pathogens. Strawberries and tomatoes alone account for approximately 40% of total preplant use of methyl bromide in the U.S. Cucumbers and squash are included in the model to reflect the impact that the ban will have on double-crop production systems in Florida, where these crops commonly follow tomatoes or peppers. These second crops are planted into the same plastic mulches and thus benefit from the fumigation of the first crops. The EPA has not labeled methyl bromide for direct use on cucumbers or squash. Watermelon is included both as a crop that is fumigated and as a second crop. Methyl bromide is labeled for use on watermelon only in Florida and California. While total use of methyl bromide in eggplant production is lower than for some crops not included in this model, it is included due to the concentration of production in Florida and increased competition with Mexican producers in recent years.

Several factors were considered to determine which production areas would be included in the model. First, an identification was made of the production regions where preplant fumigation with methyl bromide is a common cultural practice. Next, in order to determine which non–methyl bromide using production areas would be included to account for competition, monthly shipments data were reviewed [1]. In general, a region is included if in any one month it shipped at least 5% of the U.S. total shipments for that commodity.[1] In the "market windows" that they supply, the regions included in the model make up three-quarters or more of the market.

Determining if other regions could enter the markets following the ban is difficult. The horticultural industry has changed dramatically, with more products being distributed by integrated growers/shippers. Many buyers now want guaranteed year-round supply from a shipper. Therefore even with the change in cost structure that will arise following the ban on methyl bromide, whether other states can enter certain market windows is not clear. There is some possibility of increased competition from other regions such as Central America, the Caribbean, and Chile, but in this model supply increases from these regions are not considered.

California, Florida and Mexico are divided into regions because of differences in production practices and harvest dates. Production areas included in this model are four regions in California: South Coast, Central Coast, Imperial Valley and San Joaquin Valley. The five regions in Florida are West and North, Central, Southeast, Southwest and Dade County. The two regions in Mexico are Sinaloa and Baja California/Sonora. North Carolina, South Carolina, Georgia and Texas are included as individual regions. The division of California, Florida and Mexico into production regions is shown in Figures 7.2–7.4.

Estimates of harvested acreage for the crops and regions included in the model were obtained from various sources. Three-year averages are used for crop years 1993–94 through 1995–96 to ensure that the baseline reflects the most current available data. Given the nonstochastic nature of the parameters, averages are used to ensure no one “good” or “bad” year dominates the results. The Florida Agricultural Statistics Service (FASS) publishes production statistics by growing region for various crops [2]. In some instances, however, the regions used in this analysis differ from those used by FASS.

[1] Excluded regions are watermelon: Arizona, Indiana and Missouri ; cucumbers: Michigan, New York, Texas and Virginia; eggplant: North Carolina; peppers:

Therefore, the FASS data were modified using the best available information on yields and location of production [11] [22]. For California, information on watermelon and fresh tomato acreage by county was obtained from the California Agricultural Statistics Service [3]. If tomato data did not specify whether it was grown for the fresh or processing market, the county agricultural commissioners' offices were contacted to obtain this information. A small amount of crop acreage that was reported without indication of the county of production (less than 1%) was excluded. California strawberry acreage statistics were provided by the California Strawberry Commission [4]. For the other states, the state agricultural statistics services provided the data [5] [6] [7] [8].

Data on vegetable imports from Mexico were obtained from USDA Animal and Plant Health Inspection Service [9]. Monthly imports by port are averaged over the three-year period considered here. Imports through Nogales are assumed to be from the Sinaloa production region. Baja and Sonora are assumed to ship through San Diego, Calexico and San Luis. Harvested acres for Sinaloa were obtained from CAADES [37]. Average actual yields by state for strawberries, tomatoes, cucumbers, eggplant, peppers, squash, and watermelon were obtained from Mexican Department of Agriculture statistics [10] and from CAADES [37]. The harvested acres for export for Baja and Sonora are derived from Cook et al., a Sonoran growers' association, and the Mexican Department of Agriculture statistics [10] [28] [38]. Average acreages by region are shown in Table 7.15.

*Demand Specification*

To compute the inverse demand function, we utilize demand flexibilities [11] [27], wholesale prices, and arrivals data [12] [13] [14] [15] [16] for the various crops.

The flexibilities are based on an inverse Rotterdam model of four terminal markets. Scott calculated flexibilities for tomatoes, bell peppers, and cucumbers [27]. Spreen et al.

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Michigan and Virginia; squash: North Carolina; tomatoes: Virginia.

calculated flexibilities for squash, eggplant, watermelon, and strawberries [11]. These estimated demand flexibilities are presented in Table 7.7. The size of the estimated flexibilities suggests that demand for horticultural crops is relatively elastic. There is some ad hoc evidence, however, that demand for horticultural products is not relatively elastic. For example, in 1997, California strawberry producers experienced significantly lower yields due to climatic conditions (60% of normal yields). Yet they did not suffer from reduced revenues, due to price increases. Similarly, winter tomato producers have seen record earnings in years with severe weather problems and decreased yields. While in theory these demand flexibilities may produce conservative estimates of the actual price increases, the slopes computed result in estimated price changes of -33 to 35% after a methyl bromide ban is introduced.

Wholesale prices for four representative markets—Atlanta, Chicago, Los Angeles and New York—were obtained from the USDA Agricultural Marketing Service, which publishes high and low prices for each Monday [13] [14] [15] [16]. These prices were used to create average monthly prices over the three-year period from October 1993 to September 1996. Average monthly wholesale prices by market are given in Table 7.8. These prices were used to calibrate the model.

Annual arrivals data were provided by the Agricultural Marketing Service [12] [13] [14] [15] [16]. These data were used to create average monthly arrivals over the same three-year period. The slope of the total demand curve for each of the representative markets was calculated from the arrivals data. However, the arrivals data reflect only the quantity arriving directly into these four markets of the total of 16 major wholesale markets in the U.S. Thus, although these data are accurate in determining the relationship between quantity and price (the slope), they cannot be used to determine the intercept of the demand curves. For the intercept calculation, the total demand in a geographic area is needed, not just the actual arrivals into the representative regional market. Therefore, before the intercept was calculated, the arrivals data were adjusted to reflect the total demand in the market area. To determine the total demand (or total consumption of any crop) equal to total production, shipments data from all of the regions were added together. Air shipments are not included in these computations except in the case of Baja strawberries. To have a method of weighting the data, each of the four market's share of the sum of total arrivals was calculated. These percentages were used to divide the total shipments between the four markets. Thus, the division of market demand incorporates the current quantity demanded in the representative markets with the total shipments of these crops. The resulting estimates of demand by market are presented in Table 7.9.

Using this information, the parameters for the slope and intercept can be calculated. The price is a function of the quantity demanded. Thus, $P_{ikt} = a_{ikt} - b_{ikt} Q_{ikt}$. The equation defining the price flexibility for the $i^{th}$ crop in market $k$ in month $t$ is the following:

$\eta_{ikt} = (\delta P_{ikt} / \delta Q_{ikt}) * (Q_{ikt} / P_{ikt})$.

The slope of the demand equation is $-b_{ikt} = \delta P_{ikt} / \delta Q_{ikt}$ ;

Therefore, $-b = \eta_{ikt} (P_{ikt} / Q_{ikt})$.

Once $b_{ikt}$ has been calculated, one can estimate $a_{ikt} = P_{ikt} + b_{ikt} Q_{ikt}$. Thus, there is an inverse demand function for each crop in each month in each market area, which has the price as a function of the level of quantity shipped to these markets in each month.

*Transportation Costs*

Transportation costs were calculated using distances from production regions to markets as measured by Mapquest [17]. Distances were calculated assuming production from the San Joaquin Valley were shipped from Fresno, Central Coast from Salinas, South Coast from Los Angeles, Imperial Valley from Palm Springs, West and North Florida from Wildwood, Central Florida from Tampa, Southwest from Sarasota, Southeast from Palm Beach, Dade County from Miami, Georgia from Atlanta, Baja from San Diego, Sinaloa from Nogales, North Carolina from Charlotte, South Carolina from Charleston and Texas from McAllen. Distances between shipping points and wholesale markets are presented in Table 7.10. An average per-mile transportation cost of $1.31 was calculated using information from the USDA Agricultural Marketing Service [18]. These costs include truck brokers' fees for shipments in truckload volume to a single destination, based on costs of shipping from origin to destination, and do not include any costs of returning the truck to the origin.  A truck was assumed to carry 20 tons.  Average per-ton transportation costs are presented in Table 7.11.

*Production Costs*

Costs of production for current cultural practices were derived from budgets published by extension agents in the respective states [19] [20] [21] [22] [23] [24] [25] [26]. Information on costs of production for Mexican growers were calculated based on CAADES budgets with incorporation of certain costs from Cook et al., Van Sickle et al., and a Sonoran grower association [37] [38] [39] [28].  Where budgets were not available for a particular region, information about production practices and other issues affecting costs were used to derive estimates of costs.  These preharvest production costs are presented in Table 7.12.

Harvest costs were also derived from the extension budgets.  These costs include harvesting, cooling, packing, transportation to shipment point, and marketing costs. These costs for Mexico also include transportation to the U.S. border as well as all tariffs and fees to import the crop.  Harvest and postharvest production costs are presented in Table 7.13.

Estimates of yields for the crops and regions included in the model were obtained from state statistical services and averaged over the three crop years 1993–94 through 1995–96.  Because of the nature of the model, yields do not vary in the same region.  This assumes that in any area, all the producers follow the same production practice, i.e., either 100% of the growers in an area use methyl bromide on an annual basis for the given production costs, or no one uses it.

Information on monthly shipments by origin, available from the USDA Agricultural Marketing Service [1], in addition to information on harvest dates, were used to divide annual yields per acre for the various production regions into proportional monthly yield estimates. It is assumed that the crop is harvested over several months. This permits both staggered planting dates and staggered harvesting schedules without explicitly including them in the model. The percent of the annual yield produced each month for production regions in Florida were modified from those in Spreen et al. [11] and production statistics and harvest date information from FASS [2]. For Mexico, the data on monthly imports were used to determine the percent distribution of the yields [9]. For all other regions, shipments data were used to determine the percent distribution of the yields by month.

Annual per-acre yields are shown in Table 7.4. The monthly distribution of yields is shown in Table 7.5. Monthly shipments by production region are given for each crop in Table 7.6.

*Methyl Bromide Use Patterns and Best Alternative Estimation*

It is difficult to get exact figures on how much methyl bromide is used.[2] While the majority of growers follow a prescribed amount, some growers alter the quantities or choose to do bed fumigation instead of field fumigation, which requires less fumigant per acre. After interviews with extension personnel, growers, farm advisors and chemical distributors, the amount of methyl bromide used in standard cultural practices for each region and the cost of application were calculated.

Information about the alternative practices that growers would adopt when methyl bromide is no longer available and estimates of the associated yield losses that growers would experience after the ban were derived from published research, conversations with researchers, and workshops held in Florida and California during 1998. Following are

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[2] A notable exception is in California, where all pesticide use is required to be reported and is published in an annual pesticide use report.

descriptions of the alternative practices that growers are assumed to adopt. Note that yields and costs for Mexican producers are not expected to change since methyl bromide will be available for use in that country for several years after its use is banned in the U.S.

*Strawberries*

All California strawberry growers (except organic growers) are assumed to use methyl bromide in combination with chloropicrin in a 67% methyl bromide and 33% chloropicrin mix. Most growers hire a firm that applies the mixture to the entire field using 200 lb of methyl bromide per acre at a cost of $1,250 per acre. The California Strawberry Commission estimates that 95% of strawberry acreage is fumigated each year [30]. California strawberry producers are assumed to switch to a low rate of chloropicrin and Vapam. This will cost an additional $97.50 per acre. In addition to paying more for alternative fumigants, growers are likely to face increased weeding costs due to the less effective weed control associated with using alternative fumigants. Growers are expected to experience increased hand weeding costs of $100 per acre per month of production. It is estimated that weeding costs will increase by $600 in the Central Coast area and $500 in the South Coast regions. Thus the increase in costs equals $697.50 for Central Coast and $597.50 for South Coast.

Florida strawberry growers use methyl bromide in combination with chloropicrin in a 98% methyl bromide and 2% chloropicrin mix. They apply the mixture to the beds only using 200 lb of methyl bromide at a cost of $230 per acre. These growers are assumed to switch to Telone C-17 at 17.5 gal/acre at a cost of $227.50. In addition, they are assumed to use the herbicide Napropamide at 3 lb/acre at a cost of $51.23. This herbicide is not expected to be as effective against weeds as methyl bromide. Therefore, a cost of $400 per acre for hand weeding during the season is included. The increase in costs will be $448.73 per acre. These costs do not include increased costs that are anticipated due to the more stringent worker safety requirements for Telone. Nor do they include the costs of running a broadcast spreader or spray boom and disc to distribute and incorporate the herbicide.

There has been a substantial amount of research into alternatives to methyl bromide for California strawberry producers. Results suggest that growers might expect a yield loss of approximately 4% in the strawberry field using chloropicrin and vapam compared to methyl bromide in the first year, 4.5% in the second year, and 5.5% in the third year [42]. In addition, the loss of methyl bromide for production of strawberry nursery stock will have carryover effects through less transplant vigor in the growing fields. Estimates are that a 7.5% reduction in yield in the strawberry field may be expected from using alternatives in the nurseries to grow the transplants. Taking the effects of alternatives in both the nurseries and strawberry fields together, as well as how they may change in the second and third year, a yield loss of 21.5% is assumed for California strawberry growers.

There is less research into alternatives for strawberry growers in Florida. Florida workshop participants suggested a range of yield losses between 15 and 30%. Here a yield loss of 21.5% is assumed.

*Tomatoes*

Florida tomato growers fumigate their beds with a mixture of 98% methyl bromide and 2% chloropicrin at a rate of 200 lb per acre for a cost of $230 per acre. Florida growers outside of Dade County are assumed to switch to using Telone C-17 at 17.5 gal/acre, which costs $227.50 per acre. Dade County growers, who are restricted from using Telone, will use vapam instead of Telone, at 37.5 gal/acre that will cost $153.75. In addition, growers will use the herbicide Pebulate at 2 lb/acre, which costs approximately $15.86. The postban change in costs is $13.36 per acre. The postban change in costs for Dade County is -$60.39. These costs do not include increased costs that are anticipated due to the more stringent worker safety requirements for Telone. Nor do they include the costs of running a spray boom and disc to distribute and incorporate the herbicide.

Both Georgia and South Carolina tomato growers are assumed to use Telone C-17 and pebulate like Florida growers and to experience postban change in costs of $13.36 per acre.

Although all the tomato growers in Florida are assumed to fumigate their fields with methyl bromide before planting, not all fresh tomato growers in California do so. All growers in the South Coast region are assumed to fumigate, as they double or triple crop, keeping the land in production all year round. Tomato growers in other regions of California (San Joaquin, Imperial Valley, and Central Coast) are assumed not to use methyl bromide as an annual practice. Southern California tomato growers are assumed to switch to use Telone applied on the full fields with a comparable cost to methyl bromide + chloropicrin. The postban change in costs is expected to be zero. Tomato growers in other areas of California use methyl bromide as a spot treatment only rather than as a common production practice; therefore, postban change in cost is also assumed to be zero.

Many research projects have been conducted to identify alternatives for Florida tomato growers. The average yield loss from research trials using Telone C-17 + pebulate was 5%. In this model, a yield loss of 10% is assumed to account for anticipated pest buildup over time. Dade County growers are assumed to experience yield losses of 17.5% due to less effective control with vapam. Both Georgia and South Carolina growers are assumed to experience a yield loss of 10%. South Coast California tomato growers are assumed to experience a 10% yield decrease relative to methyl bromide–treated acreage.

*Cucumbers*

Methyl bromide is not labeled for use on cucumbers, which are included in the model due to common double-cropping practices in Florida. The cropping beds are fumigated with a 98% methyl bromide and 2% chloropicrin mixture and then covered with plastic mulch to grow peppers or tomatoes.  After harvesting these crops, growers retain the plastic mulch and plant cucumbers through it into the existing beds.  The cucumber crop gets a carryover benefit from the fumigation.

There has been little research on the impacts of alternatives on the yield of the second crop.  The yield loss that is assumed in the model for cucumbers as a second crop is 17.5%, based on discussions at the workshop held in Florida.

*Eggplant*

Eggplant producers in Florida fumigate their crop beds with a 98% methyl bromide and 2% chloropicrin mixture at a rate of 200 lb and a cost of $230 per acre.  Following the ban, eggplant producers in Southeast Florida are assumed to switch to Telone C-17 at 17.5 gal/acre, which costs $227.50 compared to $230 per acre.  In addition, growers are assumed to use the herbicide Napropamide at a rate of 1.5 lb/acre at a cost of $25.61.  The change in cost per acre is $23.11.  These costs do not include increased costs that are anticipated due to the more stringent worker safety requirements for Telone.  Nor do they include the costs of running a broadcast spreader or spray boom and disc to distribute and incorporate the herbicide.

No research could be found on the use of alternatives on eggplant in Florida.  Participants at a workshop held in Florida suggested that yield losses would be greater than for tomatoes.  A yield loss relative to methyl bromide of 15% is assumed for Florida eggplant.

*Peppers*

Florida pepper producers fumigate with a mixture of 98% methyl bromide and 2% chloropicrin at a rate of 200 lb and a cost of $230 per acre.  Florida pepper growers are assumed to switch to Telone C-17 at 17.5 gal/acre costing $227.50.  They will use

Napropamide at a rate of 1.5 lb/acre for a cost of $25.61 per acre. Since only 40% of North Carolina growers currently use methyl bromide, we did not include them as methyl bromide users in the model. Texas pepper growers do not use methyl bromide as part of their current production practices.

There is little research into the use of alternatives on peppers in Florida. Florida workshop participants suggested that yields relative to methyl bromide would be 70 to 100%. A yield loss of 12.5% is assumed relative to methyl bromide.

*Squash*

Methyl bromide is not labeled for use on squash. As for cucumbers, squash is included in the model due to common double-cropping practices in Florida. A yield loss of 17.5% is assumed for squash planted as a second crop. In Dade County, this yield loss is assumed to be 22% for the squash planted as a second crop, given the fact Dade growers cannot use Telone as an alternative for tomatoes.

*Watermelon*

Watermelon growers in California and Florida may use methyl bromide. In California, a section 18 emergency exemption is currently in effect, but few growers use it. California watermelon growers use methyl bromide infrequently. Costs and yields for Californa growers are assumed not to change. Florida growers currently have a section 24(c) registration for special local needs. The use of methyl bromide on watermelon in other states is not permitted. Florida watermelon is included in the current model as both a primary user of methyl bromide and a second crop, which may follow tomatoes or peppers.

Florida growers are assumed to switch to Telone C-17 at 8.75 gal/acre at a cost of $113.75 compared to methyl bromide at 100 lb/acre at $115. Growers are also assumed to use two herbicides, bensulide at 5.5 lb/acre for $58.80 and Naptalam at 3.5 lb/acre for $38.50. The postban change in cost is $96.00. These costs do not take into account increased costs due to worker safety gear requirements. Nor do they include the increased costs of running a spray boom and disc to distribute and incorporate the herbicide.

There is no available research into alternatives to methyl bromide for watermelon growers in Florida. A yield loss of 15% using Telone compared to yields using methyl bromide is assumed.

C. Baseline

The baseline was compared to the existing conditions in the horticultural sector. Ideally, the model would reproduce exactly what is occurring in the real world, where the most profitable areas would be producing the crops. However, while overall the model replicates the existing planted acres, in some cases there are divergent results. Only one region has a positive shadow value on the land constraint, California Central Coast tomatoes. A positive value would indicate that it would be profitable to plant an additional acre of these crops. Table 7.14 shows the value of an additional acre of land by crop and region.

In some crops, the model computes larger quantities being shipped to market, and therefore lower prices, than truly occur. This suggests that there are costs or other conditions that have not been included in this abstraction from reality. For example, the FOB price for California fresh strawberries is an average of $1,050 per ton in 1996 and $1,148 per ton in 1995, according to the California Agricultural Resource Directory [29]. The weighted three-year average wholesale price for the California Central Coast is $1,628.00 per ton and for the South Coast $1,768.00 per ton, based on wholesale market price data from USDA [13] [14] [15] [16]. Transportation costs did not exceed $197.55. Therefore, there are other costs such as marketing costs that have not been included in the analysis. According to Doug Edwards at the USDA Agricultural Marketing Service, these marketing costs cannot be approximated in a general sense [41]. Growers negotiate contracts with shippers or act as shippers themselves. Given the difficulties in making these approximations systematically, the explicit costs of marketing for each region for each crop were not available when parameterizing the model. From a reading of the state-level extension budgets, only the Florida strawberry budget has included these costs explicitly, as 7% of the price. Through the parameterization process, however, these marketing and other unidentified costs would be incorporated into the baseline.

*Comparison of Acres*

Overall the model reproduces the state level or large regional level of acres in the different crops. There are, however, some shifts between production regions within the states. Table 7.15 reports the actual three-year average of the harvested acres. Table 7.16 reports the baseline acreage computed by the model**.** Table 7.17 reports the percentage change between the actual and the model's calculated baselines.

*Strawberries:* For strawberries, California baseline acreage is 97% of the actual three-year average harvested strawberry acres. California's Central Coast is shown to produce more acres at almost 11,366 acres (102%), and South Coast produces fewer acres at 11,243 acres (93%); whereas, in actuality, South Coast usually harvests more than Central Coast. Central Florida produces only 85% of its three-year average at 4,523 acres.

In Mexico, Baja harvests 1,280 acres, or 102% of actual plantings. None of the strawberry regions hit the land constraint of actual acreage plus 10%.

*Tomatoes:* In the baseline acreage for tomatoes, California plants 91% of its actual three-year average tomato acreage. South Coast plants 3,814 acres, and California Central plants 2,956 acres. The Central Coast region hits the land constraint of 110% of its three-year average acreage; however, the marginal value of an additional acre of land was only $0.26, which indicates this region probably would not have planted many more acres. San Joaquin Valley plants 27,008 acres and Imperial Valley plants 1,460 acres.

Florida plants 87% of its actual tomato acres. Central Florida plants over 14,000 acres of tomatoes, as a single crop and in two crop rotations; that is, growers plant 1,651 acres in a tomato and cucumber rotation and 5,231 acres in a tomato and watermelon rotation. Dade plants 3,260 acres of tomatoes, over three-quarters of it in a tomato and squash rotation. Southwest Florida plants 17,704 acres, Southeast Florida growers plant 6,002 acres with 2,529 acres in a tomato and cucumber rotation, and North and West Florida plants 1,414 acres. Finally, Georgia plants 4,046 acres, and South Carolina plants 3,878 acres.

Mexico is shown to plant 96% of its actual tomato harvested acres, with Baja planting 13,646 acres and Sinaloa 24,277 acres.

*Peppers:* The model baseline calculated pepper acreage for Florida that is 90% of its actual average acres. Central Florida produces 4,012 acres of peppers, almost half of which is in a pepper and squash rotation; Southeast Florida produces 6,776 acres (94%); and Southwest Florida produces 7,296 acres (84%); 2,860 acres in a pepper-watermelon rotation. North Carolina plants 5,916 acres (87%), and Texas plants 4,840 acres, about 100% of their three-year average.

Similarly, Mexico's acreage is predicted at 93% of actual acres. Baja acreage is shown at 4,366 acres (90%) and Sinaloa at 9,469 acres (95%).

*Cucumbers:* Cucumber growers in Florida are predicted to plant 86% of actual acres. Cucumber acreage in Central Florida is shown at 2,982, of which 1,651 acres are a second crop after tomatoes. In Southwest Florida, cucumber acreage is 1,442 acres, and in Southeast, 4,716 acres, some of it (2,529 acres) is planted as a second crop after tomatoes. Georgia plants 11,471 acres of cucumbers. North Carolina is predicted to plant an equivalent number of acres as its actual acres at 6,057.

In the calculation for Mexico, cucumber acreage is 103% of actual acres. Baja plants 4,188 acres of cucumbers, and Sinaloa plants 8,636 acres.

*Squash:* In the baseline acreage in squash, Florida overall plants an almost equal number of acres (101%). Central Florida plants 1,903 acres of squash as a second crop following pepper; Dade County plants 6,150 acres of squash, 2,422 acres as a second crop following tomatoes, and Southwest Florida harvests 3,134 acres, according to the model, compared to the 3,167 average reported acres.

The model predicts that Mexico will plant an equal number of acres of squash. Baja produces 5,386 acres, and Sinaloa plants 7,850 acres.

*Eggplant:* The Southeast region of Florida produces all the eggplant in the state of Florida at 1,522 acres (98%) computed as the baseline eggplant acres.

Baseline acres for Mexico were 94% of the actual acres. Baja produces 288 acres, and Sinaloa has 1,949 acres.

*Watermelon:* In its two watermelon producing regions, California is predicted to plant 84% of its actual acres. California's Imperial Valley produces 1,832 acres, and in the San Joaquin Valley, acreage is estimated at 11,394 acres.

In the state of Florida, watermelon acreage equals almost 28,135 acres, 81% of actual acres. In Central Florida, the model predicts 5,231 acres, in Southwest Florida, growers are estimated to plant 7,773 acres, and North and West Florida plants 15,131 acres.

The model predicts that the other regions included would produce 92% of the actual average acres. Georgia's watermelon acreage is shown at 30,371, North Carolina plants 4,946 acres, and South Carolina plants 10,486 acres. (In parameterizing the model, it becomes clear that South Carolina and North Carolina acreage would be difficult to replicate individually. If South Carolina produces all its acreage, North Carolina produces a small percentage and vice versa due to similar marketing windows.) Texas produces 46,883 acres of watermelon.

Mexico is estimated to polatn 83% of its actual acres. Sinaloa plants 15,716 acres.

## D. Results

The results of the model are presented in Tables 7.18–7.39. The postban results are compared to the preban baseline. The baseline acreage was compared to the actual acreage in the Baseline section (7.C). The baseline itself includes estimates of acres planted by region and production system, shipments by crop by region by month to each market, and quantity purchased by wholesalers (consumption or demand quantity) of each crop by market by month, as well as the new equilibrium prices. The results demonstrate the complexities of economic systems both in computing the baseline and in assessing the impact. The attempt was made to replicate the existing conditions in the industry as closely as possible given the assumption that growers are rational profit-maximizers and will produce until profits are driven to zero or the land constraint is reached. The results presented here are compared to this baseline.

### *Consumers*

The biggest losers from the methyl bromide ban are the consumers of the seven horticultural crops. The change in consumer surplus equals -$158 million, as shown in Table 7.38. Following the ban, consumers will pay higher prices for the commodities and receive a lower quantity of the crops. (For strawberries in some months the price increase exceeds $200 per ton, the largest increase being $305 per ton.) Consumer surplus decreases $116 million, or 10.3%, for strawberries. (The initial level is $1.1 billion.) It decreases $26 million, or 1.7%, for tomatoes. (The initial level is $1.5 billion.) In the watermelon markets, consumer surplus decreases by $5 million, or 0.7%. For pepper consumers, surplus decreases $4.5 million, or 1.1%. Squash consumers see surplus decrease $4 million, or 2.2%. Cucumber consumer surplus decreases by $2 million or 1.3%. Similarly, eggplant consumers experience a -$380,000 change, a 5% decrease.

People throughout the world will experience a benefit if the expected reduction in ozone depletion occurs from this ban and the phase-out being proposed under the Montreal Protocol. The loss of consumer surplus presented here applies only to U.S. consumers, not all consumers in the world. Whether the higher prices and lower quantity experienced by U.S. consumers (i.e., the loss in consumer surplus) will be offset by the benefits incurred is an empirical question, and one would need to estimate these benefits to determine the overall welfare change for consumers.

*Producers*

While in some regions acreage in crops appears to decrease or shift to another crop in the model, for the most part acreage does not shift substantially following the ban. In fact, in several cases the acreage actually increases. Table 7.18 presents the postban acreage by crop, region and production system; Table 7.19 shows changes in regional acreage; and Tables 7.20–7.22 show aggregate changes in acreage by crop. This is a surprising result, as one would not expect to see acreage increase as costs increase and yields decrease. However, the resulting increase in price is sufficient to keep the crop in production. For Central Coast strawberries, for example, the cost per acre is $12,511 for 22.1 tons of strawberries. Costs increase postban by $697.50 per acre, and the yield decreases by 21.5% to 17.3 tons per acre. This results in an increased cost per ton of $197. During the several months when the Central Coast harvests, the price increases more than $197.

*Florida:* In the model, Florida sees acreage reductions in all crops except strawberries and squash. Strawberry acreage increases almost 1,000 acres; squash acreage increases 447 acres. Squash increases acreage in Central Florida (310 acres) and in Dade County (231 acres). Florida cucumbers decrease in the Southwest (341 acres) and in the Southeast (420 acres). Central Florida plants more cucumbers as a single crop (74 acres) and in a tomato and cucumber rotation (468 acres). Eggplants are no longer produced in Florida; 100% of the 1,522 acres will go out of production. Pepper acreage will decrease 935 acres overall with shifts out of the Southwest and Southeast (almost 1,400 acres).

Some of this acreage moves to Central Florida with shifts from fall plantings (-342 acres) to spring planting (480 acres) of peppers and a pepper and squash rotation (310 acres).

Tomato acreage decreases 2,557 acres in Florida after the ban. Southwest Florida increases acreage slightly (73 acres), while the Southeast decreases tomato acreage by 1,493 acres. Dade County stops producing tomatoes as a single crop (-838 acres) but increases the tomato and squash rotation by 232 acres. Florida North and West stops producing tomatoes on its 1,414 acres.

Watermelon acreage decreases 12,664 acres with some shifts between regions. North and West Florida stops producing watermelon on its 13,717 acres, and the Southwest stops producing watermelons on its 4,913 acres, but Central Florida actually increases watermelon acreage over 6,500 acres. This region hit the land constraint with a marginal value of $15.22 per acre. Growers would have to pay up to $15.22 to plant another acre of watermelon.

*California:* California postban results show increases in strawberry acres and decreases in tomato and watermelon acreage. Both the Central and South Coast strawberry regions increase acres with Central Coast acreage increasing 13% (1,437 acres) and South Coast acreage increasing 20% (2,259 acres). For tomatoes, California is looking at a decline in acreage of 3,270 acres, where the South Coast stops producing tomatoes or decreases acreage by 3,814 acres, and the San Joaquin Valley decreases by 1,328 acres (5%). However, Imperial Valley tomato acreage increases by 797 acres. The Imperial Valley tomato acreage hits the land constraint with a marginal value of $273.61 per acre. Tomato producers in this area will be making a profit and would be willing to further increase acreage. Central Coast tomato acreage increases 1,074 acres. Central Coast also hits the land constraint with a marginal value of $87.09 per acre. Growers in this area would pay up to $87.09 for an additional acre on which to plant tomatoes. Watermelon acreage overall decreases 513 acres. San Joaquin increases acreage by 1,318, but Imperial Valley stops producing watermelons (-1,832 acres).

*Mexico:* Mexico is predicted to increase acreage in all crops. For several crops, Mexico hits the land constraint. Strawberry acreage in Baja increases 604 acres. At that point, growers earn a rent of $3,889 per acre. They would pay up to this amount to plant another acre of strawberries. If the land constraint on strawberries was removed for Baja strawberries, growers there would plant over 18,000 acres rather than the 2,000 they do now. If the constraint on water and suitable land could be overcome, Baja could plant more acres, which would result in fewer acres planted in California to strawberries. If this constraint should be overcome, the impacts on U.S. strawberry growers would be much greater.

Similarly, Baja tomato growers are shown to plant 4,962 acres more than in the preban baseline. They have a marginal value for each acre of $144.72. Sinaloa also plants more tomato acres at 4,809 (20%) but does not hit the constraint. Cucumbers increase acres by 542: Baja cucumber growers increase acreage by 344, and Sinaloa growers increase by 308 acres. Eggplant acreage increases by 1,182 in Sinaloa and 52 acres in Baja. Sinaloa growers would pay $23.28 to have another acre on which to plant eggplant. Pepper acreage increases 6,787 in Mexico: 5,537 acres in Sinaloa and 1,250 acres in Baja. Sinaloa hits the land constraint with a marginal value of $39.09 per acre. Squash acreage increases 307 acres in Baja and 252 in Sinaloa. Watermelon acreage increases 4,320 acres in Sinaloa (27%).

*Other U.S. Regions:* For the other U.S. regions in the model, the model predicts overall increases in cucumber, pepper, tomato and watermelon acreage. Texas will increase pepper acreage by 496 acres and North Carolina decrease by 133 acres. Cucumber acreage decreases in North Carolina and increases in Georgia for an overall increase of 297 acres. Tomato acreage shifts from South Carolina (-916 acres) to Georgia, which postban grows over 2,000 more acres. Watermelon acreage increases by 14,920 in Georgia and almost 3,813 acres in South Carolina. South Carolina growers hit the land constraint with a marginal value of $36.86 per acre.  North Carolina stop growing watermelon.  Texas has an increase of 1,238 acres.

*<u>Price</u>:*  Changes in prices are shown in Table 7.23.  In many cases, the increase in price makes it profitable for the growers to stay in production.  If it is assumed that the average strawberry price received by California growers is $1,200 per ton, then a 15% price increase will maintain their current position.  Prices for strawberries increase as much as $304.76 per ton in November.  The smallest price increase is $108.61 per ton in February.  Similarly, prices for eggplant increase by as much as $84 a ton for certain months.  Eggplant price changes range from -$30.00 to $84.13 per ton. Tomato prices fall -$48.73 in September and increase $69.21 in January.   Squash price changes range from -$23.24 in January to $109.54 in April.  Pepper price changes range from -$39.82 to $51.96.  Cucumbers also have both negative and positive prices changes ranging from -$21.93 to $68.14.  Watermelon prices decrease $18.18 per ton in July and increase $23.62 per ton in May.

*<u>Production</u>:*  Pre- and postban production by region are shown in Tables 7.24 and 7.25.  Aggregate changes in production by crop following the ban can be seen in Tables 7.26–7.28.  In the U.S., eggplant had the largest total change in production, decreasing by 100%.  This is partially due to no other U.S. eggplant production region being included in the model.  The overall production available to consumers is shown to decrease by only 9% due to Mexico's increase in eggplant production.  U.S. pepper production decreases 14%, and tomato production decreases 13%.  For both of these crops, Mexico will able to respond with increased production.  U.S. strawberry production decreases over 42,000 tons, or 8%.  Squash and cucumbers decrease by 5% each, and watermelon decreases by 2%.

*<u>Revenue</u>:*  Table 7.29 presents the pre-ban calculated revenue by region and crop.  These revenue numbers do not have the costs of production deducted from them.  For most regions and most crops the net revenues from crop production is zero.  Because the model

assumes a competitive structure in the markets, costs and revenues should be approximately equal unless the land constraint is reached. Post-ban revenues (again without costs deducted) and changes in revenues are presented in Tables 7.30 and 7.31. Tables 7.32-7.34 show aggregate changes in revenue by crop. Post-ban revenues can be higher than the pre-ban revenues due to the increase in prices. However, while the producers are achieving higher revenues, they are also paying higher costs since in most regions, costs increased as yields decreased following the ban. Table 7.35 shows changes in total pre-harvest production costs. Total harvest and transportation costs also change post-ban, as shown in Tables 7.36 and 7.37.

Due to the assumptions of the model, most growers earn a zero profit, that is their revenues equal their costs. Our assumptions about the costs of production include a rent to the land which if a grower owns the land he or she earns as income and a management return which the grower earns again as income. Therefore, the revenue losses can be used to approximate the impact on local communities. First, if there are not equally profitable uses for the land, the landowner loses the value of the land rent. In addition, if the grower is not planting tomatoes for example, the suppliers for the inputs such as fertilizer, seedlings, and labor will lose revenue decreasing their income. We report revenue gains and losses here as some indication of impacts on the local agricultural area.

In the aggregate, Florida growers saw decreased revenues post-ban by $111 million. The largest revenue loser was tomatoes at $ 57.3 million with watermelon the second at $30.5 million. Peppers lost $12.6 million. Eggplant producers' revenues decreased $12 million. Cucumber revenues decreased almost $5 million. Squash producers' revenue changes were smaller at $-227 thousand. Despite the lower yield per acre, strawberry growers actually saw an increase in revenue of $6.6 million due to the additional acreage planted and higher prices. In this case, strawberry growers are not gaining additional net income, but at least are not worse off following the ban.

California growers overall see an increase in revenue for $2.7 million. Strawberry revenues increase $38.8 million due to increased prices and increased acreage although overall production has lessened. Tomato growers see a decrease of $35 million in revenues. Watermelon growers in California have decreased revenues of $1.1 million.

In the other U.S. regions, there was a revenue increase of $31.9 million. Watermelon producers in these four states saw watermelon revenues increase $27.5 million. Pepper growers increased revenues by $1 million and cucumbers growers by $951 thousand. Tomato growers saw receipts increase by $2.4 million.

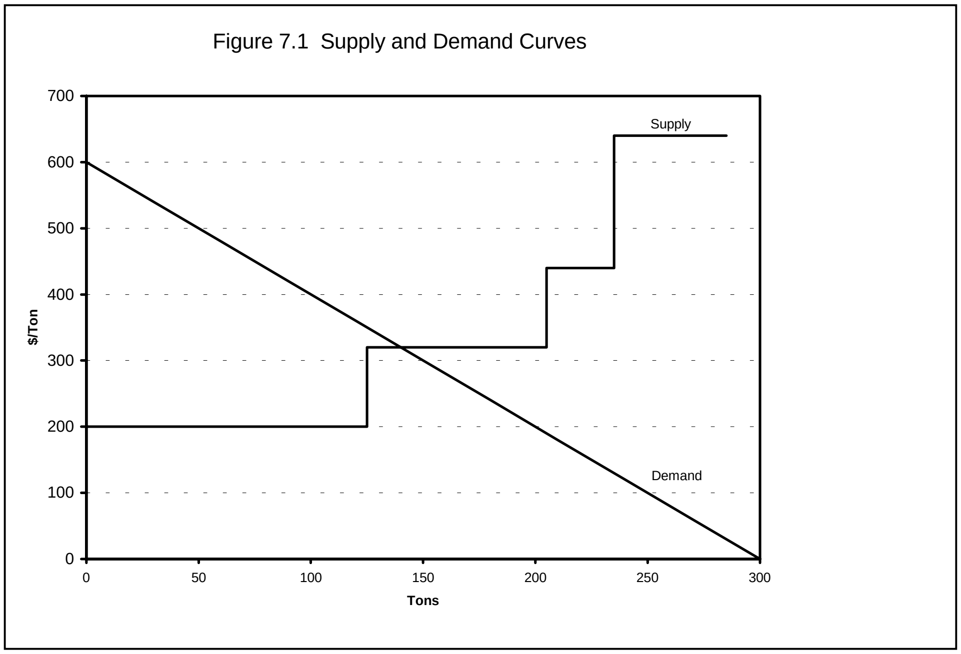
Mexico is the big winner following the ban. Revenues to the Mexican crop producers increase $159.7 million. The largest increase in revenues is for tomato growers at $97.5 million. Strawberry revenues in Baja will increase $22.2 million. Pepper revenues will increase $14.9 million. Watermelon revenues increase $8.6 million. Eggplant revenues increase $9.9 million. Cucumber revenues increase $4.4 million and squash revenues increase almost $2.2 million.

When the growers hit the land constraint however, this suggests they are making a positive profit on the crop and would like to plant additional acres. They would be willing to pay the marginal value to relax the constraint and plant one more acre. This value can be seen as the net income on the last acre they planted. The areas and crops which have positive marginal values are reported in Table 7.14. These regions and crops can also be seen as winners following the ban. Sinaloa, Mexico has positive values for two of its crops, eggplant and peppers. Baja/Sonora Mexico has positive values for strawberries and tomatoes. Two California regions, Central Coast and Imperial Valley have positive values for tomatoes. Florida Central want to plant more land to watermelons as does South Carolina.

These results indicate how, given the assumptions and computed baseline, the horticultural sector will change once methyl bromide becomes unavailable. As mentioned earlier, while the assumed change in yields and costs attempt to look beyond a one-year horizon, these results do not reflect long-run adjustments that may be made in an industry.  For example, given that green beans is not a crop considered in the model, if tomato growers shifted to this crop, the model would reflect only that the acreage had gone out of tomatoes and not the additional net revenue that may be gained from green bean production.  Similarly if a non-methyl bromide-using region (Sinaloa or Baja) can expand acreage more than was permitted, this would keep prices changes smaller.  Also, if a region not included in the model can enter these markets, the model may overpredict price increases thus underestimates the losses born by the methyl bromide using regions and overestimate losses to consumers.

The results show that the ban on methyl bromide will result in winners and losers.  Some regions and some crops will find that it is no longer profitable to continue to produce the crop at the same acreage as before the ban.  Other regions will find that their relative comparative advantage has increased and they will actually increase production.  Since some regions in California, Texas, North Carolina and Mexico, and some crops in Georgia and South Carolina do not use methyl bromide, their costs and expected yields should not change.  In most cases, non-methyl bromide users are able to respond by increasing production.  In a few regions, these growers expand acreage until they hit the land constraint.  The change in quantity and thus the change in price depend on impacts in competing regions and the assumed demand flexibilities.  While all the flexibilities assume that the percentage change in price will be less than the percentage change in quantity, the resulting change in price is sometimes sufficient to cover the increased cost.

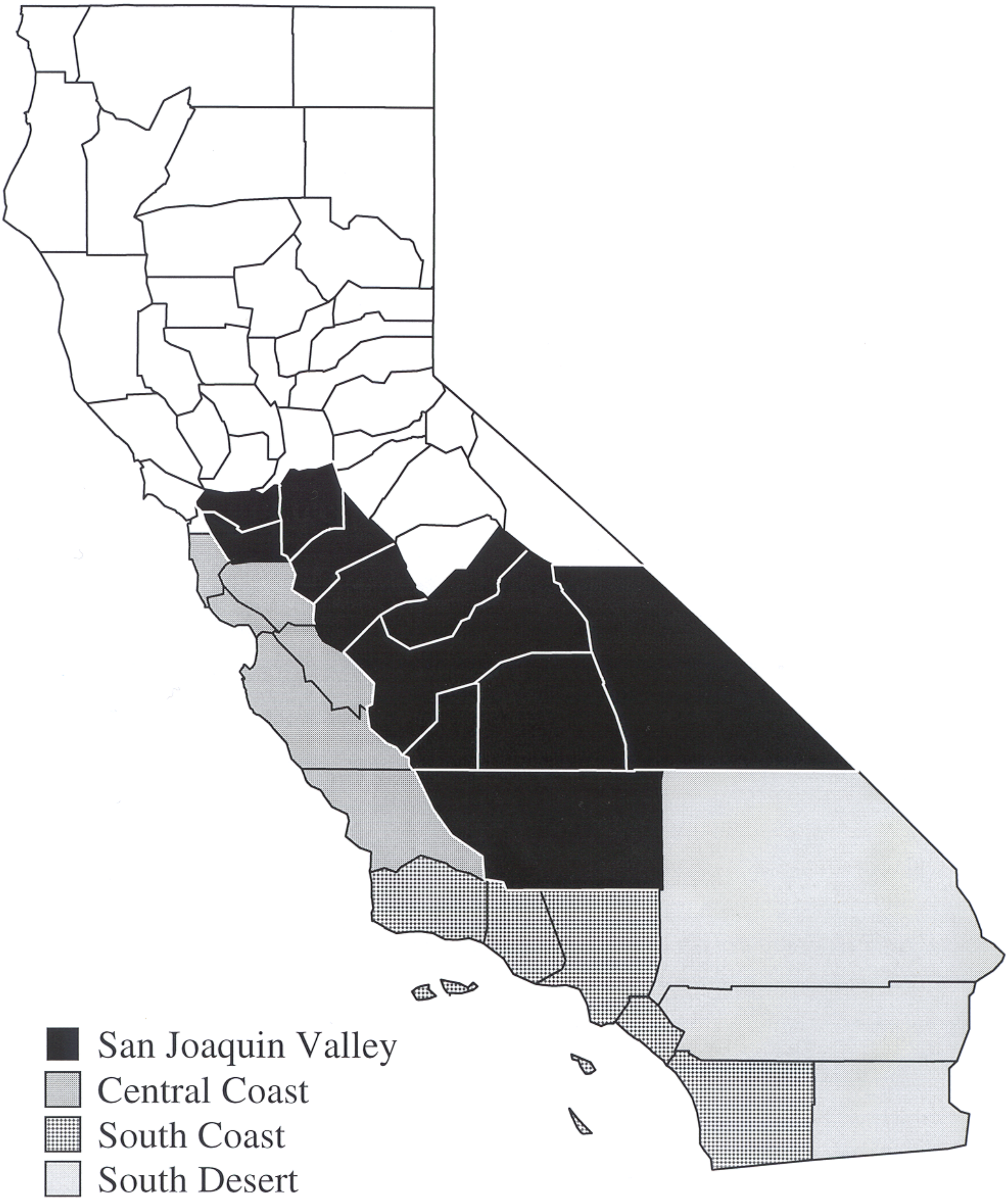
Overall economic impacts for US consumers and producers are presented in Table 7.39. Consumer surplus is expected to decrease by $158 million   If we use revenue losses as an indicator of economic loss for producers, we find that the U.S. growers who loses decrease revenue by $153.9 million dollars.  Those growers that win increase revenue by 77.3 million.  The overall net change in revenue is a decrease of $76.5 million.




Note: Each straight portion of the supply curve reflects one region's production.

# Figure 7.2  Mexican Production Regions

**Figure 7.3 California Production Regions**



## Figure 7.4 Florida Production Regions

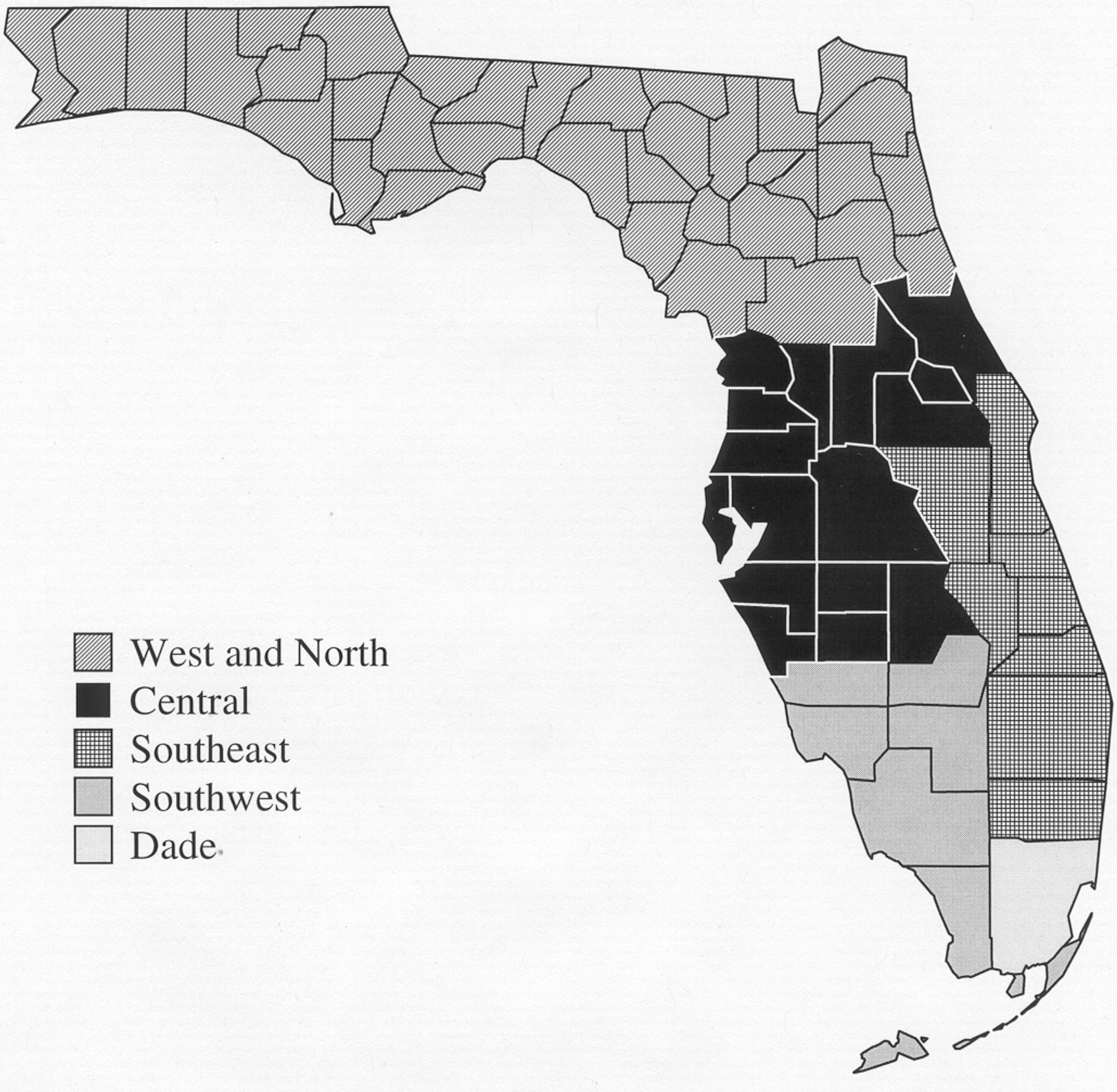


**Table 7.1. Alternatives to Methyl Bromide[1]**

| Crop | Alternative |
|---|---|
| Eggplant | Telone C-17 + Napropamide |
| Pepper | Telone C-17 + Napropamide |
| Strawberry | Telone C-17 + Napropamide in Florida<br>Chloropicrin + Vapam in California |
| Tomato | Telone C-17 + Pebulate<br>Vapam + Pebulate in Dade County<br>Telone II in California |
| Watermelon | Telone C-17 + Bensulide + Naptalam |

1 Alternatives listed here for production regions that currently use methyl bromide. Double crop production systems assumed to use same alternative as the first crop produced alone.

Table 7.2 Post-Ban Change in Pre-Harvest Costs ($/A)

| | Cucumber | Eggplant | Pepper | Squash | Strawberry | Tomato | Watermelon |
|---|---|---|---|---|---|---|---|
| California Central Coast | | | | | 697.50 | | |
| California Southern Coast | | | | | 597.50 | | |
| Florida Central | | | 23.11 | | 448.73 | 13.36 | 96.00 |
| Florida Dade | | | | | | -60.39 | |
| Florida Southeast | | 23.11 | 23.11 | | | 13.36 | |
| Florida Southwest | | | 23.11 | | | 13.36 | 96.00 |
| Florida West and North | | | | | | 13.36 | 96.00 |
| Georgia | | | | | | 13.36 | |
| North Carolina | | | 23.11 | | | | |
| South Carolina | | | | | | 13.36 | |

**Table 7.3 Post-Ban Percent Yield Loss**

| | Cucumber | Eggplant | Pepper | Squash | Strawberry | Tomatoes | Watermelon |
|---|---|---|---|---|---|---|---|
| California Central Coast | | | | | 21.5 | | |
| California Southern Coast | | | | | 21.5 | 10.0 | |
| Florida Central | 17.5 | | 12.5 | 17.5 | 21.5 | 10.0 | 15/17.5 |
| Florida Dade | | | | 22.0 | | 17.5 | |
| Florida Southeast | 17.5 | 15.0 | 12.5 | 17.5 | | 10.0 | |
| Florida Southwest | 17.5 | | 12.5 | 17.5 | | 10.0 | 15/17.5 |
| Florida West and North | | | | | | 10.0 | 15/17.5 |
| Georgia | | | | | | 10.0 | |
| North Carolina | | | 12.5 | | | | |
| South Carolina | | | | | | 10.0 | |

Note: Percent loss for cucumbers and squash are for second crop production systems. If grown as a single crop, no yield loss is assumed. For watermelon, yield losses for single crops are assumed to be 15% and for second crops, a 17.5% yield loss is assumed.

**Table 7.4. Annual Yields by Crop, Region and Production System (tons/acre)**

| | Cucumber | Eggplant | Pepper | Squash | Strawberry | Tomato | Watermelon |
|---|---|---|---|---|---|---|---|
| California Central Coast | | | | | 22.1 | 20.3 | |
| California Imperial Valley | | | | | | 17.2 | 16.5 |
| California San Joaquin | | | | | | 13.6 | 20.5 |
| California Southern Coast | | | | | 14.6 | 20.3 | |
| Florida Central | 11/14 | | 11.6 | 12/12 | 13.9 | 17.1 | 14 |
| Florida Dade | | | | 13/13 | | 16.2 | |
| Florida Southeast | 12/15 | 12.9 | 15.5 | | | 16.4 | |
| Florida Southwest | 13/16 | | 12.3 | 15.6/15.6 | | 14.9 | 17.2 |
| Florida West and North | | | | | | 15.7 | 8.3 |
| Georgia | 6.7 | | | | | 19.3 | 10.6 |
| Mexico Baja/Sonora | 8.7 | 6.8 | 9.1 | 6.1 | 19.9 | 18.0 | 8.2 |
| Mexico Sinaloa | 12.2 | 12.5 | 5.4 | 6.4 | | 13.1 | 6.7 |
| North Carolina | 3.9 | | 2.6 | | | | 7.3 |
| South Carolina | | | | | | 15.2 | 5.4 |
| Texas | | | 7.0 | | | | 8.1 |

Sources: Based on [2] [3] [4] [5] [6] [7] [8] [9] [10] [11].
Note: In regions where cucumbers and squash are grown in both single and double crop production systems, yields for single crops are given first, followed by yields from double crops systems.

**Table 7.5 Proportional Distribution of Yields by Month**

| | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cucumbers** | | | | | | | | | | | | |
| Florida Central | | | | | | | | | | | | |
| Single | | 0.43 | 0.43 | 0.14 | | | | | | | | |
| Tom.-Cuc. | | | | | | | 0.46 | 0.54 | | | | |
| Fl. Southeast | | | | | | | | | | | | |
| Single | | 0.12 | 0.22 | 0.30 | 0.28 | 0.08 | | | | | | |
| Pep.-Cuc. | | | | | | | 0.56 | 0.44 | | | | |
| Tom.-Cuc. | | | | | | 0.08 | 0.47 | 0.44 | | | | |
| Fl. Southwest | | | | | | | | | | | | |
| Single | | 0.12 | 0.22 | 0.30 | 0.28 | 0.08 | | | | | | |
| Pep.-Cuc. | | | | | | | 0.56 | 0.44 | | | | |
| Tom.-Cuc. | | | | | | 0.25 | 0.30 | 0.44 | | | | |
| Georgia | | | | | | | | | | | | |
| Fall | 0.34 | 0.40 | 0.19 | | | | | | | | | 0.07 |
| Spring | | | | | | | | 0.31 | 0.51 | 0.17 | | |
| Mex. Baj./Son. | | | | | | | | | | | | |
| Single | | | | 0.14 | 0.11 | 0.18 | 0.24 | 0.17 | 0.17 | | | |
| Mex. Sinaloa | | | | | | | | | | | | |
| Single | | | 0.17 | 0.26 | 0.23 | 0.29 | 0.05 | | | | | |
| North Carolina | | | | | | | | | | | | |
| Fall | | 0.44 | 0.44 | | | | | | | | | 0.12 |
| Spring | | | | | | | | | 0.50 | 0.30 | 0.20 | |

Table 7.5 Continued.

| | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Eggplant** | | | | | | | | | | | | |
| Fl. Southeast | | | | | | | | | | | | |
| Single | 0.04 | 0.10 | 0.11 | 0.16 | 0.12 | 0.15 | 0.16 | 0.15 | | | | |
| Mex. Baj./Son | | | | | | | | | | | | |
| Single | | | 0.13 | 0.13 | 0.13 | 0.15 | 0.15 | 0.15 | 0.15 | | | |
| Mex. Sinaloa | | | | | | | | | | | | |
| Single | 0.04 | 0.10 | 0.10 | 0.17 | 0.16 | 0.19 | 0.12 | 0.12 | | | | |
| **Peppers** | | | | | | | | | | | | |
| Florida Central | | | | | | | | | | | | |
| Fall | 0.04 | 0.48 | 0.35 | 0.13 | | | | | | | | |
| Spring | | | | | | | 0.40 | 0.60 | | | | |
| Pep.-Squash | 0.04 | 0.56 | 0.40 | | | | | | | | | |
| Pep.-Water. | 0.04 | 0.56 | 0.40 | | | | | | | | | |
| Fl. Southeast | | | | | | | | | | | | |
| Single | | | 0.06 | 0.21 | 0.25 | 0.25 | 0.16 | 0.08 | | | | |
| Pep.-Cuc. | | | 0.45 | 0.55 | | | | | | | | |
| Fl. Southwest | | | | | | | | | | | | |
| Single | | | 0.06 | 0.15 | 0.24 | 0.21 | 0.19 | 0.16 | | | | |
| Pep.-Cuc. | | | 0.43 | 0.57 | | | | | | | | |
| Pep.-Water. | | | 0.43 | 0.57 | | | | | | | | |
| Mex. Baj.-Son. | | | | | | | | | | | | |
| Single | 0.05 | 0.06 | 0.06 | 0.06 | 0.15 | 0.20 | 0.20 | 0.15 | 0.09 | | | |
| Mex. Sinaloa | | | | | | | | | | | | |
| Single | | | | 0.19 | 0.26 | 0.26 | 0.12 | 0.07 | 0.09 | | | |
| North Carolina | | | | | | | | | | | | |
| Single | | | | | | | | | 0.48 | 0.52 | | |

**Table 7.5 Continued.**

| | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Texas | | | | | | | | | | | | |
| Single | 0.16 | 0.44 | 0.40 | | | | | | | | | |
| **Squash** | | | | | | | | | | | | |
| Florida Central | | | | | | | | | | | | |
| Single | 0.02 | 0.58 | 0.40 | | | | | | | | | |
| Pep.-Squa. | | | | | | 0.06 | 0.28 | 0.66 | | | | |
| Tom.-Squa. | | | | | | 0.06 | 0.28 | 0.66 | | | | |
| Fl. Dade | | | | | | | | | | | | |
| Single | | | 0.27 | 0.33 | 0.32 | 0.08 | | | | | | |
| Tom.-Squa. | | | | | | 0.51 | 0.49 | | | | | |
| Fl. Southwest | | | | | | | | | | | | |
| Single | 0.02 | 0.58 | 0.40 | | | | | | | | | |
| Tom.-Squa. | | | | | | 0.38 | 0.62 | | | | | |
| Mex. Baj.-Son. | | | | | | | | | | | | |
| Single | | | 0.10 | 0.28 | 0.20 | 0.17 | 0.15 | 0.10 | | | | |
| Mex. Sinaloa | | | | | | | | | | | | |
| Single | | | 0.14 | 0.31 | 0.26 | 0.19 | 0.06 | 0.04 | | | | |
| **Strawberries** | | | | | | | | | | | | |
| Ca. Cen. Coast | | | | | | | | | | | | |
| Single | 0.06 | 0.02 | | | | | 0.06 | 0.16 | 0.23 | 0.20 | 0.16 | 0.11 |
| Ca. Sou. Coast | | | | | | | | | | | | |
| Single | 0.04 | 0.03 | 0.03 | 0.03 | 0.04 | 0.14 | 0.38 | 0.24 | 0.08 | | | |
| Florida Central | | | | | | | | | | | | |
| Single | | 0.02 | 0.05 | 0.19 | 0.27 | 0.48 | 0.01 | | | | | |
| Mex. Baj.-Son. | | | | | | | | | | | | |
| Single | | | | | 0.05 | 0.09 | 0.21 | 0.20 | 0.19 | 0.10 | 0.09 | 0.07 |

**Table 7.5 Continued.**

| | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tomatoes** | | | | | | | | | | | | |
| Ca. Cen. Coast | | | | | | | | | | | | |
| Single | 0.23 | 0.10 | | | | | | | 0.10 | 0.14 | 0.27 | 0.16 |
| Ca. Imp. Vall. | | | | | | | | | | | | |
| Single | | | | | | | 0.20 | 0.22 | 0.43 | 0.15 | | |
| Ca. San J. Vall. | | | | | | | | | | | | |
| Single | 0.14 | 0.14 | | | | | | | 0.06 | 0.24 | 0.21 | 0.21 |
| Ca. Sou. Coast | | | | | | | | | | | | |
| Single | 0.12 | 0.25 | | | | | 0.06 | 0.06 | 0.37 | 0.07 | 0.07 | |
| Florida Central | | | | | | | | | | | | |
| Fall | | 0.36 | 0.38 | 0.27 | | | | | | | | |
| Spring | | | | | 0.03 | 0.03 | 0.22 | 0.72 | | | | |
| Tom.-Cuc. | | | 0.53 | 0.47 | | | | | | | | |
| Tom.-Squa. | | | 0.56 | 0.44 | | | | | | | | |
| Tom.-Water. | | | 0.54 | 0.43 | 0.03 | | | | | | | |
| Florida Dade | | | | | | | | | | | | |
| Single | | | | 0.25 | 0.34 | 0.29 | 0.12 | | | | | |
| Tom.-Squa. | | 0.10 | 0.31 | 0.59 | | | | | | | | |
| Fl. Southeast | | | | | | | | | | | | |
| Single | | 0.10 | 0.11 | 0.18 | 0.23 | 0.19 | 0.19 | | | | | |
| Tom.-Cuc. | | 0.19 | 0.43 | 0.39 | | | | | | | | |
| Fl. Southwest | | | | | | | | | | | | |
| Fall | | 0.18 | 0.42 | 0.21 | 0.18 | | | | | | | |
| Spring | | | | | 0.20 | 0.27 | 0.37 | 0.17 | | | | |
| Tom.-Cuc. | | 0.20 | 0.46 | 0.34 | | | | | | | | |
| Tom.-Squa. | | 0.31 | 0.69 | | | | | | | | | |
| Tom.-Water. | | 0.19 | 0.48 | 0.34 | | | | | | | | |

**Table 7.5 Continued.**

| | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fl. We. & No. | | | | | | | | | | | | |
| Fall | 0.81 | 0.13 | | | | | | | | | | 0.06 |
| Spring | | | | | | | | 0.29 | 0.41 | 0.30 | | |
| Tom.-Water. | 0.75 | 0.25 | | | | | | | | | | |
| Georgia | | | | | | | | | | | | |
| Fall | 0.48 | 0.31 | 0.21 | | | | | | | | | |
| Spring | | | | | | | | | 0.38 | 0.63 | | |
| Mex. Baj.-Son. | | | | | | | | | | | | |
| Single | 0.15 | 0.20 | 0.10 | | | | | | 0.14 | 0.12 | 0.12 | 0.17 |
| Mex. Sinaloa | | | | | | | | | | | | |
| Single | | | 0.07 | 0.19 | 0.21 | 0.21 | 0.20 | 0.08 | 0.04 | | | |
| South Carolina | | | | | | | | | | | | |
| Single | | | | | | | | 0.17 | 0.44 | 0.39 | | |
| **Watermelon** | | | | | | | | | | | | |
| Ca. Imp. Vall. | | | | | | | | | | | | |
| Single | | | | | | | 0.07 | 0.38 | 0.54 | 0.01 | | |
| Ca. San J. Vall. | | | | | | | | | | | | |
| Single | | | | | | | | 0.49 | 0.51 | | | |
| Florida Central | | | | | | | | | | | | |
| Single | | | | | | | | 0.65 | 0.29 | 0.06 | | |
| Pep.-Water. | | | | | | | | 0.65 | 0.29 | 0.06 | | |
| Tom.-Water. | | | | | | | | 0.65 | 0.29 | 0.06 | | |
| Fl. Southwest | | | | | | | | | | | | |
| Single | | | | | | | 0.20 | 0.71 | 0.09 | | | |
| Pep.-Water. | | | | | | | 0.20 | 0.71 | 0.09 | | | |
| Tom.-Water. | | | | | | | 0.20 | 0.71 | 0.09 | | | |

**Table 7.5 Continued.**

| | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fl. We. & No. | | | | | | | | | | | | |
| Spring | | | | | | | | 0.19 | 0.81 | | | |
| Tom.-Water. | | | | | | | | 0.19 | 0.81 | | | |
| Georgia | | | | | | | | | | | | |
| Single | | | | | | | | | 0.49 | 0.33 | 0.19 | |
| Mex. Baj./Son. | | | | | | | | | | | | |
| Single | | | | | | | 0.06 | 0.06 | 0.78 | 0.05 | 0.05 | |
| Mex. Sinaloa | | | | | | | | | | | | |
| Single | | | | | | | 0.58 | 0.15 | 0.08 | 0.07 | 0.06 | 0.06 |
| North Carolina | | | | | | | | | | | | |
| Single | | | | | | | | | 0.20 | 0.41 | 0.30 | 0.09 |
| South Carolina | | | | | | | | | | | | |
| Single | | | | | | | | 0.28 | 0.35 | 0.19 | 0.09 | 0.09 |
| Texas | | | | | | | | | | | | |
| Single | | | | | | | | 0.19 | 0.36 | 0.16 | 0.15 | 0.15 |

Source: Based on [1] and [9].

**Table 7.6 Shipments by Production Region (tons)**

| | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cucumbers** | | | | | | | | | | | | |
| Florida | 7,200 | 14,317 | 10,633 | 5,083 | 1,467 | 7,150 | 22,317 | 28,567 | 4,133 | 0 | 0 | 317 |
| Georgia | 8,733 | 1,183 | 0 | 0 | 0 | 0 | 0 | 6,717 | 9,150 | 167 | 0 | 1,800 |
| Mexico | 3,683 | 23,917 | 40,217 | 46,850 | 44,283 | 42,033 | 24,100 | 9,600 | 7,050 | 5,033 | 3,317 | 2,150 |
| North Carolina | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11,217 | 117 | 0 | 0 |
| **Eggplant** | | | | | | | | | | | | |
| Florida | 800 | 1,917 | 2,050 | 1,533 | 1,083 | 1,083 | 2,133 | 2,967 | 1,283 | 33 | 0 | 17 |
| Mexico | 333 | 2,500 | 3,583 | 4,733 | 4,733 | 6,467 | 3,483 | 1,750 | 317 | 83 | 17 | 33 |
| **Peppers** | | | | | | | | | | | | |
| Florida | 1,383 | 9,967 | 18,167 | 13,217 | 12,483 | 14,633 | 22,267 | 21,883 | 3,500 | 17 | 0 | 17 |
| Mexico | 1,667 | 4,683 | 16,633 | 29,683 | 34,450 | 29,117 | 13,267 | 5,717 | 1,833 | 550 | 650 | 1,500 |
| North Carolina | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3,867 | 4,300 | 0 | 0 |
| Texas | 1,267 | 8,767 | 3,350 | 1,200 | 100 | 0 | 0 | 333 | 400 | 0 | 0 | 0 |
| **Squash** | | | | | | | | | | | | |
| Florida | 1,500 | 6,333 | 6,900 | 5,083 | 5,383 | 6,783 | 10,917 | 5,683 | 533 | 17 | 17 | 67 |
| Mexico | 5,050 | 19,700 | 32,250 | 32,017 | 24,800 | 23,000 | 15,367 | 9,633 | 4,650 | 2,100 | 1,983 | 1,383 |
| **Strawberries** | | | | | | | | | | | | |
| California | 18,533 | 4,900 | 533 | 5,383 | 10,333 | 30,583 | 87,933 | 84,150 | 65,100 | 54,117 | 39,467 | 30,700 |
| Florida | 0 | 150 | 1,883 | 3,100 | 4,500 | 15,150 | 2,500 | 17 | 0 | 0 | 0 | 0 |
| Mexico | 33 | 350 | 833 | 1,933 | 2,733 | 6,217 | 7,633 | 4,733 | 2,433 | 150 | 0 | 0 |
| **Tomatoes** | | | | | | | | | | | | |
| California | 100,800 | 38,433 | 3,533 | 0 | 0 | 0 | 0 | 9,033 | 47,150 | 92,950 | 83,033 | 84,950 |
| Florida | 27,683 | 56,200 | 69,933 | 60,117 | 47,850 | 41,567 | 72,267 | 104,417 | 59,117 | 4,300 | 0 | 500 |
| Mexico | 19,367 | 20,233 | 36,483 | 75,333 | 99,067 | 109,183 | 78,517 | 34,550 | 28,750 | 22,450 | 26,133 | 21,833 |
| South Carolina | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 27,683 | 5,100 | 50 | 17 |

**Table 7.6 Continued.**

| | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Watermelon** | | | | | | | | | | | | |
| California | 0 | 0 | 0 | 0 | 0 | 0 | 183 | 34,200 | 25,400 | 550 | 0 | 0 |
| Florida | 433 | 1,533 | 1,183 | 83 | 0 | 0 | 8,933 | 125,167 | 134,083 | 8,533 | 67 | 50 |
| Georgia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 103,200 | 40,983 | 3,200 | 0 |
| Mexico | 1,633 | 6,283 | 14,683 | 14,767 | 14,550 | 30,483 | 67,917 | 25,817 | 6,050 | 467 | 133 | 117 |
| North Carolina | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 83 | 22,550 | 6,050 | 0 |
| South Carolina | 1,933 | 1,467 | 567 | 0 | 0 | 0 | 100 | 36,833 | 52,067 | 23,133 | 22,783 | 16,217 |
| Texas | 3,333 | 2,217 | 0 | 0 | 0 | 0 | 133 | 29,367 | 219,700 | 18,833 | 22,167 | 18,350 |

Source: [1]

**Table 7.7. Demand Flexibilities by Crop and Market**

| | Atlanta | Chicago | Los Angeles | New York |
|---|---|---|---|---|
| Cucumber | -0.2519 | -0.3817 | -0.2533 | -0.2903 |
| Eggplant | -0.1601 | -0.1700 | -0.1500 | -0.1600 |
| Pepper | -0.3347 | -0.2596 | -1.0124 | -0.4411 |
| Squash | -0.2954 | -0.2589 | -0.2543 | -0.2523 |
| Strawberry | -0.2550 | -0.2650 | -0.2500 | -0.2500 |
| Tomato | -0.2766 | -0.2798 | -0.3384 | -0.2404 |
| Watermelon | -0.2500 | -0.2500 | -0.2500 | -0.2500 |

Source: [11] [27]

**Table 7.8. Three-Year Average Monthly Wholesale Prices by Market, October 1993 through September 1996 ($/ton)**

| | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Atlanta** | | | | | | | | | | | | |
| Cucumber | 311.88 | 521.84 | 574.32 | 708.65 | 609.87 | 631.56 | 442.92 | 394.93 | 409.12 | 453.00 | 373.21 | 368.79 |
| Eggplant | | 629.21 | 542.17 | 611.41 | 672.82 | 813.59 | 615.74 | 634.94 | 567.42 | | | |
| Pepper | 791.15 | 833.30 | 746.37 | 794.75 | 884.80 | 897.26 | 821.21 | 649.31 | 780.65 | 718.32 | 633.93 | 697.42 |
| Squash | 1,151.91 | 946.77 | 746.03 | 1,211.90 | 802.91 | 1,336.90 | 769.44 | 815.87 | 715.96 | 853.17 | 852.38 | 928.17 |
| Strawberry | 1,863.19 | 2,869.12 | 3,317.36 | 2,535.51 | 2,444.91 | 1,658.70 | 1,486.55 | 1,715.42 | 2,033.22 | 1,687.50 | 1,790.97 | 1,824.58 |
| Tomato | 901.33 | 1,005.07 | 1,252.09 | 1,073.74 | 883.31 | 1,226.37 | 1,078.92 | 733.59 | 946.28 | 912.61 | 770.61 | 846.21 |
| Watermelon | 352.35 | 359.52 | 401.77 | 361.19 | 447.92 | 521.47 | 456.80 | 365.41 | 226.24 | 187.85 | 190.58 | 218.97 |
| **Chicago** | | | | | | | | | | | | |
| Cucumber | 331.10 | 615.11 | 613.56 | 639.44 | 592.58 | 594.52 | 475.05 | 432.18 | 449.29 | 466.46 | 400.00 | 472.73 |
| Eggplant | 656.57 | 760.10 | 630.61 | 813.21 | 785.86 | 863.49 | 743.21 | 822.79 | 701.43 | 666.67 | | |
| Pepper | 892.42 | 1,044.79 | 990.03 | 886.98 | 964.86 | 1,068.25 | 973.37 | 763.11 | 829.37 | 853.42 | 642.86 | |
| Squash | 1,244.54 | 1,004.64 | 749.68 | 991.13 | 769.49 | 1,573.36 | 795.79 | 955.30 | 774.86 | 706.97 | | 722.22 |
| Strawberry | 1,617.59 | 2,935.19 | 3,116.03 | 2,712.64 | 2,165.04 | 1,650.43 | 1,188.64 | 1,375.00 | 1,301.62 | 1,143.06 | 1,578.13 | 1,162.73 |
| Tomato | 822.10 | 954.89 | 1,308.03 | 1,029.88 | 828.06 | 1,141.36 | 1,205.59 | 740.69 | 935.64 | 841.91 | 646.53 | 660.68 |
| Watermelon | 404.54 | 548.38 | 695.52 | 626.39 | 777.08 | 761.50 | 622.00 | 480.33 | 390.59 | 354.22 | 411.00 | 359.42 |

Table 7.8 Continued.

| | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Los Angeles** | | | | | | | | | | | | |
| Cucumber | 466.67 | 766.67 | 662.12 | 704.24 | 679.80 | 622.76 | 408.77 | 368.35 | 345.45 | | | |
| Eggplant | | 762.63 | 563.13 | 729.29 | 697.60 | 773.99 | 666.67 | 783.59 | 607.95 | | | |
| Pepper | | 1,245.04 | 970.98 | 889.29 | 948.66 | 1,049.11 | 957.59 | 816.96 | | | | |
| Squash | | 774.17 | 568.54 | 850.44 | 799.03 | 1,580.00 | 640.00 | | | | | |
| Strawberry | 1,809.72 | 2,943.06 | 4,043.40 | 3,378.58 | 2,276.83 | 1,967.54 | 1,295.33 | 1,417.48 | 1,350.69 | 1,159.72 | 1,378.47 | 1,283.33 |
| Tomato | 672.66 | 933.24 | 1,239.29 | 919.79 | 669.88 | 1,066.23 | 976.26 | 730.57 | 758.36 | 609.75 | 609.56 | 619.40 |
| Watermelon | 477.41 | 565.31 | 706.11 | 623.56 | 877.36 | 788.33 | 667.92 | 547.40 | 340.66 | 341.51 | 358.92 | 411.57 |
| **New York** | | | | | | | | | | | | |
| Cucumber | 248.67 | 299.30 | 410.23 | 612.37 | 480.97 | 395.13 | 349.33 | 363.81 | 408.44 | 276.50 | 400.00 | 298.93 |
| Eggplant | 446.72 | 476.36 | 352.46 | 575.87 | 517.59 | 718.65 | 530.16 | 540.71 | 409.62 | 409.09 | | |
| Pepper | 568.88 | 663.76 | 682.82 | 632.32 | 677.15 | 764.28 | 645.44 | 427.37 | 770.86 | 619.05 | 558.04 | |
| Squash | 848.51 | 554.74 | 568.72 | 694.89 | 543.35 | 940.15 | 520.53 | 757.93 | 480.21 | 467.08 | | |
| Strawberry | 2,011.11 | 3,796.88 | 4,653.92 | 4,136.21 | 2,222.55 | 2,252.79 | 1,817.86 | 2,496.94 | 1,765.97 | 1,411.81 | 3,693.40 | 2,052.78 |
| Tomato | 884.01 | 930.59 | 1,394.76 | 938.25 | 783.20 | 930.63 | 1,239.46 | 643.86 | 826.48 | 1,164.68 | 809.69 | 909.99 |
| Watermelon | 364.78 | 349.68 | 400.00 | 431.26 | 491.50 | 418.38 | 488.41 | 426.80 | 329.24 | 351.84 | 317.35 | 372.60 |

Note: Monthly prices calculated as three-year averages from 1993-94 through 1995-96 for produce from production regions included in economic model. Averages are weighted by arrivals from each production area.
Sources: [13] [14] [15] [16]

**Table 7.9 Representative Demand by Market (tons)**

| | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Atlanta** | | | | | | | | | | | | |
| Cucumbers | 3,027 | 3,424 | 3,139 | 5,372 | 4,756 | 5,393 | 4,687 | 4,979 | 4,507 | 1,288 | 2,156 | 2,943 |
| Eggplant | 0 | 105 | 124 | 128 | 131 | 179 | 126 | 99 | 57 | 0 | 0 | 0 |
| Peppers | 1,742 | 3,582 | 4,455 | 5,257 | 5,658 | 4,877 | 3,793 | 3,181 | 1,464 | 652 | 163 | 1,517 |
| Squash | 1,092 | 2,449 | 2,542 | 2,143 | 1,848 | 1,724 | 1,991 | 1,360 | 617 | 0 | 0 | 0 |
| Strawberries | 1,984 | 465 | 214 | 843 | 1,739 | 7,538 | 20,521 | 18,341 | 11,511 | 6,490 | 4,125 | 2,812 |
| Tomatoes | 18,236 | 15,740 | 12,996 | 17,251 | 20,271 | 21,023 | 24,309 | 21,983 | 22,505 | 11,206 | 5,595 | 6,364 |
| Watermelon | 223 | 246 | 550 | 576 | 383 | 1,081 | 2,223 | 43,509 | 79,058 | 17,819 | 4,676 | 1,575 |
| **Chicago** | | | | | | | | | | | | |
| Cucumbers | 11,806 | 18,038 | 20,403 | 16,453 | 12,270 | 11,157 | 12,167 | 13,599 | 14,662 | 2,080 | 995 | 441 |
| Eggplant | 591 | 1,893 | 1,615 | 1,631 | 1,863 | 1,503 | 1,325 | 1,266 | 722 | 27 | 0 | 0 |
| Peppers | 2,045 | 11,534 | 13,923 | 14,831 | 13,527 | 9,405 | 11,203 | 9,543 | 1,790 | 1,434 | 98 | 0 |
| Squash | 4,211 | 9,666 | 17,541 | 14,209 | 10,164 | 5,643 | 9,797 | 7,730 | 2,221 | 1,905 | 0 | 0 |
| Strawberries | 6,903 | 2,038 | 1,708 | 5,238 | 8,349 | 16,716 | 27,865 | 17,967 | 8,288 | 11,185 | 8,027 | 3,515 |
| Tomatoes | 37,061 | 29,870 | 28,118 | 35,905 | 27,565 | 23,125 | 24,989 | 25,623 | 33,989 | 33,412 | 28,210 | 19,093 |
| Watermelon | 546 | 2,491 | 6,133 | 3,972 | 4,595 | 5,189 | 12,943 | 51,930 | 59,827 | 11,329 | 2,324 | 1,240 |

**Table 7.9 Continued.**

| | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Los Angeles** | | | | | | | | | | | | |
| Cucumbers | 908 | 6,597 | 10,463 | 11,193 | 10,463 | 13,667 | 12,618 | 7,728 | 3,475 | 0 | 0 | 0 |
| Eggplant | 0 | 666 | 1,657 | 1,535 | 1,503 | 2,111 | 1,546 | 894 | 170 | 0 | 0 | 0 |
| Peppers | 0 | 3,320 | 7,519 | 7,376 | 10,609 | 10,589 | 7,527 | 3,579 | 0 | 0 | 0 | 0 |
| Squash | 0 | 7,733 | 10,677 | 10,374 | 10,574 | 8,621 | 7,566 | 0 | 0 | 0 | 0 | 0 |
| Strawberries | 5,951 | 1,395 | 427 | 1,867 | 3,826 | 14,094 | 28,945 | 30,320 | 30,237 | 23,474 | 18,284 | 17,459 |
| Tomatoes | 66,474 | 46,488 | 46,469 | 52,249 | 63,560 | 69,900 | 68,422 | 65,949 | 76,841 | 59,034 | 61,472 | 67,685 |
| Watermelon | 2,822 | 4,643 | 7,234 | 5,641 | 5,306 | 16,431 | 38,045 | 80,156 | 125,531 | 44,680 | 31,517 | 21,873 |
| **New York** | | | | | | | | | | | | |
| Cucumbers | 3,875 | 11,357 | 16,845 | 18,915 | 18,262 | 18,967 | 16,944 | 18,578 | 8,906 | 1,948 | 166 | 883 |
| Eggplant | 542 | 1,753 | 2,237 | 2,973 | 2,320 | 3,757 | 2,619 | 2,458 | 651 | 90 | 0 | 0 |
| Peppers | 530 | 4,980 | 12,253 | 16,636 | 17,240 | 18,879 | 13,011 | 11,631 | 6,346 | 2,781 | 390 | 0 |
| Squash | 1,248 | 6,186 | 8,389 | 10,374 | 7,597 | 13,794 | 6,929 | 6,227 | 2,345 | 212 | 0 | 0 |
| Strawberries | 3,729 | 1,502 | 901 | 2,469 | 3,652 | 13,602 | 20,737 | 22,272 | 17,497 | 13,118 | 9,031 | 6,913 |
| Tomatoes | 26,080 | 22,768 | 22,368 | 30,045 | 35,521 | 36,702 | 33,064 | 34,445 | 29,365 | 21,181 | 13,989 | 14,191 |
| Watermelon | 3,743 | 4,120 | 2,516 | 4,662 | 4,267 | 7,783 | 24,056 | 75,789 | 276,168 | 41,222 | 15,883 | 10,046 |

Note: Shipments by market calculated using shipments data for model production regions from 1993-94 through 1995-96 [1], divided proportionally among markets using arrivals data for model production regions [12] [13] [14] [15] [16].

**Table 7.10 Distance Between Production Areas and Markets (miles)**

| Region | Market | | | |
|---|---|---|---|---|
| | **Atlanta** | **Chicago** | **Los Angeles** | **New York** |
| California Central Coast | 2,539 | 2,234 | 307 | 3,019 |
| California Imperial Valley | 2,130 | 2,049 | 109 | 2,754 |
| California San Joaquin Valley | 2,451 | 2,167 | 218 | 2,958 |
| California Southern Coast | 2,237 | 2,041 | 0 | 2,831 |
| Florida Central | 455 | 1,176 | 2,552 | 1,155 |
| Florida Dade | 661 | 1,382 | 2,759 | 1,304 |
| Florida Southeast | 602 | 1,323 | 2,700 | 1,242 |
| Florida Southwest | 507 | 1,228 | 2,605 | 1,208 |
| Florida West and North | 389 | 1,110 | 2,489 | 1,089 |
| Georgia | 0 | 717 | 2,237 | 875 |
| Mexico Baja/Sonora | 2,165 | 2,104 | 124 | 2,849 |
| Mexico Sinaloa | 1,774 | 1,825 | 550 | 2,498 |
| North Carolina | 238 | 761 | 2,453 | 637 |
| South Carolina | 316 | 907 | 2,553 | 778 |
| Texas | 1,145 | 1,505 | 1,605 | 2,010 |

Source: Calculated using [17].

**Table 7.11 Transportation Costs Between Production Areas and Markets ($/ton)**

| | Market | | | |
|---|---|---|---|---|
| **Region** | **Atlanta** | **Chicago** | **Los Angeles** | **New York** |
| California San Joaquin Valley | 160.38 | 141.80 | 14.26 | 193.56 |
| California Central Coast | 166.14 | 146.18 | 20.09 | 197.55 |
| California South Coast | 146.38 | 133.55 | 0.00 | 185.25 |
| California Imperial Valley | 139.38 | 134.08 | 7.13 | 180.21 |
| West and North Florida | 25.45 | 72.63 | 162.87 | 71.26 |
| Central Florida | 29.77 | 76.95 | 166.99 | 75.58 |
| Southwest Florida | 33.18 | 80.35 | 170.46 | 79.05 |
| Southeast Florida | 39.39 | 86.57 | 176.67 | 81.27 |
| Dade County | 43.25 | 90.43 | 180.54 | 85.33 |
| Georgia | 0.00 | 46.92 | 146.38 | 57.26 |
| Baja and Sonora | 141.67 | 137.68 | 8.11 | 186.42 |
| Sinaloa | 116.08 | 119.42 | 35.99 | 163.46 |
| North Carolina | 15.57 | 49.80 | 160.51 | 41.68 |
| South Carolina | 20.68 | 59.35 | 167.06 | 50.91 |
| Texas | 74.92 | 98.48 | 105.02 | 131.52 |

Table 7.12 Pre-Ban Pre-Harvest Production Costs ($/acre)

| | California Central Coast | California Imperial Valley | California San Joaquin Valley | California Southern Coast | Florida Central | Florida Dade | Florida Southeast | Florida Southwest |
|---|---|---|---|---|---|---|---|---|
| Cucumber | | | | | 2,208 | | 2,208 | 2,208 |
| Eggplant | | | | | | | 6,224 | |
| Pepper | | | | | | | 6,357 | 6,357 |
| Pepper-Cucumber | | | | | | | 7,412 | 7,412 |
| Pepper-Fall | | | | | 6,357 | | | |
| Pepper-Spring | | | | | 6,357 | | | |
| Pepper-Squash | | | | | 7,561 | | | |
| Pepper-Watermelon | | | | | 7,128 | | | 7,128 |
| Squash | | | | | 1,569 | 1,569 | | 1,569 |
| Strawberry | 12,111 | | | 12,111 | 7,474 | | | |
| Tomato | 746 | 2,842 | 746 | 5,284 | | 5,570 | 5,995 | |
| Tomato-Fall | | | | | 5,995 | | | 5,995 |
| Tomato-Cucumber | | | | | 7,284 | | 7,284 | 7,284 |
| Tomato-Spring | | | | | 5,381 | | | 5,381 |
| Tomato-Squash | | | | | 7,433 | 7,433 | | 7,433 |
| Tomato-Watermelon | | | | | 7,000 | | | 7,804 |
| Watermelon | | 1,288 | 1,288 | | 624 | | | 624 |

**Table 7.12 Continued.**

| | Florida West and North | Georgia | Mexico Baja/Sonora | Mexico Sinaloa | North Carolina | South Carolina | Texas |
|---|---|---|---|---|---|---|---|
| Cucumber | | | 2,500 | 1,374 | | | |
| Cucumber-Fall | | 527 | | | 794 | | |
| Cucumber-Spring | | 527 | | | 794 | | |
| Eggplant | | | 3,500 | 2,136 | | | |
| Pepper | | | 5,000 | 2,197 | 1386 | | 1,020 |
| Squash | | | 799 | 959 | | | |
| Strawberry | | | 11,505 | | | | |
| Tomato | | | 3,000 | 3,048 | | 3,950 | |
| Tomato-Fall | 5,746 | 2,317 | | | | | |
| Tomato-Spring | 5,746 | 2,317 | | | | | |
| Tomato-Watermelon | 7,000 | | | | | | |
| Watermelon | | 390 | 824 | 869 | 430 | 396 | 593 |
| Watermelon-Fall | 624 | | | | | | |
| Watermelon-Spring | 624 | | | | | | |

Sources: [19] [20] [21] [22] [23] [24] [25] [26] [37] [38]

**Table 7.13 Harvest Costs ($/Ton)**

| | Cucumber | Eggplant | Pepper | Squash | Strawberry | Tomato | Watermelon |
|---|---|---|---|---|---|---|---|
| California Central Coast | | | | | 593 | 282 | |
| California Imperial Valley | | | | | | 340 | 60 |
| California San Joaquin Valley | | | | | | 282 | 60 |
| California Southern Coast | | | | | 593 | 300 | |
| Florida Central | 183 | | 196 | 247 | 643 | 286 | 51 |
| Florida Dade | | | | 247 | | 263 | |
| Florida Southeast | 183 | 136 | 196 | | | 280 | |
| Florida Southwest | 183 | | 282 | 247 | | 280 | 59 |
| Florida West and North | | | | | | 286 | 46 |
| Georgia | 161 | | | | | 358 | 29 |
| Mexico Baja/Sonora | 251 | 221 | 234 | 232 | 774 | 245 | 70 |
| Mexico Sinaloa | 222 | 215 | 262 | 226 | | 302 | 34 |
| North Carolina | 76 | | 83 | | | | 32 |
| South Carolina | | | | | | 367 | 35 |
| Texas | | | 227 | | | | 60 |

Sources: [19] [20] [21] [22] [23] [24] [25] [26] [37] [38]

**Table 7.14 Value of an Additional Acre of Land ($)**

| | Cucumber | | Eggplant | | Pepper | | Squash | |
|---|---|---|---|---|---|---|---|---|
| **Region** | **Pre-ban** | **Post-ban** | **Pre-ban** | **Post-ban** | **Pre-ban** | **Post-ban** | **Pre-ban** | **Post-ban** |
| California Central Coast | | | | | | | | |
| California Imperial Valley | | | | | | | | |
| California San Joaquin Valley | | | | | | | | |
| California South Coast | | | | | | | | |
| Florida Central | | | | | | | | |
| Florida Dade | | | | | | | | |
| Florida Southeast | | | | | | | | |
| Florida Southwest | | | | | | | | |
| Florida West and North | | | | | | | | |
| Georgia | | | | | | | | |
| Mexico Baja/Sonora | | 3,888.62 | | | | | | |
| Mexico Sinaloa | | | | 23.28 | | 39.09 | | |
| North Carolina | | | | | | | | |
| South Carolina | | | | | | | | |
| Texas | | | | | | | | |

**Table 7.14 Continued.**

| Region | Strawberry Pre-ban | Strawberry Post-ban | Tomato Pre-ban | Tomato Post-ban | Watermelon Pre-ban | Watermelon Post-ban |
|---|---|---|---|---|---|---|
| California Central Coast | | | 0.26 | 87.09 | | |
| California Imperial Valley | | | | 273.61 | | |
| California San Joaquin Valley | | | | | | |
| California South Coast | | | | | | |
| Florida Central | | | | | | 15.22 |
| Florida Dade | | | | | | |
| Florida Southeast | | | | | | |
| Florida Southwest | | | | | | |
| Florida West and North | | | | | | |
| Georgia | | | | | | |
| Mexico Baja/Sonora | | | | 144.72 | | |
| Mexico Sinaloa | | | | | | |
| North Carolina | | | | | | |
| South Carolina | | | | | | 36.86 |
| Texas | | | | | | |

Source: Calculated.

**Table 7.15 Average Acreage by Crop and Production Region 1993-94 through 1995-96**

| | Cucumber | Eggplant | Pepper | Squash | Strawberry | Tomato | Watermelon |
|---|---|---|---|---|---|---|---|
| California Central Coast | | | | | 11,091 | 2,687 | |
| California Imperial Valley | | | | | | 1,505 | 5,369 |
| California San Joaquin Valley | | | | | | 30,589 | 10,358 |
| California South Coast | | | | | 12,128 | 3,917 | |
| Florida Central | 3,533 | | 4,333 | 1,878 | 5,333 | 16,648 | 7,917 |
| Florida Dade | | | | 6,017 | | 4,433 | |
| Florida Southeast | 4,583 | 1,550 | 7,192 | | | 5,667 | |
| Florida Southwest | 2,567 | | 8,650 | 3,167 | | 19,533 | 7,917 |
| Florida West and North | | | | | | 2,085 | 18,833 |
| Georgia | 12,000 | | | | | 4,433 | 33,667 |
| Mexico Baja/Sonora | 4,026 | 281 | 4,828 | 5,164 | 1,256 | 12,405 | 810 |
| Mexico Sinaloa | 8,398 | 2,087 | 10,004 | 8,042 | | 27,170 | 18,070 |
| North Carolina | 5,700 | | 6,800 | | | | 9,500 |
| South Carolina | | | | | | 3,667 | 9,533 |
| Texas | | | 4,800 | | | | 47,833 |

Sources: U.S. crop acreages from [2] [3] [4] [5] [6] [7] [8]. Mexican crop acreage based on import data from [9] and yields from [10] [28] [37] [38].

Table 7.16 Baseline Acreage by Crop, Region and Production System

| | California Central Coast | California Imperial Valley | California San Joaquin Valley | California Southern Coast | Florida Central | Florida Dade | Florida Southeast | Florida Southwest |
|---|---|---|---|---|---|---|---|---|
| Cucumber | | | | | 1,331 | | 2,187 | 1,442 |
| Eggplant | | | | | | | 1,522 | |
| Pepper | | | | | | | 6,776 | 4,436 |
| Pepper-Fall | | | | | 343 | | | |
| Pepper-Spring | | | | | 1,766 | | | |
| Pepper-Squash | | | | | 1,903 | | | |
| Pepper-Watermelon | | | | | | | | 2,860 |
| Squash | | | | | | 3,728 | | 3,134 |
| Strawberry | 11,366 | | | 11,243 | 4,523 | | | |
| Tomato | 2,956 | 1,460 | 27,008 | 3,814 | | 838 | 3,473 | |
| Tomato-Cucumber | | | | | 1,651 | | 2,529 | |
| Tomato-Fall | | | | | 496 | | | |
| Tomato-Spring | | | | | 6,314 | | | 17,704 |
| Tomato-Squash | | | | | | 2,422 | | |
| Tomato-Watermelon | | | | | 5,231 | | | |
| Watermelon | | 1,832 | 11,394 | | | | | 4,913 |

**Table 7.16 Continued.**

| | Florida West and North | Georgia | Mexico Baja/Sonora | Mexico Sinaloa | North Carolina | South Carolina | Texas |
|---|---|---|---|---|---|---|---|
| Cucumber | | | 4,188 | 8,636 | | | |
| Cucumber-Fall | | 7,245 | | | 3,679 | | |
| Cucumber-Spring | | 4,226 | | | 2,378 | | |
| Eggplant | | | 288 | 1,949 | | | |
| Pepper | | | 4,366 | 9,469 | 5,916 | | 4,840 |
| Squash | | | 5,386 | 7,850 | | | |
| Strawberry | | | 1,280 | | | | |
| Tomato | | | 13,646 | 24,277 | | 3,878 | |
| Tomato-Fall | | 1,712 | | | | | |
| Tomato-Spring | | 2,334 | | | | | |
| Tomato-Watermelon | 1,414 | | | | | | |
| Watermelon | | 30,371 | | 15,716 | 4,946 | 10,486 | 46,883 |
| Watermelon-Spring | 13,717 | | | | | | |

Source: Calculated.

**Table 7.17 Baseline Acreage as Percent of Actual Acreage by Region and Crop**

| | Cucumber | Eggplant | Pepper | Squash | Strawberry | Tomato | Watermelon |
|---|---|---|---|---|---|---|---|
| California | | | | | 97% | 91% | 84% |
| Florida | 86% | 98% | 90% | 101% | 85% | 87% | 81% |
| Other US | 99% | | 93% | | | 98% | 92% |
| Total US | 94% | 98% | 91% | 101% | 95% | 90% | 89% |
| Mexico | 103% | 94% | 93% | 100% | 102% | 96% | 83% |

Source: Calculated.

**Table 7.18 Post-Ban Acreage by Crop, Region, and Production System**

| | California Central Coast | California Imperial Valley | California San Joaquin Valley | California Southern Coast | Florida Central | Florida Dade | Florida Southeast | Florida Southwest |
|---|---|---|---|---|---|---|---|---|
| Cucumber | | | | | 1,405 | | 2,139 | 1,101 |
| Pepper | | | | | | | 6,336 | 2,759 |
| Pepper-Spring | | | | | 2,246 | | | |
| Pepper-Squash | | | | | 2,213 | | | |
| Pepper-Watermelon | | | | | | | | 3,595 |
| Squash | | | | | | 3,615 | | 3,151 |
| Strawberry | 12,802 | | | 13,502 | 5,485 | | | |
| Tomato | 4,031 | 2,258 | 25,680 | | | | 1,980 | |
| Tomato-Cucumber | | | | | 2,119 | | 2,158 | |
| Tomato-Spring | | | | | 7,243 | | | 17,777 |
| Tomato-Squash | | | | | | 2,654 | | |
| Tomato-Watermelon | | | | | 5,585 | | | |
| Watermelon | | | 12,712 | | 6,291 | | | |

**Table 7.18 Continued.**

| | Florida West and North | Georgia | Mexico Baja/Sonora | Mexico Sinaloa | North Carolina | South Carolina | Texas |
|---|---|---|---|---|---|---|---|
| Cucumber | | | 4,532 | 8,945 | | | |
| Cucumber-Fall | | 7,242 | | | 3,749 | | |
| Cucumber-Spring | | 4,666 | | | 2,166 | | |
| Eggplant | | | 341 | 3,131 | | | |
| Pepper | | | 5,617 | 15,006 | 5,783 | | 5,336 |
| Squash | | | 5,693 | 8,102 | | | |
| Strawberry | | | 1,884 | | | | |
| Tomato | | | 18,608 | 29,086 | | 2,963 | |
| Tomato-Fall | | 3,911 | | | | | |
| Tomato-Spring | | 2,251 | | | | | |
| Watermelon | | 45,291 | | 20,035 | | 14,300 | 48,121 |

Source: Calculated.

**Table 7.19. Regional Acreage in Production**

| Region | Pre-Ban | Post-Ban | Change |
|---|---:|---:|---:|
| California Central Coast | 14,322 | 16,833 | 2,511 |
| California Imperial Valley | 3,292 | 2,258 | -1,034 |
| California San Joaquin Valley | 38,402 | 38,392 | -10 |
| California South Coast | 15,058 | 13,502 | -1,556 |
| Florida Central | 23,557 | 32,587 | 9,029 |
| Florida Dade | 6,988 | 6,269 | -719 |
| Florida Southeast | 16,487 | 12,611 | -3,875 |
| Florida Southwest | 34,489 | 28,383 | -6,106 |
| Florida West and North | 15,131 | | -15,131 |
| Georgia | 45,887 | 63,361 | 17,474 |
| Mexico Baja/Sonora | 29,154 | 36,674 | 7,520 |
| Mexico Sinaloa | 67,897 | 84,305 | 16,408 |
| North Carolina | 16,919 | 11,699 | -5,220 |
| South Carolina | 14,365 | 17,262 | 2,897 |
| Texas | 51,724 | 53,457 | 1,734 |

Source: Calculated.

**Table 7.20. Pre-Ban Acreage by Crop**

| | Cucumber | Eggplant | Pepper | Squash | Strawberry | Tomato | Watermelon |
|---|---|---|---|---|---|---|---|
| California | | | | | 22,609 | 35,238 | 13,225 |
| Florida | 9,140 | 1,522 | 18,084 | 11,187 | 4,523 | 42,071 | 28,135 |
| Other US | 17,528 | | 10,756 | | | 7,925 | 92,686 |
| Total US | 26,668 | 1,522 | 28,841 | 11,187 | 27,132 | 85,234 | 134,046 |
| Mexico | 12,824 | 2,237 | 13,835 | 13,236 | 1,280 | 37,923 | 15,716 |

Source: Calculated.

**Table 7.21. Post-Ban Acreage by Crop**

| | Cucumber | Eggplant | Pepper | Squash | Strawberry | Tomato | Watermelon |
|---|---|---|---|---|---|---|---|
| California | | | | | 26,305 | 31,968 | 12,712 |
| Florida | 8,921 | | 17,149 | 11,634 | 5,485 | 39,514 | 15,470 |
| Other US | 17,825 | | 11,119 | | | 9,124 | 107,712 |
| Total US | 26,746 | | 28,268 | 11,634 | 31,789 | 80,606 | 135,894 |
| Mexico | 13,477 | 3,471 | 20,623 | 13,795 | 1,884 | 47,694 | 20,035 |

Source: Calculated.

**Table 7.22. Change in Acreage by Crop**

| | Cucumber | Eggplant | Pepper | Squash | Strawberry | Tomato | Watermelon |
|---|---|---|---|---|---|---|---|
| California | | | | | 3,695 | -3,270 | -513 |
| Florida | -219 | -1,522 | -935 | 447 | 961 | -2,557 | -12,664 |
| Other US | 297 | | 363 | | | 1,200 | 15,025 |
| Total US | 78 | -1,522 | -572 | 447 | 4,657 | -4,628 | 1,848 |
| Mexico | 653 | 1,234 | 6,788 | 559 | 604 | 9,771 | 4,320 |

Source: Calculated.

**Table 7.23 Post-Ban Change in Price per Ton (dollars)**

| | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Atlanta** | | | | | | | | | | | | |
| Cucumber | -0.68 | 0.83 | -0.64 | -1.57 | 3.25 | -8.02 | 41.87 | 40.72 | -21.93 | -8.87 | 68.14 | 0.25 |
| Eggplant | | 83.97 | 79.79 | 32.72 | 14.56 | -0.01 | 56.38 | 46.99 | | | | |
| Pepper | -39.82 | -12.90 | 29.92 | -5.06 | 51.45 | 10.70 | 34.78 | 11.43 | -23.46 | 21.50 | | |
| Squash | | -9.59 | 14.16 | -23.24 | -12.44 | 95.27 | 109.54 | 24.90 | | | | |
| Strawberry | 232.84 | 304.75 | 209.23 | 237.38 | 108.61 | 187.63 | 192.76 | 270.85 | 277.58 | 219.19 | 257.74 | 200.52 |
| Tomato | 50.06 | 28.01 | -19.46 | 69.21 | 21.31 | 36.26 | 35.18 | 22.29 | 54.48 | 12.46 | -33.87 | -48.73 |
| Watermelon | | | | | | | 3.15 | 23.62 | 12.24 | -18.18 | 0.00 | -7.08 |
| **Chicago** | | | | | | | | | | | | |
| Cucumber | -0.68 | 0.83 | -0.64 | -1.57 | 3.26 | -8.02 | 41.87 | 40.72 | -21.93 | -8.87 | 68.14 | 0.25 |
| Eggplant | 2.57 | 40.13 | 35.94 | -11.12 | -29.29 | -6.04 | 12.54 | 3.15 | -5.64 | | | |
| Pepper | -39.82 | -12.90 | 29.92 | -5.06 | 51.45 | -33.14 | 34.78 | 11.43 | -23.46 | 21.50 | | |
| Squash | | -9.59 | 14.16 | -23.24 | -12.44 | 95.27 | 109.54 | 24.90 | | | | |
| Strawberry | 232.84 | 304.75 | 209.23 | 237.38 | 108.61 | 187.63 | 192.76 | 270.85 | 277.58 | 219.19 | 257.74 | 200.52 |
| Tomato | 61.51 | 28.00 | -19.46 | 69.21 | 21.31 | | 35.18 | 22.29 | 45.30 | 7.35 | -33.87 | -48.73 |
| Watermelon | | | | | | | 3.15 | 0.00 | 12.24 | -18.18 | 0.00 | -7.08 |

**Table 7.23, Continued. Post-BanChange in Price per Ton (dollars)**

| | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Los Angeles** | | | | | | | | | | | | |
| Cucumber | -0.68 | 0.83 | -0.64 | -1.57 | 3.26 | -8.02 | 41.86 | -31.49 | -21.92 | | | |
| Eggplant | | 40.13 | 35.94 | -11.12 | -29.29 | -6.04 | 12.54 | 3.15 | -5.64 | | | |
| Pepper | | -12.90 | 29.92 | -5.06 | 51.45 | -33.14 | -7.50 | 11.43 | | | | |
| Squash | | -9.59 | -45.01 | -23.24 | -12.45 | 95.27 | -31.93 | | | | | |
| Strawberry | 232.84 | 304.75 | 209.23 | 237.38 | 108.61 | 187.63 | 192.76 | 270.85 | 277.58 | 219.19 | 257.74 | 200.52 |
| Tomato | 61.51 | 28.01 | -19.46 | -19.84 | 21.31 | 23.71 | -40.26 | 22.28 | 45.30 | 7.34 | -33.86 | -48.73 |
| Watermelon | | | | | | | 3.15 | 0.00 | 0.00 | -20.75 | -0.01 | -7.08 |
| **New York** | | | | | | | | | | | | |
| Cucumber | -0.68 | 0.83 | -0.64 | -0.59 | 3.26 | -8.02 | 43.98 | 40.72 | -21.93 | -8.87 | 68.14 | 0.25 |
| Eggplant | 51.91 | 11.76 | -492.63 | 38.22 | 20.05 | 5.49 | 61.88 | 52.49 | | | | |
| Pepper | -39.82 | -12.90 | 29.99 | -5.06 | 51.96 | 13.18 | 34.78 | 11.43 | -23.46 | 21.50 | | |
| Squash | | -9.59 | 14.16 | -23.24 | -12.44 | 95.26 | 109.54 | 24.90 | | | | |
| Strawberry | 232.84 | 304.75 | 209.23 | 237.38 | 108.61 | 187.63 | 192.76 | 270.84 | 277.58 | 219.19 | 257.74 | 200.52 |
| Tomato | 61.51 | 28.01 | -16.26 | 69.21 | 21.31 | 36.26 | 35.17 | 22.29 | 61.60 | 12.46 | -33.87 | -48.73 |
| Watermelon | | | | | | | 3.42 | 23.55 | 12.24 | -18.18 | 0.00 | -7.08 |

Note: Blank spaces indicate no estimate made. Zeroes indicate no change in price.
Source: Calculated.

**Table 7.24 Pre-Ban Production of Crop by Region (tons)**

| | Cucumber | Eggplant | Pepper | Squash | Strawberry | Tomato | Watermelon |
|---|---|---|---|---|---|---|---|
| California Central Coast | | | | | 238,683 | 42,858 | |
| California Imperial Valley | | | | | | 21,903 | 30,223 |
| California San Joaquin Valley | | | | | | 375,409 | 216,667 |
| California Southern Coast | | | | | 205,753 | 74,763 | |
| Florida Central | 38,661 | | 50,143 | 24,739 | 59,707 | 226,328 | 68,523 |
| Florida Dade | | | | 82,411 | | 52,815 | |
| Florida Southeast | 62,573 | 19,025 | 94,864 | | | 96,628 | |
| Florida Southwest | 18,742 | | 94,997 | 47,317 | | 265,566 | 132,143 |
| Florida West and North | | | | | | 22,621 | 121,046 |
| Georgia | 80,294 | | | | | 64,567 | 317,814 |
| Mexico Baja/Sonora | 43,136 | 1,930 | 34,054 | 32,317 | 21,767 | 249,713 | |
| Mexico Sinaloa | 103,636 | 24,330 | 53,972 | 54,951 | | 327,745 | 95,866 |
| North Carolina | 30,286 | | 13,607 | | | | 36,599 |
| South Carolina | | | | | | 69,811 | 56,626 |
| Texas | | | 33,882 | | | | 350,325 |

Source: Calculated.

**Table 7.25. Post-Ban Production of Crop by Region (tons)**

| | Cucumber | Eggplant | Pepper | Squash | Strawberry | Tomato | Watermelon |
|---|---|---|---|---|---|---|---|
| California Central Coast | | | | | 211,047 | 56,581 | |
| California Imperial Valley | | | | | | 33,863 | |
| California San Joaquin Valley | | | | | | 356,951 | 241,916 |
| California Southern Coast | | | | | 193,965 | | |
| Florida Central | 40,881 | | 48,610 | 23,737 | 56,833 | 222,116 | 130,405 |
| Florida Dade | | | | 76,179 | | 35,468 | |
| Florida Southeast | 51,833 | | 77,610 | | | 59,947 | |
| Florida Southwest | 14,312 | | 69,971 | 47,587 | | 239,989 | 50,417 |
| Florida West and North | | | | | | | |
| Georgia | 83,361 | | | | | 84,349 | 417,746 |
| Mexico Baja/Sonora | 46,680 | 2,282 | 40,547 | 34,160 | 32,028 | 340,517 | |
| Mexico Sinaloa | 107,339 | 39,131 | 85,534 | 56,712 | | 392,667 | 122,215 |
| North Carolina | 29,580 | | 13,301 | | | | |
| South Carolina | | | | | | 47,994 | 77,217 |
| Texas | | | 37,115 | | | | 387,184 |

Source: Calculated.

**Table 7.26. Pre-Ban Production by Crop (tons)**

| | Cucumber | Eggplant | Pepper | Squash | Strawberry | Tomato | Watermelon |
|---|---|---|---|---|---|---|---|
| California | | | | | 444,436 | 514,932 | 246,889 |
| Florida | 119,976 | 19,025 | 240,004 | 154,467 | 59,707 | 663,959 | 321,711 |
| Other US | 110,580 | | 47,489 | | | 134,378 | 761,365 |
| Total US | 230,556 | 19,025 | 287,493 | 154,467 | 504,143 | 1,313,269 | 1,329,965 |
| Mexico | 146,773 | 26,260 | 88,026 | 87,268 | 21,767 | 577,458 | 95,866 |

Source: Calculated.

**Table 7.27. Post-Ban Production by Crop (tons)**

| | Cucumber | Eggplant | Pepper | Squash | Strawberry | Tomato | Watermelon |
|---|---|---|---|---|---|---|---|
| California | | | | | 405,013 | 447,394 | 241,916 |
| Florida | 107,026 | | 196,191 | 147,503 | 56,833 | 557,520 | 180,821 |
| Other US | 112,940 | | 50,416 | | | 132,343 | 882,148 |
| Total US | 219,966 | | 246,607 | 147,503 | 461,845 | 1,137,257 | 1,304,885 |
| Mexico | 154,020 | 41,414 | 126,081 | 90,872 | 32,028 | 733,184 | 122,215 |

Source: Calculated.

**Table 7.28. Change in Production by Crop (tons)**

| | Cucumber | Eggplant | Pepper | Squash | Strawberry | Tomato | Watermelon |
|---|---|---|---|---|---|---|---|
| California | | | | | -39,423 | -67,539 | -4,973 |
| Florida | -12,950 | -19,025 | -43,813 | -6,965 | -2,875 | -106,438 | -140,890 |
| Other US | 2,360 | | 2,927 | | | -2,035 | 120,783 |
| Total US | -10,590 | -19,025 | -40,886 | -6,965 | -42,298 | -176,012 | -25,080 |
| Mexico | 7,247 | 15,153 | 38,055 | 3,604 | 10,261 | 155,727 | 26,349 |

Source: Calculated.

**Table 7.29 Pre-Ban Revenues by Region and Crop ($1,000)**

| | Cucumber | Eggplant | Pepper | Squash | Strawberry | Tomato | Watermelon |
|---|---|---|---|---|---|---|---|
| California Central Coast | | | | | 350,113 | 26,950 | |
| California Imperial Valley | | | | | | 16,740 | 4,821 |
| California San Joaquin Valley | | | | | | 183,298 | 31,699 |
| California Southern Coast | | | | | 270,276 | 44,922 | |
| Florida Central | 18,402 | | 16,722 | 11,749 | 73,981 | 129,251 | 12,578 |
| Florida Dade | | | | 49,634 | | 32,403 | |
| Florida Southeast | 33,734 | 11,939 | 34,641 | | | 57,949 | |
| Florida Southwest | 12,049 | | 31,725 | 27,503 | | 159,970 | 25,277 |
| Florida West and North | | | | | | 17,120 | 28,326 |
| Georgia | 32,985 | | | | | 41,614 | 49,583 |
| Mexico Baja/Sonora | 20,381 | 1,116 | 10,171 | 17,843 | 31,474 | 140,528 | |
| Mexico Sinaloa | 61,125 | 14,166 | 18,193 | 32,202 | | 225,800 | 25,112 |
| North Carolina | 13,809 | | 5,114 | | | | 5,409 |
| South Carolina | | | | | | 50,865 | 10,407 |
| Texas | | | 11,701 | | | | 73,012 |

Source: Calculated.

**Table 7.30. Post-Ban Revenues by Region and Crop ($1,000)**

| | Cucumber | Eggplant | Pepper | Squash | Strawberry | Tomato | Watermelon |
|---|---|---|---|---|---|---|---|
| California Central Coast | | | | | 361,503 | 36,304 | |
| California Imperial Valley | | | | | | 26,727 | |
| California San Joaquin Valley | | | | | | 173,651 | 35,380 |
| California Southern Coast | | | | | 297,678 | | |
| Florida Central | 20,499 | | 16,880 | 12,563 | 80,581 | 130,237 | 25,766 |
| Florida Dade | | | | 48,294 | | 22,029 | |
| Florida Southeast | 29,588 | | 30,278 | | | 37,184 | |
| Florida Southwest | 9,177 | | 23,359 | 27,803 | | 149,953 | 9,923 |
| Florida West and North | | | | | | | |
| Georgia | 34,257 | | | | | 58,069 | 71,900 |
| Mexico Baja/Sonora | 22,057 | 1,320 | 12,373 | 18,861 | 53,636 | 191,345 | |
| Mexico Sinaloa | 63,861 | 23,894 | 30,868 | 33,395 | | 272,531 | 33,665 |
| North Carolina | 13,488 | | 4,999 | | | | |
| South Carolina | | | | | | 36,841 | 14,718 |
| Texas | | | 12,831 | | | | 79,273 |

Source: Calculated.

**Table 7.31. Change in Revenues by Region and Crop ($1,000)**

| | Cucumber | Eggplant | Pepper | Squash | Strawberry | Tomato | Watermelon |
|---|---|---|---|---|---|---|---|
| California Central Coast | | | | | 11,389 | 9,354 | |
| California Imperial Valley | | | | | | 9,987 | -4,821 |
| California San Joaquin Valley | | | | | | -9,647 | 3,681 |
| California Southern Coast | | | | | 27,403 | -44,922 | |
| Florida Central | 2,097 | | 158 | 814 | 6,600 | 986 | 13,189 |
| Florida Dade | | | | -1,340 | | -10,374 | |
| Florida Southeast | -4,146 | -11,939 | -4,362 | | | -20,765 | |
| Florida Southwest | -2,872 | | -8,367 | 299 | | -10,017 | -15,354 |
| Florida West and North | | | | | | -17,120 | -28,326 |
| Georgia | 1,272 | | | | | 16,455 | 22,317 |
| Mexico Baja/Sonora | 1,676 | 204 | 2,202 | 1,018 | 22,163 | 50,817 | |
| Mexico Sinaloa | 2,736 | 9,729 | 12,675 | 1,193 | | 46,731 | 8,553 |
| North Carolina | -321 | | -115 | | | | -5,409 |
| South Carolina | | | | | | -14,024 | 4,311 |
| Texas | | | 1,130 | | | | 6,261 |

Source: Calculated.

**Table 7.32. Pre-Ban Revenue by Crop ($1,000)**

| | Cucumber | Eggplant | Pepper | Squash | Strawberry | Tomato | Watermelon |
|---|---|---|---|---|---|---|---|
| California | | | | | 620,389 | 271,910 | 36,520 |
| Florida | 64,185 | 11,939 | 83,088 | 88,886 | 73,981 | 396,693 | 66,181 |
| Other US | 46,794 | | 16,815 | | | 92,479 | 138,411 |
| Total US | 110,979 | 11,939 | 99,903 | 88,886 | 694,370 | 761,082 | 241,112 |
| Mexico | 81,507 | 15,282 | 28,365 | 50,045 | 31,474 | 366,328 | 25,112 |

Source: Calculated.

**Table 7.33. Post-Ban Revenue by Crop ($1,000)**

| | Cucumber | Eggplant | Pepper | Squash | Strawberry | Tomato | Watermelon |
|---|---|---|---|---|---|---|---|
| California | | | | | 659,181 | 236,681 | 35,380 |
| Florida | 59,264 | | 70,517 | 88,660 | 80,581 | 339,402 | 35,689 |
| Other US | 47,745 | | 17,830 | | | 94,910 | 165,891 |
| Total US | 107,009 | | 88,347 | 88,660 | 739,762 | 670,994 | 236,961 |
| Mexico | 85,918 | 25,214 | 43,241 | 52,256 | 53,636 | 463,876 | 33,665 |

Source: Calculated.

**Table 7.34. Change in Revenue by Crop ($1,000)**

| | Cucumber | Eggplant | Pepper | Squash | Strawberry | Tomato | Watermelon |
|---|---|---|---|---|---|---|---|
| California | | | | | 38,792 | -35,229 | -1,139 |
| Florida | -4,922 | -11,939 | -12,571 | -227 | 6,600 | -57,290 | -30,492 |
| Other US | 951 | | 1,015 | | | 2,432 | 27,480 |
| Total US | -3,970 | -11,939 | -11,556 | -227 | 45,392 | -90,088 | -4,151 |
| Mexico | 4,412 | 9,932 | 14,876 | 2,211 | 22,163 | 97,549 | 8,553 |

Source: Calculated.

**Table 7.35 Change in Pre-Harvest Production Cost ($1,000)**

| | California Central Coast | California Imperial Valley | California San Joaquin Valley | California Southern Coast | Florida Central | Florida Dade | Florida Southeast | Florida Southwest |
|---|---|---|---|---|---|---|---|---|
| Cucumber | | | | | 237 | | -231 | -1,641 |
| Eggplant | | | | | | | -7,796 | |
| Pepper | | | | | | | -779 | -3,557 |
| Pepper-Fall | | | | | -606 | | | |
| Pepper-Spring | | | | | 902 | | | |
| Pepper-Squash | | | | | 1,215 | | | |
| Pepper-Watermelon | | | | | | | | 1,692 |
| Squash | | | | | | -358 | | 66 |
| Strawberry | 31,313 | | | 35,174 | 8,643 | | | |
| Tomato | 3,133 | 4,809 | -2,663 | -19,503 | | -4,626 | -6,737 | |
| Tomato-Cucumber | | | | | 2,845 | | -2,136 | |
| Tomato-Fall | | | | | -1,760 | | | |
| Tomato-Spring | | | | | 3,404 | | | 527 |
| Tomato-Squash | | | | | | 1,748 | | |
| Tomato-Watermelon | | | | | 1,595 | | | |
| Watermelon | | -2,801 | 1,781 | | 5,303 | | | -6,068 |

**Table 7.35 Continued.**

| | Florida West and North | Georgia | Mexico Baja/Sonora | Mexico Sinaloa | North Carolina | South Carolina | Texas |
|---|---|---|---|---|---|---|---|
| Cucumber | | | 680 | 847 | | | |
| Cucumber-Fall | | -4 | | | 119 | | |
| Cucumber-Spring | | 643 | | | -358 | | |
| Eggplant | | | 99 | 3,385 | | | |
| Pepper | | | 1,402 | 3,621 | -82 | | 403 |
| Squash | | | 533 | 465 | | | |
| Strawberry | | | 5,498 | | | | |
| Tomato | | | 24,651 | 19,347 | | -5,138 | |
| Tomato-Fall | | 8,694 | | | | | |
| Tomato-Spring | | -298 | | | | | |
| Tomato-Watermelon | -11,275 | | | | | | |
| Watermelon | | 13,294 | | 4,255 | -2,750 | 2,026 | 406 |
| Watermelon-Spring | -12,812 | | | | | | |

Source: Calculated.

**Table 7.36 Change in Total Harvest Costs ($1,000)**

| | Cucumber | Eggplant | Pepper | Squash | Strawberry | Tomato | Watermelon |
|---|---|---|---|---|---|---|---|
| California Central Coast | | | | | -16,388 | 3,864 | |
| California Imperial Valley | | | | | | 3,365 | -1,805 |
| California San Joaquin Valley | | | | | | -5,198 | 1,541 |
| California Southern Coast | | | | | -6,990 | -25,419 | |
| Florida Central | 406 | | -208 | -247 | -1,850 | -1,129 | 3,156 |
| Florida Dade | | | | -1,537 | | -4,555 | |
| Florida Southeast | -2,035 | -2,596 | -2,339 | | | -9,904 | |
| Florida Southwest | -839 | | -3,392 | 66 | | -6,906 | -4,822 |
| Florida West and North | | | | | | -6,108 | -5,568 |
| Georgia | 495 | | | | | 7,676 | 3,627 |
| Mexico Baja/Sonora | 926 | 97 | 860 | 446 | 7,891 | 20,458 | |
| Mexico Sinaloa | 994 | 4,232 | 4,187 | 434 | | 22,677 | 1,281 |
| North Carolina | -54 | | -20 | | | | -1,134 |
| South Carolina | | | | | | -8,005 | 710 |
| Texas | | | 422 | | | | 2,064 |

Source: Calculated.

**Table 7.37 Change in Total Transportation Costs ($1,000)**

| | Cucumber | Eggplant | Pepper | Squash | Strawberry | Tomato | Watermelon |
|---|---|---|---|---|---|---|---|
| California Central Coast | | | | | -3,536 | 2,006 | |
| California Imperial Valley | | | | | | 1,195 | -216 |
| California San Joaquin Valley | | | | | | -1,787 | 360 |
| California Southern Coast | | | | | -781 | | |
| Florida Central | 239 | | -54 | -29 | -192 | -2,092 | 3,886 |
| Florida Dade | | | | -733 | | -1,653 | |
| Florida Southeast | -888 | -1,548 | -1,245 | | | -2,981 | |
| Florida Southwest | -391 | | -2,046 | 167 | | -3,638 | -5,528 |
| Florida West and North | | | | | | -1,058 | -8,626 |
| Georgia | 138 | | | | | 384 | 5,396 |
| Mexico Baja/Sonora | 70 | 8 | -60 | 39 | 1,448 | 3,015 | |
| Mexico Sinaloa | 895 | 2,039 | 4,279 | 295 | | 4,707 | 3,017 |
| North Carolina | -28 | | -13 | | | | -1,526 |
| South Carolina | | | | | | -881 | 1,048 |
| Texas | | | 305 | | | | 3,790 |

Source: Calculated.

**Table 7.38 Consumer Surplus ($1,000s)**

| | Pre-Ban | Post-Ban | Change | Percent Change |
|---|---|---|---|---|
| Cucumber | 163,888 | 161,830 | -2,057 | -1.3% |
| Eggplant | 7,580 | 7,200 | -380 | -5.0% |
| Pepper | 413,248 | 408,713 | -4,535 | -1.1% |
| Squash | 195,262 | 190,914 | -4,348 | -2.2% |
| Strawberry | 1,127,755 | 1,011,760 | -115,996 | -10.3% |
| Tomato | 1,499,486 | 1,473,795 | -25,692 | -1.7% |
| Watermelon | 673,134 | 668,174 | -4,960 | -0.7% |
| **TOTAL** | **4,080,353** | **3,922,387** | **-157,968** | **-3.9%** |

Source: Calculated.

**Table 7.39. Economic Impact of Methyl Bromide Ban on U.S. Consumers and Producers**

| | Change in Consumers' Surplus ($1,000) | Increase in US Producers' Revenues ($1,000)[1] | Decrease in US Producers' Revenues ($1,000)[2] | Total Impact ($1,000) |
|---|---|---|---|---|
| Cucumbers | -2,057 | 951 | -4,922 | -6,028 |
| Eggplant | -380 | 0 | -11,939 | -12,319 |
| Peppers | -4,535 | 1,015 | -12,571 | -16,091 |
| Squash | -4,348 | 0 | -227 | -4,575 |
| Strawberry | -115,996 | 45,392 | 0 | -70,604 |
| Tomato | -25,692 | 2,432 | -92,520 | -115,780 |
| Watermelon | -4,960 | 27,480 | -31,631 | -9,111 |
| **TOTAL** | **-157,968** | **77,270** | **-153,809** | -234,507 |

[1] For those production regions where producer revenues increased.
[2] For those production regions where producer revenues decreased.
Source: Calculated.

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## 8. Summary

A prodigious amount of research has been conducted regarding potential alternatives for methyl bromide that could be used when the scheduled ban on its use occurs. The research has included numerous chemical and nonchemical control techniques that have been evaluated for their effectiveness in controlling diseases, nematodes and weeds and for the resulting yields.

These experiments have considerable utility in the estimation of potential economic impacts of the scheduled ban on methyl bromide. The economic effects will result from differences in yields and control costs between the alternatives and methyl bromide. Many of the experiments measure yield differences between methyl bromide and alternative treatments. Estimates of treatment costs depend on rates of inputs used as replacements, and these are defined in the experiments as well.

However, there are several crops for which very little research has been completed regarding methyl bromide alternatives – watermelon, squash, peppers, ornamentals, nurseries, eggplant and cucumbers. For these crops, the economic analysis of alternatives has to be based on assumptions based on the crops that have been studied more extensively – strawberries and tomatoes. However, even for these two crops, it is not possible to rely solely on the experimental data for economic analysis since continuous experiments have not been conducted on the same plots of ground. Consequently, the results may not be representative of the long-run situation because pest populations may build up and shift over time due to the use of less effective alternatives. Thus, expert opinion still plays an important role in the specification of likely yield changes resulting from the scheduled ban.

The research experiments conducted in the last several years have produced some significantly different estimates of the potential yield impacts of the scheduled ban on methyl bromide. For example, earlier estimates of the potential negative impact on Florida tomato production resulting from the methyl bromide ban range from 20 to 40% production losses. Much of the predicted loss was attributable to poorly controlled weed species. However, subsequent research with herbicides in Florida tomatoes has resulted in a predicted loss of 10% without methyl bromide.

For California strawberries, the yield loss estimate used in this report is higher than those in previous economic impact studies based on research that has shown cumulative negative effects over time and the carryover impact from the strawberry nurseries.

Undoubtedly, as additional research is conducted prior to the scheduled 2005 ban of methyl bromide, the economic impact analyses can be refined further. In addition to a more complete understanding of the performance of alternatives, there most likely will be regulatory changes affecting the available alternatives. For example, new herbicides may be registered, and current regulatory limitations on the use of 1,3-D may be eased.

Much uncertainty surrounds the question of whether and how many of the postharvest uses of methyl bromide will be exempt from the scheduled ban. This report's economic impact analysis assumes that they all will be banned. However, many, if not most, may be exempt.

The economic impact analysis relies on the identification of the single alternative likely to be used by the majority of growers following the scheduled methyl bromide ban. In all cases, this alternative has been a specific combination of fumigants and herbicides for each crop and region. These alternatives were identified based on an assessment of their performances, not only in terms of yields and costs, but also in terms of variability and potentially inadequate performance under variable climatic conditions. There are many alternatives that have performed very well experimentally in certain tests *vis-à-vis* methyl bromide. These include nonchemical alternatives, such as solarization. Nonchemical alternatives were not selected as the predominant alternative likely to be used following the scheduled methyl bromide ban since they are more variable in performance and more dependent on specific climatic conditions. However, in reality, a certain number of growers may choose to use a strictly nonchemical set of alternatives to methyl bromide. This may be the case because of the fit between the alternative (such as solarization) and the specific local climatic and pest conditions. Growers may choose to use nonchemical alternatives such as solarization on an every-other-year basis.

The truly extraordinary fact about methyl bromide is how consistently well it has performed as a control for numerous weeds, diseases, insects and nematode species for more than three decades. The fact that growers of strawberries in California and tomatoes in Florida currently choose to use methyl bromide year after year on close to 100% of their acreage indicates that it does provide more cost-effective pest control than currently available alternatives. As a result, economic losses can be expected following its scheduled removal.

Table 8.1 summarizes this report’s economic impact estimates for the scheduled ban on methyl bromide. Table 8.2 ranks preplant uses of methyl bromide according to the value of a pound of the active ingredient, and Table 8.3 ranks postharvest uses of methyl bromide according to the value of a pound of active ingredient. For preplant uses, per-pound values were calculated by adding per-acre value of yield losses using the next best alternative and the cost changes associated with alternative practices, then dividing by the per acre application rate. The preplant per-acre values do not take into account price or production changes. For postharvest uses, per pound values were based on calculating the impact per pound of commodity and dividing by the application rate per pound of commodity.

**TABLE 8.1: U.S. Economic Losses from the Ban on Methyl Bromide**

| | ($1,000/yr) |
|---|---|
| Preplant Uses | |
| Perennials | |
| Almonds | 45,717 |
| Grapes | 75,446 |
| Nectarines | 7,955 |
| Peaches | 5,732 |
| Prunes | 4,937 |
| Walnuts | 3,414 |
| Total | 143,201 |
| | |
| Nurseries/Ornamentals | |
| Caladium | 1,206 |
| Cut flowers | 14,387 |
| Sod | 55,638 |
| Strawberry nurseries | 2,907 |
| Perennial nurseries | 18,633 |
| Rose plant nurseries | 6,275 |
| Tobacco | 2,516 |
| Total | 101,562 |
| | |
| Annuals | |
| Strawberries | 70,604 |
| Tomatoes | 115,780 |
| Watermelons | 9,111 |
| Cucumbers | 6,028 |
| Squash | 4,575 |
| Peppers | 16,091 |
| Eggplant | 12,319 |
| Total | 234,507 |
| | |
| Total Preplant Uses | 479,270 |
| | |
| Postharvest Uses | 4,262 |

**Table 8.2. Crop Value Per Pound of Methyl Bromide**

| Region | Crop | Value ($/lb) |
|---|---|---|
| California South Coast | Strawberry | 55.07 |
| California Central Coast | Strawberry | 55.01 |
| California | Premium Wine Grapes | 54.36 |
| California San Joaquin Valley | Almonds | 47.03 |
| Florida Central | Strawberry | 34.27 |
| California | Sod | 33.81 |
| California | Perennial Nurseries | 33.59 |
| California | Carnations | 32.85 |
| California Sacramento Valley | Almonds | 30.98 |
| Florida Dade | Tomato-Squash | 23.57 |
| California | Chrysanthemum-Pompon | 21.07 |
| Florida Southwest | Tomato-Squash | 21.01 |
| Florida Central | Tomato-Squash | 19.20 |
| California Sacramento Valley | Walnuts | 18.07 |
| Florida Central | Pepper-Squash | 17.17 |
| California South Coast | Tomato | 16.91 |
| Florida Southwest | Tomato-Watermelon | 15.51 |
| California San Joaquin Valley | Walnuts | 15.20 |
| Florida Central | Tomato-Cucumber | 15.11 |
| Florida Central | Tomato-Watermelon | 15.09 |
| Florida Southeast | Tomato-Cucumber | 14.70 |
| California San Joaquin Valley | Prunes | 14.48 |
| Florida Southwest | Tomato-Cucumber | 14.42 |
| California | Other Wine Grapes | 14.30 |
| California | Nectarines | 13.60 |
| Florida Central | Pepper-Watermelon | 13.06 |
| Florida Southeast | Pepper-Cucumber | 13.02 |
| Florida Dade | Tomato | 13.02 |
| Florida Southwest | Pepper-Watermelon | 12.99 |
| Florida Southwest | Pepper-Cucumber | 12.99 |
| Florida West and North | Tomato-Watermelon | 12.93 |
| California Sacramento Valley | Prunes | 12.69 |

**Table 8.2 Continued.**

| Region | Crop | Value ($/lb) |
|---|---|---|
| Georgia | Sod | 12.53 |
| Florida West and North | Watermelon-Fall | 12.18 |
| Florida Central | Watermelon | 11.96 |
| Florida Southwest | Watermelon | 11.96 |
| California | Rose Plant Nurseries | 10.79 |
| California | Peaches | 9.93 |
| Florida West and North | Watermelon-Spring | 9.70 |
| Florida Southwest | Tomato-Fall | 9.51 |
| South Carolina | Tomato | 9.51 |
| Florida Central | Tomato-Fall | 9.07 |
| California | Raisin Grapes | 8.79 |
| Florida | Other Cut Flowers | 8.48 |
| Florida Southeast | Tomato | 8.31 |
| Florida Southwest | Tomato-Spring | 8.30 |
| California | Table Grapes | 8.24 |
| Georgia | Tomato-Fall | 8.17 |
| Florida Southeast | Pepper | 8.10 |
| Florida West and North | Tomato-Fall | 7.99 |
| Georgia | Tomato-Spring | 7.93 |
| Florida Southwest | Pepper | 7.81 |
| Florida Central | Tomato-Spring | 7.74 |
| Florida Central | Pepper-Fall | 7.57 |
| Florida West and North | Tomato-Spring | 7.25 |
| Florida Southeast | Eggplant | 6.59 |
| Florida Central | Pepper-Spring | 6.20 |
| California | Other Cut Flowers | 6.13 |
| Florida Dade | Eggplant | 5.80 |
| California | Strawberry Plants | 5.31 |
| Florida | Sod | 4.87 |
| Florida Central | Eggplant-Spring | 4.02 |
| Florida Southwest | Eggplant-Spring | 4.02 |
| Florida Central | Eggplant-Fall | 3.76 |
| Florida Southwest | Eggplant-Fall | 3.76 |
| Florida | Caladium | 2.97 |
| Florida | Tobacco Plants | 2.88 |
| Georgia | Tobacco Plants | 2.88 |
| Tennessee | Tobacco Plants | 2.88 |
| North Carolina | Pepper | 2.73 |
| California | Roses | 1.90 |
| Florida | Gladiola | 1.03 |

**Table 8.3. Post Harvest Impact Per Pound of Methyl Bromide**

| Crop | Origin | Impact Per Pound of MB ($) |
|---|---|---|
| Sweet Cherries | Oregon | 85.26 |
| Sweet Cherries | California | 85.26 |
| Sweet Cherries | Washington | 85.26 |
| Oranges | Texas | 83.08 |
| Grapefruit | Texas | 83.08 |
| Blueberries | Arkansas | 43.66 |
| Peaches and Nectarines | U.S. | 43.31 |
| Prunes | California | 28.67 |
| Blueberries | Georgia | 26.74 |
| Dates | California | 18.75 |
| Figs | California | 18.75 |
| Raisins | California | 17.81 |
| Tangerines | Florida | 15.91 |
| Grapefruit | Florida | 15.85 |
| Oranges | Florida | 15.85 |
| Blueberries | Florida | 15.74 |
| Apricots | Washington | 11.30 |
| Oak logs | U.S. | 9.55 |
| Walnuts | California | 5.08 |
| Strawberries | California | 3.98 |
| Plums and Prunes (fresh) | Washington | 0.72 |
| Cotton | U.S. | 0.00 |
| Rice | U.S. | 0.00 |
| Tobacco | U.S. | 0.00 |