Economic and pest management evaluation of the withdrawal of chlorpyrifos: six major California commodities

Prepared for the Department of Pesticide Regulation by the California Department of Food and Agriculture's Office of Pesticide Consultation and Analysis and the University of California

Rachael Goodhue[1], Kevi Mace[1,2], Jessica Rudder[1], Tor Tolhurst[1], Daniel Tregeagle[1], Hanlin Wei[1], Beth Grafton-Cardwell[3], Ian Grettenberger[1], Houston Wilson[3], Robert Van Steenwyk[4], John Steggall[1,2]

[1]University of California, Davis
[2]California Department of Food and Agriculture
[3]University of California, Riverside
[4]University of California, Berkeley

Executive Summary

Chlorpyrifos was listed as a toxic air contaminant by the California Department of Pesticide Regulation (DPR) in 2019 due to evidence identified in its risk assessment that exposure to chlorpyrifos causes developmental neurotoxicity in children and sensitive populations. As a result, DPR determined that use of chlorpyrifos is a detriment to public health and sent notices to cancel chlorpyrifos product registrations to registrants on August 14, 2019 (CDPR 2019). On October 9th, DPR announced that virtually all use of chlorpyrifos products would end by December 31, 2020, following an agreement with Dow AgroSciences and several other registrants (CalEPA 2019). DPR did not seek to cancel granular product registrations, and those registrations are not subject to the agreement, as granular products are not associated with health effects from exposures identified in DPR's risk assessment. These products represent less than 2% of the pounds of chlorpyrifos used in California from 2015-2017.

This report is a discussion of the role of chlorpyrifos in pest management and an estimate of economic impacts of the withdrawal of chlorpyrifos in six crops: alfalfa, almond, citrus, cotton, grape, and walnut. Citrus includes orange, grapefruit, lemon, tangerine and hybrids, and pomelo. Grape includes table, raisin, and wine grape. Crops were chosen based on their use of chlorpyrifos relative to their harvested acreage, their use relative to other crops, and their economic importance to California agriculture. These six crops accounted for 86% of chlorpyrifos use and 48% of the value of California's field, fruit, nut, vegetable and melon production in 2017.

This report considers two economic impacts: reductions in gross revenues due to yield losses, and changes in pest management costs due to replacing chlorpyrifos with alternative pesticides. Increases in pest management costs and decreases in gross revenues due to yield losses both reduce net returns. For the six crops considered, annual pest management costs are estimated to increase by $10.9 million to $12.5 million, depending on the base year used for acreage (Table ES-1). Table ES-2 presents the per acre costs with and without chlorpyrifos and the total number of acres affected for each crop in 2017. Full results are presented in the body of the report. For crops other than cotton, net return losses were due only to increases in pest management costs because yield and/or quality reductions are not anticipated to occur as a result of the withdrawal of chlorpyrifos. In cotton, the withdrawal of chlorpyrifos could lead to inadequate control of late season aphids and whiteflies, resulting in sticky cotton. Sticky cotton is a multi-pronged problem. It is not marketable and if a region consistently produces sticky cotton, growers may receive lower prices or be barred from selling to individual processors. Accounting for yield losses of 25% for Pima cotton and 15% for Upland cotton results in calculated annual gross revenue losses of up to $14.1 million when 2018 national average prices are used, and it is assumed that the decrease in supply does not increase the market-clearing price (Table ES-3). We use the most recent cotton prices to parallel the use of current rather than historical pesticide product prices.

*Table ES-1. Estimated Increase in Chlorpyrifos-Related Pest Management Costs by Crop and Year ($1,000s)**

Crop	**2015**	**2016**	**2017**
Alfalfa	2,116.8	1,304.5	1,457.7
Almond	892.2	421.3	550.0
Citrus	900.2	1,006.0	952.3
Cotton			
Pima	458.6	504.2	773.1
Upland	181.8	203.0	312.9
Grape			
Raisin and table	2,509.6	2,355.8	2,250.3
Wine	1,873.5	1,892.7	1,915.2
Walnut	3,580.6	3,297.5	2,702.1
Total	**12,513.3**	**10,985.0**	**10,913.6**

*Note: Entries may not sum to totals due to rounding

*Table ES-2. Estimated Per-Acre Chlorpyrifos-Related Pest Management Costs with and Without Chlorpyrifos by Crop in 2017**

Cost	**Chlorpyrifos program costs**	**Alternative program costs**	**Percent difference (%)**	**2017 acres affected**
Alfalfa	$4.28	$13.77	221.7	153,607
Almond	$15.02	$20.34	35.4	103,447
Citrus	$28.23	$42.32	49.9	62,858
Cotton				
Pima	$7.98	$15.04	88.4	109,560
Upland	$7.98	$15.04	88.4	44,333
Grape				
Raisin/table	$14.51	$68.85	437.7	35,424
Wine	$15.18	$78.18	479.1	26,340
Walnut	$15.25	$64.14	320.6	55,266

*Note: Entries may not sum to totals due to rounding

Table ES-3. Estimated Gross Revenue Losses for Cotton by Year ($1,000s): 2018 Average Prices, Perfectly Elastic Demand

Type (yield loss)	**2015**	**2016**	**2017**
Pima (25%)	-4,346.6	-5,535.6	-6,644.8
Upland (15%)	-626.2	-851.5	-781.3
Total	**-4,972.8**	**-6,387.2**	**-7,426.1**

*Note: Entries may not sum to totals due to rounding

Alfalfa. In 2017, there were 660,000 harvested acres of alfalfa used for hay, which produced 4.5 million tons worth $785 million (CDFA 2018a). In addition, 4.7 million tons of alfalfa used for forage was produced on 700,000 acres, with no value of production reported. Alfalfa pests managed with chlorpyrifos include blue alfalfa aphid, cowpea aphid, pea aphid, spotted alfalfa aphid, alfalfa weevil, Egyptian alfalfa weevil, alfalfa caterpillar, several *Empoasca* genus leafhoppers, beet armyworm, and western yellowstriped armyworm, granulated cutworm, variegated cutworm, and webworms. Chlorpyrifos use in alfalfa peaks around February, mainly from use against aphid and alfalfa weevil, and July, mainly for use against caterpillars, aphids, and leafhoppers. Although there are alternatives for all the pests, blue alfalfa aphid, cowpea aphid, and alfalfa weevil have only limited alternatives, mostly other broad spectrum insecticides. The $10 per treated acre increase in cost due to replacing chlorpyrifos with an alternative was 1.6% of gross revenues. The associated total annual cost increase is $1.5 million to $2.1 million.

Almond. Almond is California's second largest agricultural commodity in terms of value of production, ranked only behind milk and cream. Gross revenues totaled $5.6 billion in 2017 and exports were $4.5 billion from 1.36 million acres (CDFA 2018a; UC AIC 2018). Chlorpyrifos is mostly used for leaf footed bugs, stink bugs, navel orangeworm, peach twig borer, and San Jose scale. Although there are alternatives, chlorpyrifos is particularly important in the management of leaf footed bugs and stink bugs because the alternatives are mainly pyrethroids. Pyrethroids can cause secondary pest outbreaks by killing resident natural enemies. Additionally, limiting management options to one class of insecticide can lead to more rapid development of resistance in insects. Costs on acres previously using chlorpyrifos are expected to increase by approximately one-third per chlorpyrifos application replaced with an alternative: the absolute value of the increase per treated acre is $5.32, a negligible share of the $5,743 gross revenue per bearing acre. Relatively few almond acres were treated with chlorpyrifos, leading to total annual cost increases ranging from $0.4 million to $0.9 million.

Citrus. Citrus—specifically grapefruit, lemon, orange, mandarin, and their hybrids—constitute one of California's top ten most economically important commodities, with $2.2 billion in gross revenues and $971 million in exports in 2017 from over 318,000 harvested acres (CDFA 2018a; UCAIC 2018). In citrus, chlorpyrifos is used to manage ants, Asian citrus psyllid, scale, and a number of other pests. For many of these pests, chlorpyrifos is not the preferred AI for controlling the specific pest. Rather, its broad spectrum of control makes it advantageous to apply when multiple pests are present. It is also helpful when facing new invasive pests. The absolute value of the increase per treated acre for using an alternative is $14.09, which is a negligible share of gross revenues per acre, which ranged from $5,790 for navel oranges to $15,269 for lemons in 2016-17. Annual pest management costs in citrus are expected to increase by around $1 million.

This analysis was completed before the DPR's announcement in October 2019 that use of virtually all chlorpyrifos would end by December 31, 2020, excluding granular chlorpyrifos products. Citrus is the only focal crop in which continued use of granular chlorpyrifos products could mean that the cost reported here are significantly overestimated because 9.4% of citrus acres treated with chlorpyrifos were treated with granular products.

Cotton. Cotton generated $475 million in gross revenues and $377 million in exports in 2017 (CDFA 2018a; UCAIC 2018). Acreage had been decreasing gradually until recently when it rapidly expanded from its ten-year low of 164,000 acres planted in 2015 to 304,000 planted acres in 2017. In cotton, chlorpyrifos is used to manage cotton aphid, sweet potato whitefly, brown stink bug, cutworms, beet armyworms, and pink bollworm. Cotton aphid and sweet potato whitefly are particularly difficult to control without chlorpyrifos because even small populations can be very damaging in the late season. The main concern is that late season aphids and whiteflies will cause cotton fibers to become sticky, making the cotton potentially unmarketable and possibly damaging California cotton's reputation. Provided that alternatives paired with non-chemical management tools can control these and other pests so that there is no yield loss, the annual cost of the withdrawal of chlorpyrifos would be relatively small, owing to the relatively small acreage treated with chlorpyrifos and the relatively low costs of chlorpyrifos and the composite alternative, totaling $0.6 million to $1.1 million.

Unlike the other crops in this analysis, cotton might experience yield loss with the withdrawal of chlorpyrifos. If late season aphids and whiteflies cannot be controlled with alternatives, then there is the risk of California cotton becoming unmarketable due to cotton stickiness. Pima cotton is more susceptible than Upland to aphids and whiteflies. Accounting for yield losses of 25% (Pima) and 15% (Upland) in addition to the increase in pesticide material costs results in annual net revenue losses of up to $8.5 million when 2018 national average prices are used, and it is assumed that the decrease in supply does not increase the market-clearing price.

Grape. Grape is California's third largest agricultural commodity by value of production, with gross revenues of $5.8 billion and exports totaling $2.5 billion in 2017 (CDFA 2018a; UCAIC 2018). There are three categories of grape produced in California: wine, raisin, and table. In grape, growers almost exclusively use chlorpyrifos to control vine mealybug (*Planococcus ficus)* and ants. Ant control is also important for managing vine mealybug, hence essentially all chlorpyrifos use in grape is directly or indirectly for vine mealybug. Without access to chlorpyrifos, growers would likely increase the number of times they treat with several alternative products in addition to maintaining the rest of the vine mealybug treatment program. On a per-acre basis, the increases in costs of utilizing an alternative AI amount to 2% of gross revenue for raisin grapes, 1% of gross revenue for wine grapes, and less than 0.5% of gross revenue for table grapes. Withdrawal of chlorpyrifos in table, raisin, and wine grapes would result in a $4.2 million to $4.3 million annual cost increase.

Walnut. California accounts for all national walnut production and is the second largest walnut producer in the world, second only to China. For 2017-18, California accounted for 28.1% of world production and 58.7% of world export value (USDA FAS 2018). Gross receipts for walnut totaled nearly $1.6 billion in 2017, which was the seventh largest agricultural commodity by production value (CDFA 2018a). In walnut, chlorpyrifos is used to control codling moth, walnut husk fly, walnut and dusty-veined aphid, and to a lesser extent the Pacific flatheaded and other borers. Withdrawal of chlorpyrifos in walnut would result in a $2.7 million to $3.6 million annual increase in insecticide costs, based on 2015-2017 use. Treatment costs would increase by $48.89 per acre, representing 1% of $4,758 gross revenues per acre.

This analysis was completed before the announcement in October 2019 that virtually all use of chlorpyrifos other than granular products would end by December 31, 2020. Walnut is the only focal crop besides citrus to use granular products; only 0.1% of walnut acres were treated with granular products. The estimated costs from this analysis might be a slight overestimate as that small percentage of use will continue to be allowed.

Caveats. There are a number of caveats regarding the estimates in this report. Here we mention the most significant general ones regarding methodology and ones that hold across crops. Crop-specific caveats are included in the individual analysis of that crop. Caveats regarding methodology include the following. First, not all of California agriculture is included. Total industry costs will be greater than those reported here. Second, the analysis uses data from 2015-2017, the three most recent years available. This time period may not represent production conditions in current and future years owing to differences in weather, invasive species that became pests after 2017, and other factors that vary over time. Also, there may have been significant changes in pesticide use since 2017 that are not reflected here that could affect the impacted acres or alter the relative use of the alternative AIs. Any such changes could affect the cost of the withdrawal of chlorpyrifos, although whether the impact is to increase or decrease withdrawal costs is indeterminate ex ante. New permit conditions for chlorpyrifos implemented in January 2018 and 2019 are recent changes that most likely will reduce affected acres because fewer growers are using chlorpyrifos under the new permit conditions. Another methodological caveat is that growers may change their allocation of land to various crops, which could alter the cost of withdrawal. Steggall et al. (2018) provide a more complete discussion of the methods used here and addresses the logic behind each major modeling decision.

Other caveats regard regulatory and biological considerations that are common across crops. New regulations may change the availability of alternative active ingredients (AIs). In addition, new AIs or uses of existing AIs could be registered. There are three particularly significant biologically based caveats. First, chlorpyrifos has a relatively broad spectrum of control compared to many alternatives. Depending on the crop and which pests are present, multiple alternative AIs may need to be applied in order to manage them, while an application of chlorpyrifos would have addressed multiple pest species. Second, invasive species may increase the cost of the withdrawal of chlorpyrifos. The development of pest resistance to AIs can increase the cost of withdrawal by reducing the number of modes of action available. Even if an alternative AI may manage a specific pest, using it for that pest may limit its availability for managing others, which can increase the cost of pest management and/or reduce yields and gross revenues. Finally, impacts on yield are critical determinants of the cost of withdrawal. Given the current availability of alternatives, growers are anticipated to adjust their pest management programs so that yield losses do not occur for five of the six crops considered (excluding cotton); if growers cannot do so, losses would increase relative to those estimated here.

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Introduction

Chlorpyrifos is an organophosphate insecticide that works by inhibiting acetylcholinesterase. Chlorpyrifos was listed as a toxic air contaminant by the California Department of Pesticide Regulation (DPR) in 2019 due to evidence that exposure to chlorpyrifos causes developmental neurotoxicity in children and sensitive populations. As a result, DPR determined that use of chlorpyrifos is a detriment to public health and sent notices to cancel chlorpyrifos product registrations to registrants on August 14, 2019 (CDPR 2019). On October 9th, DPR announced that virtually all use of chlorpyrifos products would end by December 31, 2020, following an agreement with Dow AgroSciences and several other registrants (CalEPA 2019). DPR did not seek to cancel granular product registrations, and those product registrations are not subject to the agreement, as granular products are not associated with health effects from exposures identified in DPR's risk assessment. Granular products represent less than 2% of the pounds of chlorpyrifos used in California from 2015-2017.

This report is a discussion of the general role of chlorpyrifos in pest management and an estimate of the economic impact of the withdrawal of chlorpyrifos on pest management costs in six crops: alfalfa, almond, citrus, cotton, grape, and walnut. It is part of the interagency consultation between DPR and the Office of Pesticide Consultation and Analysis (OPCA) in the California Department of Food and Agriculture (CDFA). Accordingly, the analysis is limited to evaluations of the pest management and economic effects on California agriculture of regulations regarding pesticides under consideration by DPR, which is OPCA's mandate as specified in the California Food and Agricultural Code, Section 11454.2. It considers two economic impacts: reductions in gross revenues due to yield losses, and changes in pest management costs due to replacing chlorpyrifos with alternative pesticides.

Crops were chosen based on their use of chlorpyrifos relative to their harvested acreage, their use of chlorpyrifos relative to use on other crops, and their economic importance. These six crops accounted for 86% of chlorpyrifos use and 48% of the value of California's field, fruit, nut, vegetable and melon production in 2017.

Figure 1. Statewide chlorpyrifos use: 2000-2017

Chlorpyrifos use statewide has generally decreased since 2005 (Figure 1), although there was an uptick in total use in 2017, mainly driven by cotton (Figure 2). After DPR made chlorpyrifos a restricted use material in 2015, updates to interim permit conditions in 2018 and 2019 further restricted the use of chlorpyrifos. PUR data are not yet available for 2018 or 2019. However, in informal communications county agricultural commissioner offices report major reductions in use, particularly after the latest set of permit conditions went into effect in January 2019.

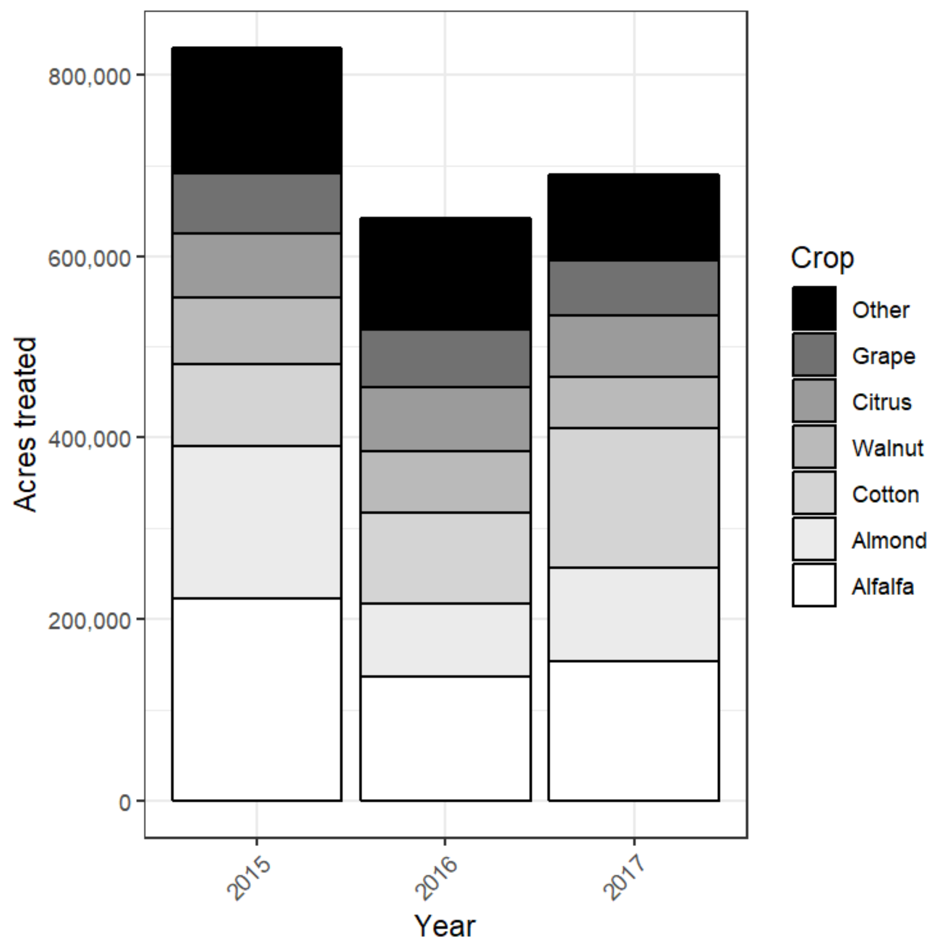


Figure 2. Acres treated with chlorpyrifos by crop: 2015-2017

The 2017 chlorpyrifos use for the top twenty crops by acreage is presented in Appendix A: 2017 Chlorpyrifos Use.

Considerations across All Crops

Several pest management issues are common across crops: resistance management, secondary pest outbreaks, and regional differences that lead to differences in the relative efficacy of chlorpyrifos and available alternatives. Another issue is the availability of alternatives, which could be impacted by ongoing and anticipated regulatory actions, such as the current review of four neonicotinoid insecticides. Our crop analyses identify instances in which one or more of these are particularly important; however, none are entirely absent for any crop.

Resistance management. Resistance, a major pest management issue, is when pests become less susceptible or immune to a specific pesticide through a change that is heritable. In the case of insects with resistant populations, an insecticide will not be as effective, thereby increasing the cost of insect management and/or reducing yield owing to more insect damage. How insecticides kill insects – their modes-of-action (MoA) – is important because insects can quickly evolve resistance to one MoA, and thus multiple active ingredients, if one or more active ingredients in a group are heavily used (Le Goff and Giraudo 2019). Insecticides are classified based on MoA by the Insecticide Resistance Action Committee (IRAC, https://www.irac-online.org/). These classifications are routinely used by growers and pest control advisors (PCAs) because one of the best ways to slow the development of resistance is to limit the exposure of insect populations to specific MoAs by rotating between groups for sequential applications in a given location. Specific guidelines are available to growers and PCAs about how to rotate insecticides to reduce the risk of resistance and, in some instances, product labels restrict applications specifically to reduce the development of resistance.

Chlorpyrifos is regularly used in rotation with insecticides with other MoAs, particularly for pests that are known to have developed or have already developed resistance to some active ingredients (AIs). In these situations, there are chemistries other than chlorpyrifos that are effective against these pests; however, if chlorpyrifos is no longer available in California, there would be fewer AIs to rotate. This is likely to allow resistance to evolve more quickly. We do not address the economic impact of resistance developing faster than it would have otherwise. The mode of action classification for all alternatives mentioned are presented in Appendix B: Mode of Action for all Alternatives.

Secondary pest outbreaks. Primary pests generally require annual application(s) of some control measures while secondary pests more often only require occasional control measures. Secondary pests can quickly become very damaging if an insecticide applied for a primary pest eliminates natural enemies that were keeping the secondary pest in check. This is called a 'secondary pest outbreak' (Gross and Rosenheim 2011). This is a common situation with spider mites. They are typically well controlled by natural enemies. However, when a broad spectrum insecticide like a pyrethroid is used, natural enemies are killed and mite populations can explode very rapidly.

Because of these issues, pest managers take into account how an application targeting one pest will affect populations of other pests when selecting what insecticide to use. Despite being a broad spectrum insecticide, chlorpyrifos can actually be less damaging to some populations of natural enemies owing to evolved resistance (Grafton-Cardwell and Gu 2003, Grafton-Cardwell 2019). Chlorpyrifos alternatives which are more damaging to natural enemies could increase the use of insecticides if secondary pest outbreaks necessitate more treatments. The cost of any such increase in use is not captured in the economic analyses, but it could be substantial. Additionally, it could make the problem of rapidly developing resistance worse because fewer MoAs would be available for an increased number of applications.

Spectrum of control. As a broad-spectrum insecticide, chlorpyrifos is active against multiple pests. This means that one application can be used to control multiple co-occurring pests. If more selective alternatives are used for co-occurring pests, multiple applications could be necessary. This is not accounted for in the economic analysis, meaning that in these situations the cost increases are very likely to be underestimates.

Other regulatory considerations. Regulatory processes addressing various AIs can occur concurrently or in rapid succession, altering the economic impact of an individual regulation. Four neonicotinoids are currently under review by DPR owing to concerns about bee safety:

clothianidin, dinotefuran, imidacloprid, and thiamethoxam. Beta-cyfluthrin/cyfluthrin is also under review by DPR (https://www.cdpr.ca.gov/docs/registration/canot/2018/ca2018-04.pdf). One or more of these are alternatives to chlorpyrifos in several crops. However, this report restricts attention to evaluating the economic impacts of withdrawing chlorpyrifos only and does not incorporate any regulatory actions regarding other AIs.

Caveats

There are a number of caveats regarding this analysis in addition to the considerations common across all crops discussed above. Here we focus on the most significant methodological caveats that apply across crops. Crop-specific considerations are addressed in the crop analyses. First, not all of California agriculture is examined in this report, only the six focal crops. Second, the three-year historical period used for the analysis, 2015-2017, may not represent production conditions in current and future years due to differences in weather, which affects pest population development and management as well as other dimensions of crop production, or due to invasive species that became pests after 2017. Related to this, a third caveat is that there may have been significant changes in pesticide use since 2017 that are not reflected here that could affect the impacted acres or alter the relative use of the alternative AIs. Any such changes could affect the cost of the withdrawal of chlorpyrifos, although the sign of the impact is indeterminate ex ante. New permit conditions for chlorpyrifos implemented in January 2019 are a recent change that most likely will reduce affected acres. Another caveat is that growers may change their allocation of land to various crops, which could alter the cost of withdrawal. Finally, impacts on yield are critical determinants of the cost of withdrawal. Given the current availability of alternatives, growers are anticipated to adjust their pest management programs so that yield losses do not occur for five of the six crops considered; if growers cannot do so, losses would increase relative to those estimated here. For cotton, the one exception, the estimates in this report assume that all acreage of cotton treated with chlorpyrifos could sustain a yield loss due to the loss of use of chlorpyrifos; if not all treated acreage is infested with the cotton aphid and/or sweetpotato whitefly, losses would be smaller than those presented here. Steggall et al. (2018) provide a more complete discussion of the methods used here and addresses the logic behind each major modeling decision.

Methods

Crop Selection

Crops were first assessed by how many pounds of the AI were used cumulatively in crops between 2015 and 2017. Six crops had over 250,000 lbs applied: almond, citrus (including grapefruit, oranges, lemons, and mandarins), alfalfa, walnut, grape (including raisin, table and wine grapes), and cotton. These crops also had the most acres treated with chlorpyrifos over the same time period. The crops were all in the top twenty California commodities in terms of value of production in 2017 (CDFA 2018a). Based on their chlorpyrifos use and economic importance, these crops were selected as the focal crops for this report.

Pesticide Use Data

Pesticide pounds applied and acreage treated by AI, were obtained from the Pesticide Use Report (PUR) database. The PUR compiles data from California's pesticide use reporting program that has been operating since 1990. Use trends were examined at various time intervals within a year depending on crop. Economic analyses relied on data from 2015-2017, the three most recent years available. There may have been substantial changes in use since then that are not captured in these analyses.

Regions. Table 1 presents the standard growing regions for California as defined in the PUR.

Table 1: Growing Regions in California as Defined by the PUR

Region	Counties
Middle Coast	Monterey, San Benito, San Francisco, San Luis Obispo, San Mateo, Santa Clara, Santa Cruz
North Coast	Del Norte, Humboldt, Lake, Marin, Mendocino, Napa, Sonoma, Trinity
North East	Alpine, Amador, Calaveras, El Dorado, Lassen, Mariposa, Modoc, Nevada, Placer, Plumas, Shasta, Sierra, Siskiyou, Tuolumne
Sacramento Valley	Butte, Colusa, Glenn, Sacramento, Solano, Sutter, Tehama, Yolo, Yuba
San Joaquin Valley	Alameda, Contra Costa, Fresno, Kern, Kings, Madera, Merced, San Joaquin, Stanislaus, Tulare
South Coast	Los Angeles, Orange, San Diego, Santa Barbara, Ventura
South East	Imperial, Inyo, Mono, Riverside, San Bernardino

Citrus was examined using crop-specific regions, which are presented in the crop section.

IPM Overview

The PUR does not contain information on the target pest for an application. In order to determine the appropriate alternatives, it is necessary to know what growers are generally targeting with chlorpyrifos and alternative AIs, as well as a sense of the factors influencing variations in use within and across years. We discuss these considerations for each crop and for each target pest, identify alternative AIs used in the economic analyses.

Maps

The maps presented in each crop section visually represent the spatial distribution of the production of each crop across California. They were created using PUR data. PUR data are organized spatially using the Public Land Survey System (PLSS), which divides the country into sections of one square mile. As such, the highest resolution possible with PUR data is one square mile. The maps represent every square mile in which any application of any material was made to the crop in 2017. It is rare for fields to have zero PUR records in a whole year. This method does not capture the acreage within a square mile. The map would show the same result if there were one acre or 100 within the square mile. Citrus is an exception; the map was developed in 2011 by UC ANR with data from the county agricultural commissioners and commodity groups.

Economic Analysis

Changes in net returns are determined by changes in gross revenues and changes in costs. Gross revenues decline with yields. In some cases, a reduction in yields can lead to an increase in price, reducing gross revenue losses. Pest management costs depend on pesticide material costs, the cost per application, and the number of applications required. Although it's often the case that field sanitation measures and other production practices are components of integrated pest management programs, we assume here that growers are already utilizing these practices so that those costs are unchanged. Accordingly, we determined the expected change in pest management costs for each crop based on the acres treated with chlorpyrifos, what alternatives are available, and the costs of the AIs (Steggall et al. 2018). The baseline cost is established by multiplying the cost per acre for chlorpyrifos by the acres treated with it. This is compared to the cost of the regulated scenario. In the regulated scenario we are evaluating, chlorpyrifos would no longer be available. To estimate the cost, we assign all the acres that had been treated with chlorpyrifos to the alternative AIs in proportion to how the alternative AIs were used in 2015-2017 (Steggall et al. 2018). Below we provide the details for the general methods applied to all crops and then describe variations designed to address crop-specific factors.

Gross revenues. No changes in yields are anticipated for five of the six crops considered here given the availability of the identified alternative AIs, so gross revenues are not affected. Cotton is the exception; there is the possibility that marketable yield for Pima cotton could decline. Yield losses ranging from 0% to 50% for Pima cotton were examined for the acres that would have been treated with chlorpyrifos if it were available. Because a yield loss reduces the quantity produced, there is the possibility that the price could increase, which would reduce the loss in gross revenues. The own-price elasticity of demand represents the relationship between the change in quantity and the change in price. Two elasticities are used to consider this impact: a perfectly elastic demand curve, so that price is unchanged, and an own-price elasticity of -0.95 for California cotton (Russo et al. 2008), so that price increases as demand decreases.

Acres treated and pounds applied. The acres treated with each AI and the pounds of AI applied were extracted from the PUR database for chlorpyrifos and each alternative AI. These data were used to construct the use trend graphs and tables presented for each crop as well as in the economic analysis. Applications with zero acreage reported were dropped from the study.

Selection of representative products. For each target pest, crop, and alternative AI, we identified a representative product to use in determining the cost of the withdrawal of chlorpyrifos. The representative product for an AI was generally one that was used on the most acres of the crop in question from 2015-2017. When there were substantial disparities in the ranking of products by use between years, 2017 was used because it reflects the most recent decision making by growers.

Representative product prices. Once representative products were identified, we determined the price for each product. Prices were obtained from communications with industry members, Farm Business Network reports, internet searches, and recent cost and return studies. Prices are variable across time, crop, and quantity purchased. Growers may be paying more or less than the prices we identify for a given representative product.

Calculating material cost per acre. The price for the representative products is standardized to cost per pound of product. For example, if the price is $10/oz, the standardized cost is $10/oz * 16 oz/lb, or $160/lb. We used the density of the products for aqueous products, provided in the PUR database product table, to convert the product cost to cost per pound. Because we are interested in the cost of the AI and not inert ingredients, the cost per pound is multiplied by the percentage of the product that is AI, also found in the PUR database product table, to obtain the cost per pound of the AI. The cost of the AI per acre is simply the cost per pound multiplied by the average use rate (pounds of AI applied/acres treated) for that crop across the study period (Steggall et al. 2018). It is important to note that we use the average use rate to calculate the cost per acre. Some growers apply less per acre so their material costs are lower, and some apply more so their material costs are higher.

Cost of the composite alternative. We first calculate the share of acreage treated with chlorpyrifos or an alternative AI for each AI. We then assume that if chlorpyrifos were withdrawn that alternative AIs will replace it on the affected acreage proportionately to their shares of all treated acreage. We weight the material cost per acre of the identified alternatives AIs by their share of acreage treated in order to construct a cost per acre of a "composite alternative." This cost is a weighted average cost; some applications will cost more per acre, and others less.

Scenario costs. In order to calculate the cost of the loss of chlorpyrifos for each focal crop, we compare net revenues under the status quo to net revenues if chlorpyrifos was withdrawn. In this study, UC Cooperative Extension personnel determined that there would not be a yield loss for five of the six crops examined, so the change in net revenues reduces to the change in cost. The change in cost per acre is only the change in the material cost per acre because alternatives utilize the same application methods as chlorpyrifos and the same number of applications is required. The total change in costs if chlorpyrifos was withdrawn is the acres currently treated with chlorpyrifos multiplied by the change in the cost per acre. As noted above, Pima cotton could also incur a reduction in gross revenues, which would increase the cost of withdrawal.

Crop-specific considerations. Table 2 summarizes methodological refinements required to address specific dimensions of the use of chlorpyrifos and its alternatives in individual crops.

Table 2. Summary of Methodological Refinements by Crop

Crop	Crop-specific considerations
alfalfa	
almond	
citrus	Regions are different from those defined in the PUR. Abamectin and pyriproxyfen bait and spray are analyzed separately.
cotton	Pima and Upland cotton analyzed separately. Treated cotton acreage divided in proportion to harvested acreage in CDFA (2018). Yield losses included.
grape	Multiple applications needed to replace some chlorpyrifos applications.
walnut	Spinosad spray and bait analyzed separately.

Alfalfa

Alfalfa is used in multiple ways as animal feed, including as fresh (green-chop), dried (hay) and fermented (silage) feed. There were 660,000 harvested acres of alfalfa used for hay, which produced 4.5 million tons worth $785 million (CDFA 2018a). In addition, 4.7 million tons of alfalfa used for forage was produced on 700,000 acres, with no value of production reported. California is the 10th largest producer of alfalfa (hay, silage, and green-chop) in the U.S. in terms of quantity. By export value, hay of all types, including alfalfa, was the 13th most important agricultural product in California, with $345 million of production exported in 2017. California's exports accounted for 26.8% of total U.S. alfalfa exports.

Alfalfa is grown throughout the Central Valley, the Southeast Desert and the northernmost counties of California (Figure 3). The largest alfalfa hay-producing county by value is Imperial County, which produced over $148 million, or 17% of state production, in 2017. The next highest alfalfa hay-producing counties were Merced (13.2% of production value), Kern (11.6%), Tulare (9.9%), and Riverside (6.9%). Alfalfa hay was also a top-two agricultural commodity by value in 2017 for Inyo ($3 million), Lassen ($21 million), Mono ($10 million), and Siskiyou ($39 million) counties.

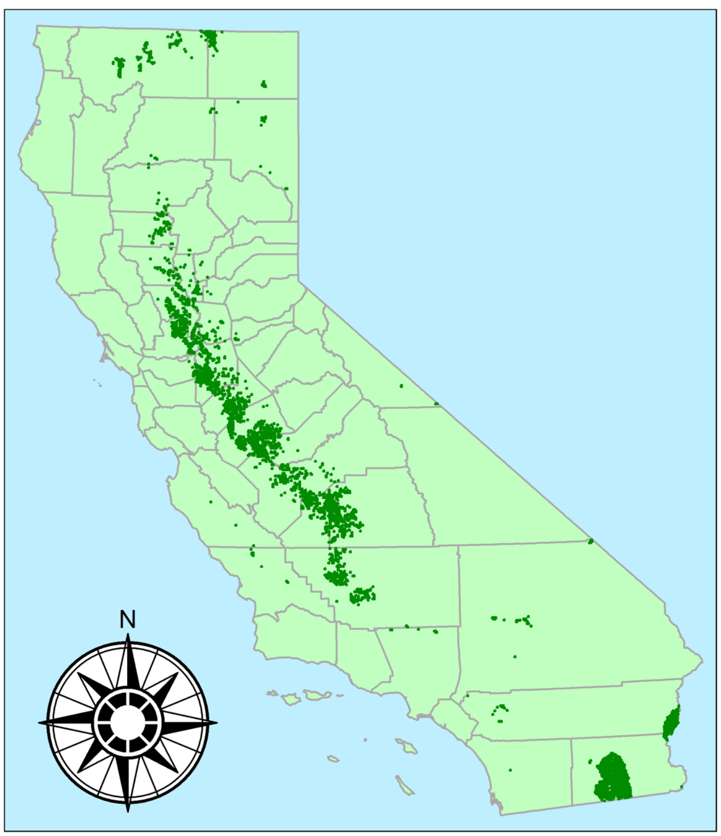


Figure 3. California alfalfa production: 2017

IPM Overview

A number of insect pests pose a threat to alfalfa production across California. Chlorpyrifos is crucial for aphid control and an important component in the management of several others such as weevils. IPM is widely used in California alfalfa production. Chlorpyrifos is used to manage severe outbreaks while ensuring the effectiveness of other insecticides by delaying resistance. In addition to the use of insecticides, resistant cultivars, early cutting, modified strip cutting, and conservation of natural enemies are also employed in alfalfa IPM.

Target Pests

Aphids. Four aphid species are pests of alfalfa: blue alfalfa aphid (*Acyrthosiphon kondoi*), cowpea aphid (*Aphis craccivora*), pea aphid (*Acyrthosiphon pisum),* and spotted alfalfa aphid (*Therioaphis maculata*). Depending on the growing region, they can occur throughout the year, damaging alfalfa via direct feeding and injecting toxins (variable among species) that can stunt growth in later cuttings. Aphids also produce honeydew that can reduce palatability for livestock and interfere with harvesting.

The two most damaging aphids are the blue alfalfa aphid and cowpea aphid. The blue alfalfa aphid is a cool weather aphid that often develops well before the presence of natural enemies. Cowpea aphid numbers are higher in the summer months. Chemical alternatives to chlorpyrifos include the carbamate methomyl (the methomyl label lists only pea aphid but it does control all aphids), organophosphates - dimethoate and malathion, pyrethroids - beta-cyfluthrin, lambda-cyhalothrin and cypermethrin and others, flupyradifurone and flonicamid[1]. Alternative management strategies include border cutting, resistant varieties (for blue alfalfa aphid, but not cowpea aphid) and conservation of natural enemies (parasitoids, *Aphidius ervi*, *A. smithi*, etc. and predators, lady beetles and lacewings, etc.). Pyrethroids and methomyl can be very disruptive for natural enemy populations. Reduced dimethoate efficacy has been noted, though it may be more efficacious than chlorpyrifos and malathion at cooler temperatures. Although spotted alfalfa aphid and pea aphid have fewer chemical alternatives, resistant cultivars are available and often used.

Weevils. Alfalfa weevil (*Hypera postica*) and Egyptian alfalfa weevil (*Hypera brunneipennis*) are serious pests of alfalfa throughout California. Both young and older larvae can damage alfalfa via feeding, potentially causing complete defoliation. Damage is more prevalent in the first cutting, which is where control is typically focused. Chemical alternatives to chlorpyrifos include the more selective insecticides indoxacarb and spinosad, the pyrethroids lambda-cyhalothrin and beta-cyfluthrin, and the organophosphates malathion and phosmet. Indoxacarb does not provide aphid control. Spinosad has a short residual and is used to suppress rather than control weevils. Phosmet also has a shorter residual than chlorpyrifos and can be disruptive to natural enemies of other pests and cause secondary pest outbreaks. It is not commonly used Table 3. Parasitic wasp introductions to California have generally not resulted in adequate weevil control. The soil dwelling fungus (*Zoophthora phytonomi*) can provide some control in certain regions with adequate soil moisture. Early harvest can sometimes prevent serious damage but can also concentrate surviving larvae in the windrows where they can damage regrowing plants. Resistance is a growing issue for alfalfa weevil management with resistance to pyrethroids evident in multiple locations (Long et al. 2002) and options for rotating insecticides are limited.

Leafhoppers. Several species of the *Empoasca* genus are occasional pests on alfalfa, primarily in the summer. Damage, which manifests as stunting and yellowing, usually starts at the field margin, spreading inward. A number of chemical alternatives are available such as the pyrethroids permethrin, beta-cyfluthrin, zeta-cypermethrin, and lambda-cyhalothrin; the carbamate methomyl; the organophosphates dimethoate and phosmet; and the narrower spectrum flupyradifurone. Early cutting can be used to control leafhoppers. Uncut border strips can lead to damaging levels of leafhoppers.

Alfalfa caterpillar (Colias eurytheme). The alfalfa caterpillar is a summertime pest of alfalfa that feeds on alfalfa foliage. Control can be achieved by conservation of natural enemies particularly the parasitoid, *Cotesia medicaginis*. The alfalfa caterpillar is prone to cyclical outbreaks every few years, which can be due in part to the presence of hyperparasitoids which disrupt biological control. Insecticide sprays may be necessary when natural enemies do not provide adequate control; during hot, dry weather; when crop growth is slow and uneven; and/or when other pests are also present. Alternatives to chlorpyrifos include the more selective insecticides chlorantraniliprole, methoxyfenozide, and indoxacarb, along with *Bacillus thuringiensis kurstaki*, which currently is largely, perhaps exclusively, used in organic production. The carbamate methomyl is also available but is broad spectrum and a restricted material. Modified strip cutting or early cutting can also be used in alfalfa caterpillar IPM programs.

Strip cutting is the practice of leaving uncut strips of alfalfa in the field as habitat for beneficial insects. The standard strip cutting method developed by Stern et al. (1967) has not been widely adopted because of logistical problems regarding water loss and moving equipment. However, growers may split larger alfalfa blocks and then cut them on a rotation pattern as a variation on strip cutting.

Armyworms. Beet armyworm (*Spodoptera exigua*) and western yellowstriped armyworm (*Spodoptera praefica*) are prone to cyclical summer outbreaks in the Central Valley and desert valley. Larvae skeletonize foliage, causing a whitish appearance on the tips of leaves known as "whitecaps." Chlorpyrifos alternatives include more selective insecticides such as chlorantraniliprole, methoxyfenozide, and indoxacarb, along with *Bacillus thuringiensis aizawai*, which is currently used mostly in organic production. The carbamate methomyl is another chemical option. Important IPM strategies include early harvest, modified strip cutting, and biological control. Natural enemies, including the parasitoid *Hyposoter exiguae,* frequently control armyworms, especially when populations are small.

Cutworms. Granulate cutworm (*Feltia subterranea*) and variegated cutworm (*Peridroma saucia*) are sporadic pests throughout the growing region though they are more common in the low desert. The larvae damage alfalfa by feeding on seedlings, new growth and roots at or below the soil surface. Alternatives to chlorpyrifos include the selective insecticide indoxacarb and the pyrethroids beta-cyfluthrin, permethrin, and lambda-cyhalothrin. Non-chemical control options include water and weed management, tillage, and conservation of natural enemies.

Webworms (*Loxostege* spp). Webworms are an occasional pest of alfalfa. They spin webs, folding leaves into shelters, allowing them to feed undisturbed. In abundance, these webs can be clearly visible, though this pest rarely requires pesticide treatment. For large outbreaks, a number of chlorpyrifos alternatives are available: the more selective insecticides methoxyfenozide and *Bacillus thuringiensis*, the pyrethroids beta-cyfluthrin, permethrin, lambda-cyhalothrin, and zeta-cypermethrin along with the restricted carbamate carbaryl. Pyrethroids disrupt natural enemies. *Bacillus thuringiensis* is mainly used in organic production but could see increased use in conventional fields. Early cutting may also be used to manage webworm larvae.

Chlorpyrifos Use: 2015-2017

Chlorpyrifos use in alfalfa peaks around February, mainly from use against aphid and alfalfa weevil, and July, mainly for use against caterpillars, aphids, and leafhoppers (Figure 4). Although the seasonal pattern is consistent across all three years, the acreage treated in February in 2015 was over twice as large as acreage treated in February in either 2016 or 2017. In contrast, summer acres treated were somewhat smaller in 2015 than in 2016 and 2017.

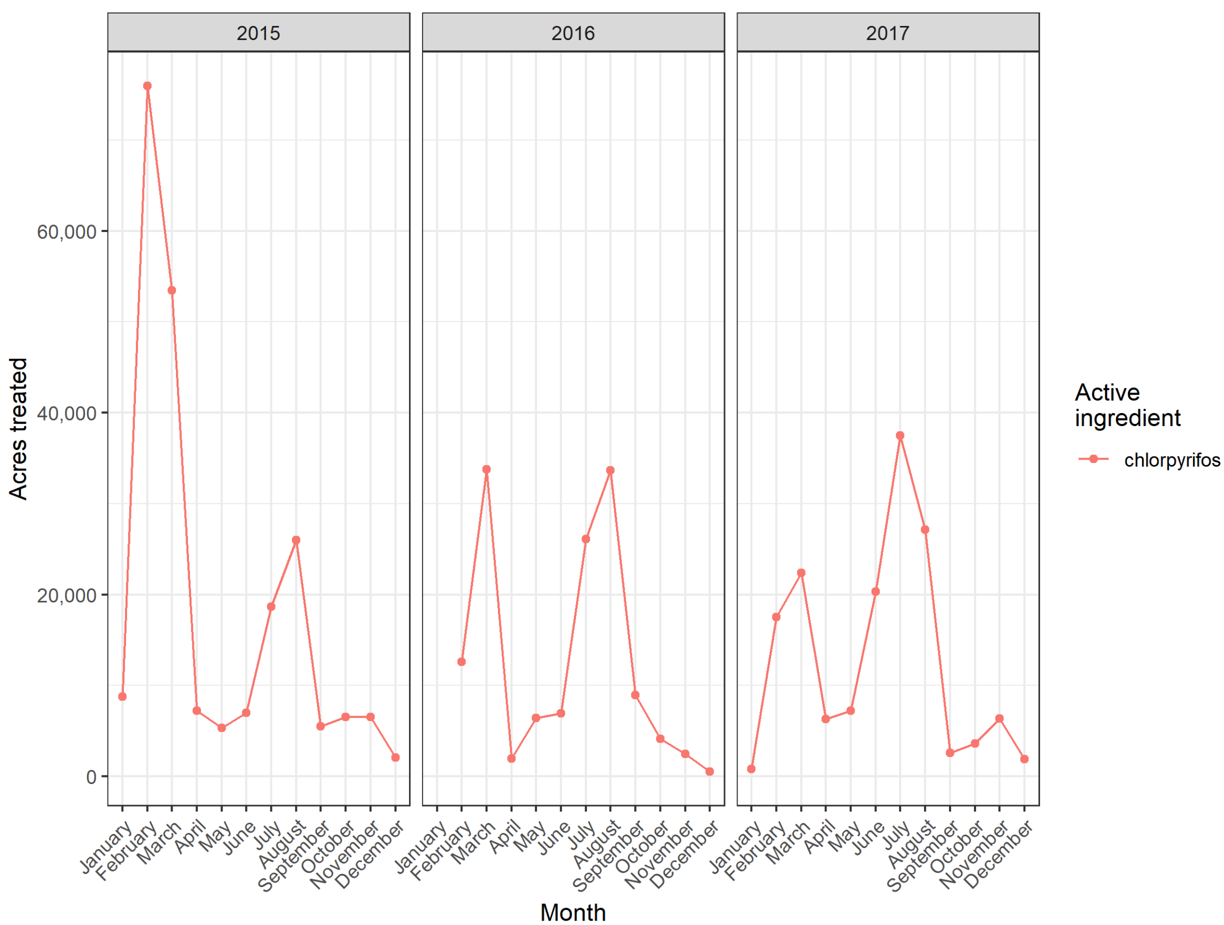


Figure 4: Monthly use of chlorpyrifos: alfalfa, 2015-2017

Table 3: Annual Use of Chlorpyrifos and Alternative Active Ingredients: Alfalfa, 2015-2017

Active ingredient	**-------Pounds applied-------**				**-----------Acres treated----------**				**Use rate (lbs /ac)**
	2015	2016	2017	Total	2015	2016	2017	Total	
bacillus thuringiensis	587	2,256	3,549	6,392	2,820	17,018	26,922	46,760	0.14
beta-cyfluthrin	1,516	687	667	2,870	73,050	32,573	29,022	134,645	0.02
chlorantraniliprole	1,044	2,238	3,935	7,217	27,600	57,544	108,796	193,940	0.04
chlorpyrifos	123,748	67,413	75,642	266,803	223,051	137,455	153,607	514,113	0.52
cypermethrin	234	31	3	268	4,883	631	220	5,733	0.05
dimethoate	137,116	90,189	86,760	314,066	292,984	199,287	188,647	680,919	0.46
flonicamid	5,598	6,713	8,935	21,245	64,144	77,784	103,480	245,408	0.09
flupyradifurone	6,508	16,179	11,846	34,533	58,067	69,652	114,805	242,524	0.14
indoxacarb	11,814	18,060	15,442	45,316	133,343	216,528	178,232	528,103	0.09
lambda-cyhalothrin	11,817	10,495	10,374	32,686	412,613	368,384	359,078	1,140,075	0.03
malathion	75,379	60,586	42,632	178,598	65,930	52,604	36,497	155,030	1.15
methomyl	26,620	24,785	26,300	77,705	38,757	31,376	34,769	104,902	0.74
methoxyfenozide	10,317	14,573	19,289	44,179	93,947	120,657	154,035	368,639	0.12
permethrin	11,572	4,712	7,257	23,541	64,706	32,699	41,217	138,622	0.17
phosmet	2,258	396	1,233	3,886	3,361	566	1,999	5,926	0.66
spinosad	110	168	130	408	1,874	2,927	2,209	7,009	0.06

Economic Analysis

This section presents the estimated change in costs to alfalfa due to the withdrawal of chlorpyrifos. This cost includes only the change in pesticide material costs and does not consider changes in application costs because the application method remains unchanged if an alternative AI is used. In the absence of any anticipated effect on yields, gross revenues will not change. The estimates rely on a single application of an alternative replacing an application of chlorpyrifos. However, as noted above, one of the advantages of chlorpyrifos is its capacity to control multiple pests. If multiple treatments with alternative AIs are required to control multiple pests, while a single application of chlorpyrifos would have done so, then these costs are an underestimate.

Table 4 presents representative products for chlorpyrifos used on alfalfa in 2015–17 and their costs per acre. The material cost per acre is the product of the average use rate (lbs/ac) over this period and the price per pound. The material cost per acre of AIs, ranging from $2.21 to $39.68 per acre. Growers consider other factors in addition to price per acre when deciding which insecticides to use, as discussed in the pest management section above.

Table 4: Representative Products and Costs per Acre: Alfalfa

Active ingredient	Representative product	Material cost per acre ($)
bacillus thuringiensis	Dipel DF Biological Insecticide	5.30
beta-cyfluthrin	Baythroid XL	9.29
chlorantraniliprole	Dupont Coragen Insecticide	23.73
chlorpyrifos	Lorsban Advanced	4.28
cypermethrin	Fury 1.5 EW Insecticide	4.43
dimethoate	Dimethoate 400	6.65
flonicamid	Beleaf 50 SG Insecticide	33.07
flupyradifurone	Sivanto Prime	39.68
indoxacarb	Dupont Steward EC Insecticide	24.55
lambda-cyhalothrin	Silencer	2.21
malathion	Fyfanon 8 Lb. Emulsion	7.55
methomyl	Du Pont Lannate SP Insecticide	31.87
methoxyfenozide	Intrepid 2F	14.85
permethrin	Perm-Up 3.2 EC Insecticide	7.11
phosmet	Imidan 70-W	13.26
spinosad	Success	17.37

Averaged over the three-year period 2015–17, chlorpyrifos was used on 11.4% of total alfalfa acres treated with chlorpyrifos or an alternative AI. Table 5 shows the average acreage shares for each alternative AI, with and without chlorpyrifos being available. Total acres treated with one of these insecticides does not correspond to total acres of alfalfa grown because multiple applications may have been made to a field.

Table 5. Average Annual Acreage Shares of Alternative Insecticides with and without Chlorpyrifos: Alfalfa, 2015–2017

Active ingredient	Chlorpyrifos available (%)	Chlorpyrifos withdrawn (%)
bacillus thuringiensis	1.0	1.2
beta-cyfluthrin	3.0	3.4
chlorantraniliprole	4.3	4.9
cypermethrin	0.1	0.1
dimethoate	15.1	17.0
flonicamid	5.4	6.1
flupyradifurone	5.4	6.1
indoxacarb	11.7	13.2
lambda-cyhalothrin	25.3	28.5
malathion	3.4	3.9
methomyl	2.3	2.6
methoxyfenozide	8.2	9.2
permethrin	3.1	3.5
phosmet	0.1	0.1
spinosad	0.2	0.2
Total	88.6	100

Note: Three years average from 2015-2017. Numbers may not add to 100% due to rounding

In order to construct the composite alternative, the use of alternative AIs is scaled up in proportion to their acreage shares, as discussed in the methods section. The three most common alternative AIs were lambda-cyhalothrin, dimethoate, and indoxacarb, together accounting for 52.1% of total alfalfa acres treated.

Table 6 shows the average per acre costs for chlorpyrifos and the composite alternative. Switching to the alternative would lead to an increase in insecticide material cost of 221.7% per acre on acres that were treated with chlorpyrifos.

Table 6. Costs Per Acre for Chlorpyrifos and the Composite Alternative: Alfalfa

Active ingredient	Material cost per acre ($)	Cost increase for switching to composite alternative (%)
chlorpyrifos	4.28	221.7
composite Alternative	13.77	-

Table 7 reports the estimated change in total annual costs owing to the withdrawal of chlorpyrifos: $1.3 million to $2.1 million. Costs are expected to increase because most of the alternative AIs cost more than chlorpyrifos. Two of the three most common alternative AIs, dimethoate and indoxacarb, are more expensive than chlorpyrifos, costing $6.65 per acre and $24.55 per acre, respectively. The material cost of the third, lambda-cyhalothrin, is $2.21 per acre, which is lower than the material cost of chlorpyrifos. Although it is one of the three alternative AIs with the largest acreage treated, lambda-cyhalothrin accounts for only 25.3% of acres treated and does not offset the higher costs of other alternatives.

Table 7. Change in Treatment Costs due to the withdrawal of Chlorpyrifos: Alfalfa, 2015–2017

Year	Chlorpyrifos available($)	Chlorpyrifos withdrawn ($)	Change in cost ($)	Change in cost (%)
2015	954,687	3,071,456	2,116,770	221.7
2016	588,324	1,892,779	1,304,455	221.7
2017	657,458	2,115,201	1,457,742	221.7

No yield losses are anticipated if chlorpyrifos was withdrawn, so there is no expected change in gross revenues. The application method is the same for chlorpyrifos and alternatives. Therefore, the expected change in material costs are the expected change in net returns for alfalfa. If the proportions of alternative AIs used change over time, these figures may over- or underestimate the costs of the policy, depending on whether the bundle of alternative AIs shifts towards products with a lower or higher cost per acre.

Conclusions

In the case of alfalfa, the total annual cost of the withdrawal of chlorpyrifos is $1.3 million to $2.1 million. Gross alfalfa revenue in 2017 was $1,190 per acre harvested. Without chlorpyrifos, treatment costs would increase from 0.7% of gross revenue to 2.3% of gross revenue on affected acres. As in other crops, the impact of the possibility of insects developing resistance is not evaluated here. The fewer modes of action that remain available for managing a given pest or set of pests, the more likely it is that resistance will develop, and the more quickly it will develop.

Almond

Almond is one of California's most economically important crops. Gross returns for almonds totaled $5.6 billion in 2017, second only to grape in crop value (CDFA 2018a). Almonds are produced throughout the entirety of the Central Valley, from Redding in the north to Bakersfield in the south. Over 80% of this production value, nearly $4.5 billion, is exported, making almonds California's most important export agricultural commodity by value. California accounts for all U.S. almond production and is by far the largest almond producer and exporter in the world. For 2018-2019, California was forecast to produce nearly 80% of world almonds and more than 87% of almonds exchanged through export markets (USDA FAS 2018). There were one million acres of bearing almond orchards in 2017, plus 330,000 acres of non-bearing acreage.

Almond orchards are spread across a number of counties in the Central Valley. The three largest almond producing counties, Kern ($1,235 million), Fresno ($1,168 million), and Stanislaus ($1,028 million), accounted for 61.2% of state production in 2017. Almond was a top four agricultural commodity by value in 13 counties (Kern, Fresno, Stanislaus, Merced, San Joaquin, Kings, Madera, Colusa, Glenn, Butte, Yolo, Tehama, and Solano), the second most important agricultural commodity in three of these counties (Kern, Merced, and Tehama), and the top agricultural commodity in six (Fresno, Stanislaus, Madera, Colusa, Glenn, and Yolo). Almond was a top three agricultural export commodity to eight of the top ten agricultural export markets in 2017: European Union, China/Hong Kong, Japan, Korea, India, United Arab Emirates, Turkey, and Vietnam. Figure 5 maps the distribution of California's 2017 almond acreage.

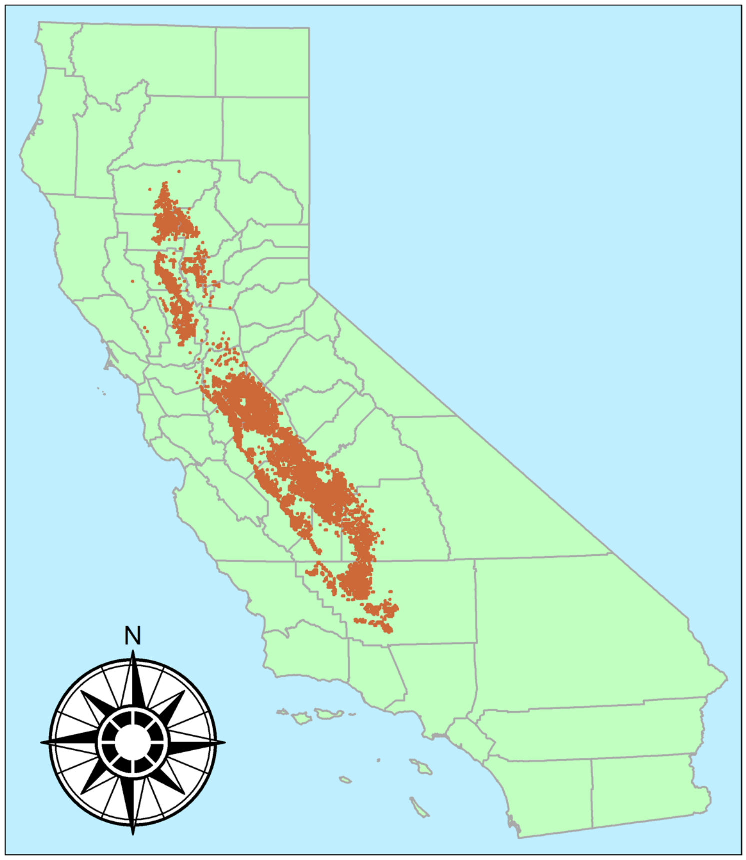


Figure 5. California almond production: 2017

IPM Overview

Given the geographic extent of almond orchards in California, production of this crop takes place under a wide variety of agronomic and climatic conditions, which in turn leads to a diverse array of production practices and, in particular, patterns of pesticide use. Almond production can broadly be divided between the Sacramento Valley and San Joaquin Valley. Although there are differences within each of these macro-regions, for the purpose of this analysis, pesticide use will be evaluated cohesively across all regions, and therefore requires some generalization about key pests and their management.

Chlorpyrifos is mostly used for leaf footed bugs, stink bugs, navel orangeworm, peach twig borer, and San Jose scale. Leaf footed bugs and stink bugs were identified as critical uses (Goodell and Berger 2014)

Target Pests

Leaf footed bugs. Three leaf footed bug species are sporadically found in almond orchards: *Leptoglossus zonatus* (most common), *L. clypealis*, and *L. occidentalis*. These leaf footed bugs overwinter as adults in sheltered areas near almond orchards and then migrate into orchards in

April and May in search of food. These insects are not a consistent pest but in the right weather conditions can have large populations and cause significant damage in almond orchards. The adults can feed on young nuts using their piercing mouthparts, which can cause the forming nuts to abort, and on mature nuts, which can cause black spots on the kernel or nut drop. Alternatives to chlorpyrifos include bifenthrin, lambda-cyhalothrin, esfenvalerate, and abamectin. The first three are sometimes more destructive of natural enemies than chlorpyrifos, owing to some natural enemies' evolved resistance to chlorpyrifos, and growers often report secondary pest outbreaks when used.

Stink bugs. There are four species of stink bugs commonly found in California almond orchards: green plant bug (*Chlorochroa uhleri*), green stink bug (*Acrosternum hilare*), redshouldered stink bug (*Thyanta pallidovirens*), and consperse stink bug (*Euschistus conspersus*). Adults stick their mouthparts through the hull and into the developing kernels, which become misshapen or develop black spots. The green stink bug is the main cause of damage. When organophosphate and/or carbamate insecticides are regularly used in an orchard for other reasons, stink bugs do not usually cause problems. As the regular use of those insecticides is declining, stink bugs have been reported to be causing more damage in almond orchards. Chlorpyrifos was the standard treatment until its use was severely restricted. Although there are potential alternatives to treat stink bug, they all cause secondary mite outbreaks. They are the pyrethroids bifenthrin, esfenvalerate, and lambda-cyhalothrin.

Navel orangeworm (NOW) (*Amyelois transitella*). NOW is the primary pest of the California almond crop. Adult female moths lay eggs on nuts after hull split and the larvae feed on developing nuts, causing direct crop loss, and this can open the door to fungal infections that produce aflatoxin, a contaminate that is heavily regulated in key export markets. NOW larvae overwinter in nuts that remain in the orchard from the previous season, i.e., "mummy" nuts. Almond varieties that mature later in the season are more susceptible to NOW damage. Modern navel orangeworm management consists of (1) sanitation, (2) monitoring, (3) well-timed sprays, (4) early-harvest, and more recently, (5) mating disruption.

Sanitation is the foundation of NOW management. During the winter growers are strongly advised to remove overwintered mummy almonds from their orchards. Sanitation typically involves shaking trees or hand poling to remove "stick tight" nuts from the canopy followed by blowing/sweeping mummies into windrows that can then be destroyed via disking or flail mowing.

Monitoring is important to know when to expect peak NOW activity. Monitoring with egg traps can allow growers to determine a biofix and begin calculating degree days in order to estimate peak NOW flight and, most importantly, egg-laying activity. This can be supplemented with the use of flight traps with pheromone lures to monitor adult male activity. If a spray is warranted, insecticides are typically applied at hull-split (July) and thereafter, when the new crop is susceptible. Some growers also utilize spring sprays (April/May) during the first flight of NOW.

The AIs that are most commonly applied for NOW include pyrethroids (bifenthrin, lambda-cyhalothrin), insect growth regulators (methoxyfenozide), and diamides (chlorantraniliprole). Historically chlorpyrifos was used in a similar manner, with most applications for NOW going on at hull-split and later. In some cases, chlorpyrifos was applied aerially.

Mating disruption can also be an effective tool for NOW management. There are currently four commercially available products that are all about equally effective when used in combination with the aforementioned cultural and chemical control strategies. Continuing research on mating disruption would benefit NOW control in almond.

Peach twig borer (*Anarsia lineatella*). Peach twig borer is a lepidopteran pest that can damage both young trees and maturing nutmeat through direct feeding. Chlorpyrifos applied during the dormant period was often used to treat peach twig borer when scales and/or mites were also present. There are alternatives that can also be applied during dormancy: acetamiprid, chlorantraniliprole, spinetoram, and spinosad.

San Jose scale (*Diaspidiotus perniciosus*). Like all scales, San Jose scale feeds by extracting plant sap, which reduces tree vigor and productivity. On young trees, infestations can harm growth potential. Imidacloprid is occasionally used against scale in the spring. Chlorpyrifos was historically one option for controlling San Jose scale. It was particularly useful when other pests (such as peach twig borer) were also present. Alternatives are pyriproxyfen, buprofezin, and carbaryl.

Chlorpyrifos Use: 2015-2017

Before 2018, chlorpyrifos was applied to around 15% of total almond acreage. Chlorpyrifos was most often used as part of a dormant spray to control scale and peach twig borer; as an April spray for leaf footed bug, peach twig borer, and stink bugs; and/or as a July spray for NOW and peach twig borer control. In 2015-2017, July was the peak month for chlorpyrifos applications (Figure 6). Due to increased regulation of chlorpyrifos beginning in 2018, these historical data may not reflect current use patterns. Specifically, the use of chlorpyrifos has likely declined in response to the new permit conditions.

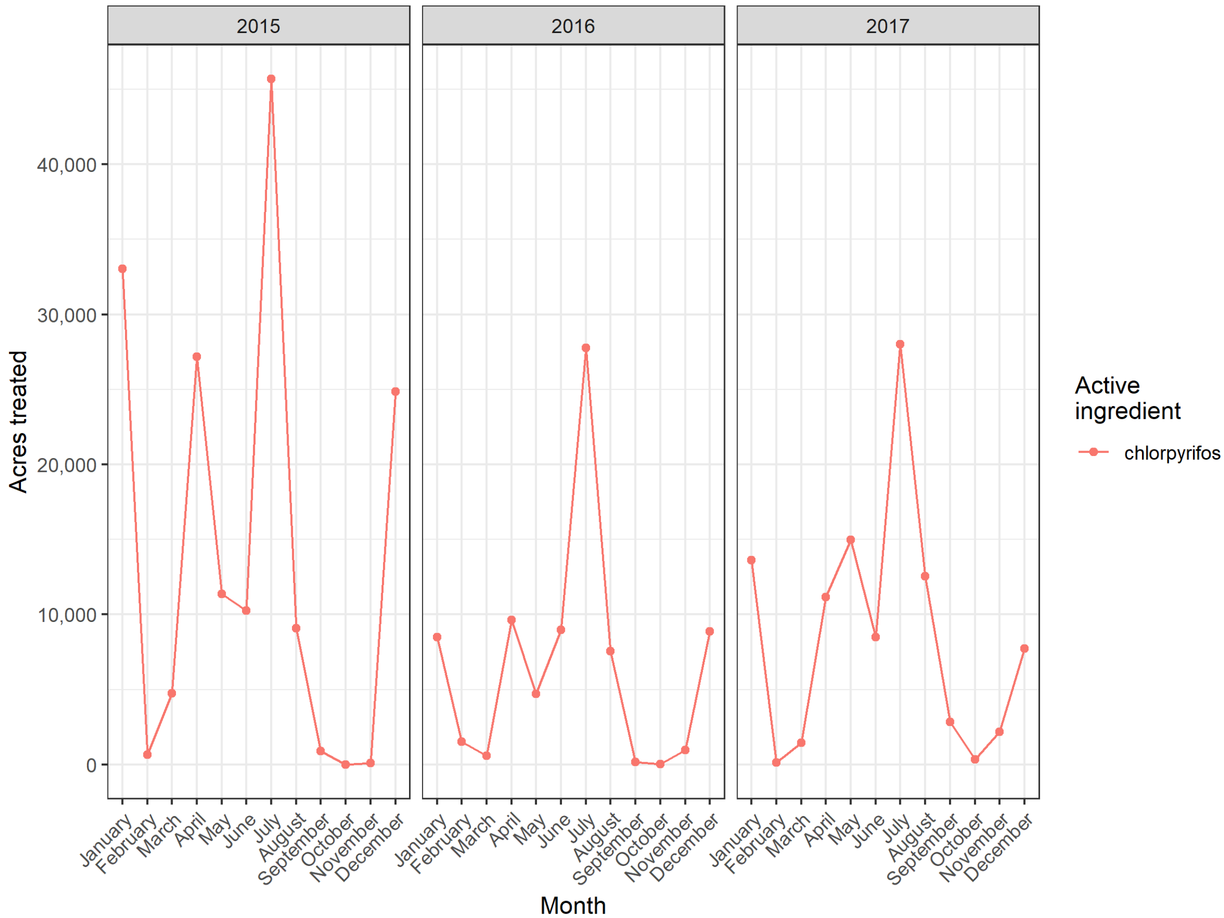


Figure 6. Monthly use of chlorpyrifos: almond, 2015-2017

Most of the alternative AIs were already applied to more acres than chlorpyrifos in 2015-2017 (Table 8). Abamectin, methoxyfenozide, and bifenthrin were applied to a total of 3.3 million, 2.1 million, and 1.6 million acres, respectively, in that time period.

Table 8. Annual Use of Chlorpyrifos and Alternative AIs: Almond, 2015-2017

AI	-----------Lbs applied------------				----------------Acres treated--------------				Use rate (lbs/ac)
	2015	2016	2017	Total	2015	2016	2017	Total	
abamectin	17,168	19,732	23,518	60,419	1,025,970	1,073,426	1,244,740	3,344,136	0.02
bifenthrin	93,712	81,675	95,808	271,195	569,167	494,365	575,357	1,638,889	0.17
buprofezin	5,329	7,682	3,930	16,942	12,717	14,272	3,783	30,771	0.55
carbaryl	3,368	1,379	2,680	7,427	1,268	1,375	1,357	4,000	1.86
chlorantraniliprole	44,085	44,411	53,623	142,120	477,370	488,280	616,278	1,581,928	0.09
chlorpyrifos	308,957	142,621	186,885	638,463	167,805	79,245	103,447	350,497	1.82
esfenvalerate	17,799	16,487	13,139	47,425	289,583	251,052	204,092	744,728	0.06
lambda-cyhalothrin	8,597	8,162	12,915	29,674	249,256	232,080	344,502	825,837	0.04
methoxyfenozide	190,878	193,909	219,348	604,135	658,806	659,748	740,385	2,058,940	0.29
pyriproxyfen*	4,253	5,461	2,324	12,038	127,766	249,717	164,329	541,812	0.02
spinetoram	15,687	17,339	15,916	48,942	237,887	253,868	248,254	740,008	0.07
spinosad	1,419	1,246	1,310	3,975	17,312	18,684	13,049	49,045	0.08

*Does not include baits

Economic Analysis

This section presents the anticipated change in costs to almond due to the withdrawal of chlorpyrifos. This cost consists of the change in pesticide material costs on acres previously treated with chlorpyrifos. We anticipate no change in application costs. In the absence of any anticipated effect on yields, gross revenues will not change. Consequently, the only impact on net returns is the impact on pesticide material costs.

Table 9 presents representative products for chlorpyrifos and alternative AIs used on almond in 2015–2017 and their material costs per acre. The material cost per acre is the product of the average use rate (lb/ac) over this period and the price per pound. The cost per acre ranged from $6.32 to $44.78 per acre. Growers consider other factors in addition to cost per acre when deciding which insecticides to use, as discussed above.

Table 9. Representative Products and Costs Per Acre: Almond

AI	Representative product	Material cost ($)
abamectin	Abba Ultra Miticide/Insecticide	6.32
bifenthrin	Bifenture EC Agricultural Insecticide	8.18
buprofezin	Centaur WDG Insect Growth Regulator	20.45
carbaryl	Sevin Brand XLR Plus Carbaryl Insecticide	27.77
chlorantraniliprole	Altacor	43.57
chlorpyrifos	Lorsban Advanced	15.02
esfenvalerate	Asana XL	7.37
lambda-cyhalothrin	Warrior II	7.35
methoxyfenozide	Intrepid 2F	36.36
pyriproxyfen	Seize 35 Wp Insect Growth Regulator	11.22
spinetoram	Delegate WG	44.78
spinosad	Success	24.16

Table 10 shows the average acreage shares for each alternative AI with chlorpyrifos available and if it was withdrawn. Averaged over the three-year period 2015–2017, chlorpyrifos was used on 3.1% of total almond acres treated with chlorpyrifos or an alternative AI. Total acres treated with one of these insecticides does not correspond to total acres of almond grown because multiple applications of one or more of these insecticides may be made to an orchard.

Table 10. Average Annual Acreage Shares of Alternative AIs with and without Chlorpyrifos: Almond, 2015–2017

AI	Chlorpyrifos available (%)	Chlorpyrifos withdrawn (%)
abamectin	29.2	30.1
bifenthrin	14.3	14.8
buprofezin	0.3	0.3
carbaryl	0.03	0.04
chlorantraniliprole	13.8	14.2
esfenvalerate	6.5	6.7
lambda-cyhalothrin	7.2	7.4
methoxyfenozide	18	18.5
pyriproxyfen	0.8	0.8
spinetoram	6.5	6.7
spinosad	0.4	0.4
Total	**96.9**	**100**

To evaluate costs if chlorpyrifos was withdrawn, the use of alternative AIs is scaled up in proportion to their acreage shares, as discussed in the methods section. The two most common alternative AIs were abamectin and methoxyfenozide, together accounting for 47.2% of total almond acres treated with chlorpyrifos and alternative AIs, which is 48.6% of acres treated with an alternative to chlorpyrifos.

Table 11 shows the costs per acre for chlorpyrifos and the composite alternative, whose cost we use as a representative material cost if chlorpyrifos were withdrawn. For almond, switching to the composite alternative would increase material costs by 35.4% on acres previously using chlorpyrifos.

Table 11: Costs Per Acre for Chlorpyrifos and the Composite Alternative: Almond

AI	Material Cost ($)	Cost increase for switching to composite alternative (%)
chlorpyrifos	15.02	35.4
composite alternative	20.34	-

Table 12 reports the change in costs due to the withdrawal of chlorpyrifos. Application costs on acres that previously used chlorpyrifos are estimated to increase by approximately one third, leading to total annual costs increasing by $0.4 million to $0.9 million.

Table 12. Change in Treatment Costs due to the Withdrawal of Chlorpyrifos: Almond, 2015–2017

Year	Chlorpyrifos available ($)	Chlorpyrifos withdrawn ($)	Change in cost ($)	Percent change (%)
2015	2,521,044	3,413,261	892,217	35.4
2016	1,190,546	1,611,890	421,344	35.4
2017	1,554,154	2,104,181	550,027	35.4

There is no anticipated yield loss from the withdrawal of chlorpyrifos if the alternatives are used, so there is no expected change in gross returns to almond. The application method and hence cost would not change. Therefore, the expected change in material costs is the expected change in net revenues for almond. If the proportions of alternative AIs used change over time, the estimated change may over- or underestimate the cost of withdrawal, depending on whether the bundle of alternative AIs shifts towards products with a lower or higher cost per acre.

Conclusion

Pest management costs in almond are expected to increase by around $421,000 to 892,000 per year, due to a $5.32 increase in pest management costs per acre. Overall, these estimated impacts on the almond industry are relatively small. Restricting attention to the per acre effect on acres previously treated with chlorpyrifos, a $5.32 cost increase is less than 1% of gross revenues per bearing acre: $5,743. As in other crops, the impact of the possibility of insects developing resistance is not evaluated here. The fewer modes of action that remain available for managing a given pest or set of pests, the more likely it is that resistance will develop, and the more quickly it will develop.

Citrus

Citrus (grapefruit, lemon, mandarin, orange and their hybrids) is one of California's top ten crops in terms of value of production, totaling $2.2 billion in 2017 (CDFA 2018a).[1] Table 13 reports the value of production for California citrus fruit in the 2016-17 crop year and Table 14 reports the total acres planted in each citrus crop (bearing and non-bearing). The California citrus market is a fresh fruit market with maximum returns received from fancy grade export fruit. Citrus was California's sixth largest agricultural export commodity in 2017, with a value of $979 million.

Table 13. California Citrus Production Value: 2016-17 Crop Year

Citrus Crop	Production Value (thousands)
Grapefruit, All	83,647
Lemon	717,746
Orange, All	888,331
Mandarin (and Hybrids)	532,038
Total	2,221,762

Source: CDFA 2018

Table 14. Total Citrus Acreage: 2016 and 2018

Crop	Acres standing in 2016	Acres standing in 2018
Grapefruit*	8,493	8,226
Lemon	44,621	45,389
Orange, Navel	120,784	117,338
Orange, Valencia	29,906	28,648
Pomelo and hybrids	1,144	1,160
Mandarin and hybrids	58,941	61,282
Total	255,396	252,657

*Excludes pomelos and hybrids.

Source: 2018 California Citrus Acreage Report (CDFA 2018b)

There are four major citrus production regions in California (San Joaquin Valley, coastal area, inland southern California, and desert) (Figure 7). The counties in each region are presented in Table 15. While most regions grow all cultivars of citrus, the environmental conditions favor some cultivars over others. For example, the cool climate of the coast allows lemons to produce multiple crops per year, the desert heat provides the best conditions for grapefruit, and the San Joaquin Valley's cold winters favor oranges and mandarins.

[1] Commonly used groupings for citrus are different than how crops are named in the Pesticide Use Report database. This report uses the following groupings: grapefruit (grapefruit and pomelo), lemon (lemon), orange (orange), mandarin (tangelo and tangerine), and lime (lime).

Table 15. Counties in Citrus Regions

Region	Counties
Coastal	Monterey, Ventura, San Luis Obispo, Santa Barbara
Desert	Imperial
Inland south	Riverside, San Bernardino, San Diego, Orange
San Joaquin Valley	Fresno, Kern, Madera, Tulare

Figure 7. California citrus production and growing regions: 2017

Figure 8 plots the number of acres harvested for each citrus crop category from 2006-2017. Since 2006, the acreage planted with mandarin (satsuma, clementine, mandarin and their hybrids) has increased by more than 50,000 acres in the San Joaquin Valley and the coastal areas of California. The increase in mandarin acreage is due to the popularity of easy peeling fruit with consumers. Orange plantings, primarily Valencia, are concentrated in the San Joaquin Valley and have declined somewhat, despite remaining one of the largest crops by acreage harvested. Other regions and cultivars have remained relatively stable in acres harvested.

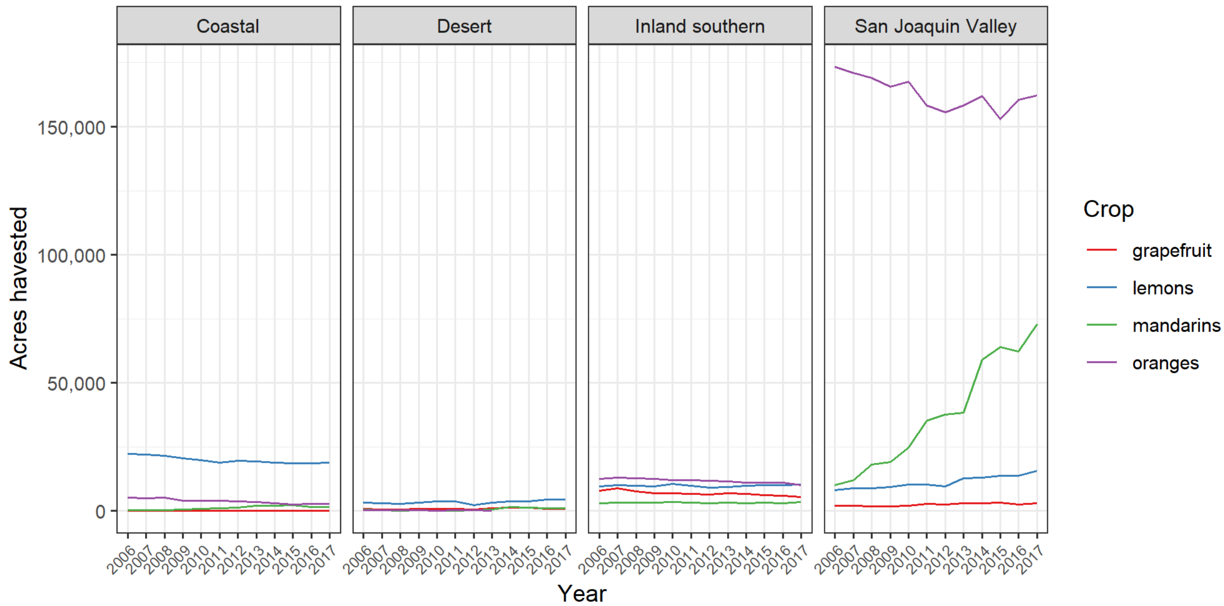


Figure 8. Acres planted to orange, mandarin, lemon and grapefruit in the four California growing regions, 2006-2017

Within the four growing regions, the combination of cultivar and environment results in different pest complexes that require specific management tactics. For example, the hot dry climate of the desert promotes mites, citrus thrips and citrus leafminer. The mild coastal and inland areas of Southern California climate support natural enemies year-round and common pests are easily managed without pesticides in this region, with the exception of bud mite and broad mites infesting lemons. The more extreme winter and summer temperatures of the San Joaquin Valley reduce the effectiveness of biological control, and common pest problems include California red scale, citrus thrips, citricola scale, katydids and citrus red mite. Because biological control is less effective in this region, there is greater insecticide use.

The arrival of the Asian citrus psyllid (ACP) in 2008 and its spread throughout southern California by 2012 has intensified insecticide treatments since 2012 in the southern regions, where treatments were traditionally infrequent. ACP is the vector of huanglongbing (HLB), also known as citrus greening disease, a devastating, incurable bacterial disease of citrus that has reduced Florida citrus production by 50% and is threatening the California citrus industry.

IPM Overview

A total of 14 pest species were identified by the Citrus Crop Team in the Chlorpyrifos Critical Uses Report for DPR (Goodell and Berger 2014) as important species for which chlorpyrifos is a key component of their citrus IPM programs. In all production areas, chlorpyrifos is central for ant control, especially liquid sugar feeding ants, which are a major problem because they protect hemipteran pests from natural enemies. Another critical use is for earwig and ant control inside cardboard wraps around the trunks of newly planted trees. In new invasions, chlorpyrifos remains an essential tool until new, effective active ingredients are registered for use for these pests. For other pests, there are alternatives to this active ingredient, however, chlorpyrifos is considered a superior choice for specific situations owing to its efficacy, broad spectrum of activity on multiple pests, cost, established maximum residue limits (MRLs), and IPM compatibility. Chlorpyrifos is also important for responding to weather generated pest outbreaks and invasive pests.

Chlorpyrifos is effective against a broad range of pests. Growers often choose it over other insecticides because a single chlorpyrifos treatment simultaneously controls multiple pests, a common situation in citrus. Minimizing the number of applications of any insecticide in an orchard reduces physical damage to the fruit in the tree row, reduces emissions, reduces compaction of the orchard, and reduces application costs. Newer alternative insecticides tend to be more selective, affecting only a specific group of pests. Consequently, situations with multiple pests may require multiple insecticides. Fig. 3 shows that when the insect growth regulators replaced chlorpyrifos in 1998 for California red scale control, there was initially a 70% drop in chlorpyrifos use. However, after a few years, growers discovered that citricola scale and katydids were not controlled by the insect growth regulators. Citricola scale and katydids reached outbreak levels in the early 2000s, requiring the return to use of chlorpyrifos for control of these pests.

Even though chlorpyrifos is broad spectrum, some natural enemies are compatible with it. In the San Joaquin Valley, key natural enemies have been selected for resistance to organophosphates due to exposure over many decades (Grafton-Cardwell 2019). Vedalia beetles easily survive exposure to organophosphates, and continue to control cottony cushion scale whereas some of the newer insecticides such as neonicotinoids and insect growth regulators are quite toxic to the beetle (Grafton-Cardwell and Gu 2003). Predatory mites survive chlorpyrifos treatments and assist with management of pest mites and citrus thrips (Grafton-Cardwell and Ouyang 1993). Extremely low rates of chlorpyrifos can be used for katydids, which lack natural enemies, allowing parasitoid wasps such as *Aphytis melinus* to survive to control California red scale. Citrus growers have learned that if organophosphates are used rarely and/or at low rates, the natural enemies will survive and rebound and the IPM program is sustained.

Target Pests

In citrus, chlorpyrifos is used to manage ants, Asian citrus psyllid, scale, and a number of other pests. For many of them, chlorpyrifos is not the preferred AI for controlling the specific pest. Rather, its broad spectrum of control makes it advantageous to apply when multiple pests are present.

Ants – Protein feeding: Red imported fire ant (*Solenopsis invicta*) and Southern fire ant (*Solenopsis xyloni*).

Fire ants, both native southern and red imported, directly damage plants by chewing twigs and tender bark of newly planted trees; they also sting people working in the orchard and may cause allergic reactions. Tree wraps are needed for the first two years after planting citrus trees to prevent sunburn of the trunks, protect the tree from herbicides, reduce suckers from the rootstock, and protect against rodent feeding damage. Native southern fire ant nests at the base of trees and girdle the bark under the wraps of young trees. Fire ants can also plug up irrigation sprinklers and have been demonstrated to protect pests, especially honeydew producing scales, whiteflies, aphids, and psyllids from natural enemies (Martinez-Ferrer et al. 2003).

Chlorpyrifos is effective against fire ants when applied to the ground as a granular or as a liquid spray applied inside tree wraps. Abamectin and pyriproxyfen baits are available as alternatives, however they are slower acting than chlorpyrifos (Grafton-Cardwell and Reagan 2001). Metaflumizone bait is available but less effective. Chlorpyrifos is needed in situations where rapid control is necessary – such as fire ant girdling of young trees. The bait alternatives are slow acting and do not always prevent this damage from occurring. Coating the trunk in a sticky material can prevent damage but is extremely labor intensive and not practical for commercial citrus orchards.

Ants – Sugar Feeding: Argentine ant (*Linepithema humile*) and Native gray ant (*Formica aerate*). Many ants feed on liquid sugar; however, the Argentine and native gray are the most common in agricultural settings. Argentine ants are more common in Southern California and the coast, and native gray ants are more common in the San Joaquin Valley. These ants feed on honeydew excreted by various soft scales, mealybugs, cottony cushion scales, whiteflies, psyllids, and aphids. As part of this relationship, they protect these insects from their natural enemies, thus interrupting biological control of the honeydew-producing pests (Martinez-Ferrer et al. 2003). Interestingly, they also protect some non-honeydew producing pests such as California red scales. Argentine ants can also plug up irrigation sprinklers. Ant populations are highest February – October.

Chlorpyrifos is effective when applied to the ground as a granular or as a liquid spray. There are currently no alternative insecticides for liquid feeding ant species, as they simply cannot take up the granular baits. As with protein feeding ants, coating the trunk with stickem can prevent pest damage but is extremely labor intensive and will damage the tree if applied directly to the trunk. Additionally, this material must be stirred or reapplied to maintain efficacy, and pruning is needed to prevent other access points. Thus, this approach is not practical for commercial citrus orchards.

Asian Citrus Psyllid (Diaphorina citri). ACP attacks all varieties of citrus and, because of the salivary toxin that it injects, causes the new leaf tips to twist or burn back. However, the more serious issue is that it vectors the bacterium '*Candidatus* Liberibacter asiaticus' that causes Huanglongbing (HLB or citrus greening disease). HLB causes shoots to yellow, asymmetrical leaf mottling, and abnormally shaped fruit with bitter juice. The disease can kill a citrus tree in as little as five years, and there is no known cure. ACP arrived in southern California from Mexico in 2008 and HLB is now found in southern California. Currently, treatments that are applied to California citrus orchards are designed to disinfest trees and thus minimize the risk of moving ACP in bins of harvested fruit and to limit the natural and human-assisted spread of ACP and HLB throughout California.

Chlorpyrifos is an important ACP management tool in the late fall because it can be used close to harvest due to its well-established MRLs. Chlorpyrifos is one of many tools for managing psyllids. It plays an important role when other pests such as citricola scale, Fuller rose beetle, and citrus bud mite need control at the same time. There are many alternative insecticides for ACP; however, not all work as well as chlorpyrifos. Alternatives include beta-cyfluthrin, carbaryl, cyantraniliprole, diflubenzuron, dimethoate, fenpropathrin, fenpyroximate, flupyradifurone, imidacloprid, spinetoram, Spinosad, spirotetramat, thiamethoxam, and zeta-cypermethrin. Carbaryl and fenpyroximate are less efficacious. Diflubenzuron and spirotetramat are primarily active against nymphs. Three options for organic production, narrow range oil, pyrethrins, and spinosad, have short residual effect, and are primarily contact insecticides.

Although these alternatives are available in theory, they are not always usable in practice. There are limits on the number of applications and total amount of AI applied for many of these insecticides, and, if they are used when they are most effective for other key pests, then they may not be not available to apply for ACP. Many of these AIs that could be used to manage ACP are crucial for other pests. For example, spinetoram is reserved for thrips control after petal fall and spirotetramat is used for mealy bug and California red scale control. Thiamethoxam is needed for the Fuller rose beetle control program. The pyrethroids, including beta-cyfluthrin, fenpropathrin, and zeta-cypermethrin, work best in eradication efforts, bulk citrus disinfestation, and as the winter dormant spray (excluding zeta-cypermethrin). Imidacloprid applications are limited to summer in order to protect bees during pollination. Cyantraniliprole does not have established MRLs for all markets, making it impossible to use near harvest. Spinetoram's use is also limited by MRL considerations. Chlorpyrifos has a role in providing control when these insecticides are needed for other pests and provides an alternative mode of action to reduce pesticide resistance selection in the psyllids.

Black Scale (*Saissetia oleae*). Black scale is a major but cyclical citrus pest in the coastal and inland districts in southern California that requires intervention every 5 to 10 years. It occurs only occasionally on citrus in the San Joaquin Valley. Feeding by black scale reduces tree vigor and can cause leaf or fruit drop and twig dieback. Excreted honeydew supports the growth of sooty mold. Heavy infestations can cause significant damage to trees and marketable crop.

Control by natural enemies is effective in managing black scale, however, if parasite activity is disrupted by ants, dust, or pesticides, chemical treatments may be necessary. When black scale occasionally becomes a problem, chlorpyrifos is the first choice to keep populations at low levels. Chlorpyrifos is applied once during May through July for black scale. There are only two alternatives: carbaryl and spirotetramat. Chlorpyrifos treatments for black scale also control California red scale.

Broad Mite (*Polyphagotarsonemus latus).* Broad mites feed on citrus leaves and fruit. They prefer young fruit that are located on the inside of the canopy. Feeding results in scarred tissue that cracks as fruit grows, leaving a characteristic pattern of scars and new tissue. Although most feeding occurs on fruit, broad mites may also feed on young expanding leaves causing them to curl. This cupping and curling of leaves can appear similar to mild damage caused by glyphosate applications.

Broad mites are occasional pests of coastal lemon from late July through early October; infestations are enhanced by the presence of Argentine ants, which defend them from natural enemies, and warm weather conditions. Managing ant populations is very important when broad mites are a concern. This mite often occurs in conjunction with citrus rust/silver mite. Chlorpyrifos applied for citrus rust mite will also control broad mite. No treatment thresholds have been developed for broad mite in citrus. If high and increasing populations warrant treatment, growers use miticides.

Chlorpyrifos is one of several active ingredients used for broad mite. While it is not the primary choice for control, it is useful when additional pests such as ants, bud mite or silver mites are present. It is less disruptive to natural enemies than sulfur. Alternatives used for broad mite are abamectin, fenpyroximate, spirodiclofen, and sulfur. Conservation of natural enemies, especially when coupled with ant control, can be a successful alternative in many situations.

California Red Scale (*Aonidiella aurantii*). California red scales attack all aerial parts of the tree including twigs, leaves, branches, and fruit by inserting their mouthparts and extracting sap. Heavy infestations can cause serious damage to the tree, and fruit may be downgraded in the packinghouse. Severe infestations cause leaf yellowing and drop, dieback of twigs and limbs, and occasionally death of the tree. Tree damage is most likely to occur in late summer and early fall when scale populations are highest and moisture stress on the tree is greatest.

Management of California red scale varies according to location and the other pests present in the orchard. Natural enemies can provide good control of California red scale in all regions of California except the Coachella Valley, where a pesticide-based eradication program is in place. Biological control tends to be easiest in the coastal areas and some inland districts of southern California because milder weather in these regions allows the overlap of generations, which provides susceptible host stages for parasitism year-round.

The use of chlorpyrifos is most beneficial in situations where multiple pests are present, such as when California red scale and citricola scale are present at the same time and a single treatment will manage them both. Pyriproxyfen is the most relied upon pesticide for California red scale control alone. Carbaryl, buprofezin, and spirotetramat are also alternatives. However, during the drought and intensive heat years of 2012-2017, weather conditions induced California red scale outbreaks and pyriproxyfen alone did not manage California red scale populations well. The number of insecticide treatments needed to manage scale increased from an average of 0.5 treatments per year to 3 per year. Chlorpyrifos was needed as one of these treatments to help manage red scale during those years.

Low to moderate infestations can be managed with pheromone disruption. This requires careful monitoring. There is a group of biological control agents – *Aphytis melinus* and *A. lingnanensis* (coastal areas) and *Comperiella bifasciata* (San Joaquin Valley) – that are helpful for maintaining low to moderate populations, but they are not regularly effective against outbreaks. They need to be released into the environment and monitored regularly. Additionally, there are two cultural practices that can help reduce the risk of scale outbreaks: internal pruning and skirt treatments.

Citricola Scale *Coccus pseudomagnolarium.* Citricola scale is one of the most serious pests of citrus in the San Joaquin Valley. When populations exceed the threshold of 0.5 nymphs/leaf or 1 adult/twig, yield is likely to be reduced. A severe infestation may reduce tree vigor, kill twigs, and reduce flowering and fruit set. As they feed, citricola scale excretes honeydew, which accumulates on leaves and fruit; this can lead to sooty mold growing on honeydew and that interferes with photosynthesis in leaves and causes fruit to be downgraded in quality during packing.

Citricola scale is not effectively controlled by selective insecticides or natural enemies. Growers use neonicotinoids and chlorpyrifos to manage citricola scale. Chlorpyrifos is preferable in situations where multiple pests such as California red scale and citricola scale are present, so that both are controlled with one insecticide treatment. Chlorpyrifos is effective against most populations of citricola scale. Alternatives for citricola scale alone include acetamiprid, carbaryl, malathion, buprofezin, thiamethoxam, and imidacloprid.[2] Carbaryl and buprofezin are effective.

Citrus Bud Mite (*Eriophyes sheldoni).* Citrus bud mite is primarily a pest of coastal lemons but in recent years has also been increasingly problematic in interior regions of southern California. The mites feed inside the buds, killing them or causing a rosette-like growth of the subsequent foliage and distortion of flowers and fruit, which may or may not reduce yield and fruit quality. Chlorpyrifos is one of several active ingredients used for citrus bud mite, but abamectin and fenbutatin-oxide are more commonly used. Although chlorpyrifos is not the primary choice for control, it is useful when additional pests are present.

[2] Imidacloprid used in citrus was determined by DPR to be high risk to bees (Troiano et al. 2018). It is under review by DPR and may not be available for use in the future.

Citrus Rust Mite or Silver Mite (*Phyllocoptruta oleivora).* This pest is known as the rust mite on oranges and the silver mite on lemons. It is an occasional pest in coastal areas of southern California and is a problem in some years in the inland southern California growing areas. Rust mite feeds on the outside exposed surface of fruit that is 0.5 inch (1.3 cm) or larger. Feeding destroys rind cells and the surface becomes silvery on lemons, rust brown on mature oranges, or black on green oranges. Rust mite damage is similar to broad mite damage, except that somewhat larger fruit are affected. Most rust mite damage occurs from late spring to late summer.

Chlorpyrifos is an effective treatment, mostly applied in Sept.-Oct. Chlorpyrifos is the choice if several pests, such as citrus bud mite, broad mite and ants, need to be controlled in addition to citrus rust mite. However, there are alternatives that also work well for rust mite: abamectin, diflubenzuron, fenpyroximate, spirotetramat, spirodiclofen, and sulfur. As noted in the discussion of ACP, seasonal limits on applications apply.

Earwigs (*Forficula auricularia*). The introduced European earwig (family *Forficulidae*) is the most damaging earwig species that occurs in citrus. Earwig adults feed on dead and living insects and insect eggs, other organisms most of their life, but in the spring they feed on plants (Romeu-Dalmau et al. 2012). Earwigs can develop large populations at the base of citrus trees, feeding on young tree leaves and on mature fruit just after petal fall. They can be especially problematic inside trunk wraps or cardboard guards of newly planted trees, causing extensive damage to the leaves. Wraps are needed for the first two years after planting to prevent sunburn of the trunks, protect the tree from herbicides, reduce suckers from the rootstock and protect against rodent feeding damage. The leaf damage can be difficult to distinguish from that of other chewing pests that hide during day and feed at night, including brown garden snail and Fuller rose beetle.

Liquid chlorpyrifos is very effective when sprayed inside the wraps of young trees or on the foliage of mature trees. The granular formulation is also very effective. Alternatives are carbaryl and beta-cyfluthrin. Earwigs are very difficult to kill with products other than organophosphates, carbamates, and pyrethroids. Earwigs are not listed as pests on the alternative insecticide labels. Thus, there is a critical need for insecticide registrations for earwigs that utilize other MoAs.

Fuller Rose Beetle (*Naupactus (Asynonychus) godmani*). In California, Fuller rose beetle (FRB) is rarely considered a pest except on new trees grafted onto older rootstock where the beetles will feed on new buds or when a young tree is planted in a mature grove and beetles concentrate their feeding on the new growth of that tree. However, the presence of viable eggs on fruit exported to South Korea is a cause for rejection of fruit loads, which results in a serious economic loss to the grower. South Korea is the number one importer of California oranges and accounted for 34% of total export value ($230 million) in 2017.

Fuller rose beetle adults feed along the margins of citrus leaves, creating notches, and leaving a characteristic sharp, ragged appearance. Adults often lay eggs under the calyx of citrus fruit. The larvae live in the ground and feed on tree roots. The beetles are flightless, so skirt pruning and trunk treatments limit their access to fruit to climbing up the trunk (Morse and Grafton-Cardwell 2013). A systems approach for managing Fuller rose beetle for fruit destined for South Korea requires skirt pruning and two in-season trunk, ground, or foliar treatments to prevent egg laying.

Thiamethoxam is the primary choice for this treatment. Chlorpyrifos is preferred when other pests such as California red scale also require control. Alternatives such as thiamethoxam, cryolite and carbaryl are effective for controlling Fuller rose beetle, but cryolite and carbaryl have significant MRL issues. This is discussed further below in the Maximum Residual Limits section.

Katydids (*Scudderia furcata*). Fork-tailed bush katydid feeds on the rind of young fruit at petal fall with subsequent buildup of scar tissue and distortion/scarring of the expanding fruit. Katydids take a single bite from a fruit and then move to another feeding site on the same or nearby fruit. In this way, a few katydids can damage a large quantity of fruit in a short time.

Katydids are easily killed by extremely low rates of chlorpyrifos at petal fall. Alternatives are beta-cyfluthrin, cryolite, diflubenzuron, dimethoate, fenpropathrin, and naled. Chlorpyrifos is faster acting than the alternative stomach poisons diflubenzuron and cryolite.

Mealybugs. Citrus mealybug *(Planococcus citri)*, citrophilus mealybug *(Pseudococcus calceolariae)*, longtailed mealybug (*Pseudococcus longispinus)*, and Comstock mealybug *(Pseudococcus comstocki)* all attack California citrus. Mealybugs extract plant sap, thereby reducing tree vigor, and excrete honeydew, which provides a surface upon which sooty mold grows. If a cluster of mealybugs feeds along a fruit stem, fruit drop can occur. Damage is most severe in spring and fall. The role of mealybugs in citrus IPM is pivotal to other pest issues because mealybugs attract ants. Ants protect mealy bugs from natural enemies which then require insecticides which reduce predatory mites, causing outbreaks of pest mites, e.g., broad mite.

Unlike almost all of the insecticides registered for mealybug control, beetle predators of mealybugs have developed resistance to chlorpyrifos, making chlorpyrifos relatively less disruptive for natural enemy populations (Grafton-Cardwell 2019). The only alternative is spirotetramat. Conservation of natural enemies and management of the sugar feeding ants are crucial to mealybug control. In addition to resident natural enemies, *Cryptolaemus montrouzieri*, known as the mealy bug destroyer, can be purchased and released.

Chlorpyrifos Use: 2015-2017

In 2017, a total of 225,394 pounds of liquid chlorpyrifos was applied on 62,831 acres (24%) of citrus and 3,566 pounds granular chlorpyrifos was applied on 6,650 acres (2.5%). Application rates vary depending on the sensitivity of the pest to chlorpyrifos and the coverage needed to reach the pest using liquid application. Armored scales and mealybugs infest all areas of the tree and require > 3 lb ai/acre whereas soft scales, mites, earwigs, caterpillars, small exterior canopy pests such as katydids and psyllids tend to be on the exterior of the tree and require ≤ 3 lb ai/acre.

Table 16 shows the uses of > 3lb ai/acre liquid applications of chlorpyrifos statewide, with the greatest uses in the San Joaquin Valley and Ventura. In the San Joaquin Valley, these treatments are primarily applied for California red scale, a pest that requires high water volume (750-1,500 gallons of water per acre) to achieve coverage of the trunk, branches and leaves where the scale resides. In Ventura, high rate applications were applied primarily for mealybugs and for bud mite that attack lemons as they are forming and causes distortions of the growth. Mealybug requires thorough coverage (750-1500 gpa) and bud mite requires intermediate coverage (500 gpa) in combination with the higher rates of chlorpyrifos to achieve coverage and kill of the pest.

Table 16. Pounds of Chlorpyrifos Applied, Number of Applications and Acres Treated by County: Citrus, 2017, Liquid Applications of >3 lbs. AI/Acre

County	**Pounds of chlorpyrifos**	**Number of applications**	**Acres treated with chlorpyrifos**
Madera	4,410	28	846
Fresno	23,817	189	4,721
Tulare	86,193	871	16,435
Kern	59,700	279	10,994
San Joaquin Valley total	**174,120**	**1,367**	**32,996**
San Luis Obispo	426	8	118
Ventura	19,609	191	5,135
Coastal CA total	**20,035**	**199**	**5,253**
Riverside	2,185	12	446
San Diego	548	3	131
Inland South total	**2,733**	**15**	**577**
Imperial	106	2	24
Desert CA total	**106**	**2**	**24**
Other regions	**811**	**4**	**214**
State total	**197,804**	**1,587**	**39,067**

Table 17 shows the lower rates of chlorpyrifos (<3 lbs ai/acre) were applied in all citrus growing counties of the state. In the San Joaquin Valley, lower rates are applied for citricola scale, earwigs, Fuller rose beetle, ants, caterpillars and katydids. In Ventura and the inland areas of southern California, the lower rates are used for scales, silver mite, broad mite, Asian citrus psyllid, and the aggressive Argentine ant.

Table 17. Pounds of Chlorpyrifos Applied, Number of Applications and Acres Treated by County: Citrus, 2017, Liquid Applications of ≤3 lbs. AI/Acre

County	Lbs. applied	Number of applications	Acres treated
Madera	567	19	611
Fresno	2,593	59	3,477
Tulare	6,560	246	5,196
Kern	11,181	191	7,740
San Joaquin Valley total	20,901	515	17,024
San Luis Obispo	122	1	122
Santa Barbara	73	3	50
Ventura	1,009	21	548
Coastal CA total	1,203	25	720
Orange	85	2	84
Riverside	2,375	140	2,166
San Bernardino	2,399	142	2,199
San Diego	400	47	515
Interior S. CA total	5,259	331	4,965
Imperial	270	29	1,068
Desert CA total	270	29	1,068
Other regions	30	2	14
State total	**27,664**	**902**	**23,791**

Figure 9 shows that since 1996, foliar applications of chlorpyrifos in the San Joaquin Valley have declined by more than 50% both in the lbs AI applied and the acreage treated. Figure 10 shows a similar trend in the lbs AI applied in S. California and an even greater reduction in the acreage treated. These changes have occurred because of the introduction of new chemical classes for specific pests including insect growth regulator pyriproxyfen for California red scale, neonicotinoids for citricola scale, and abamectin for bud mite control.

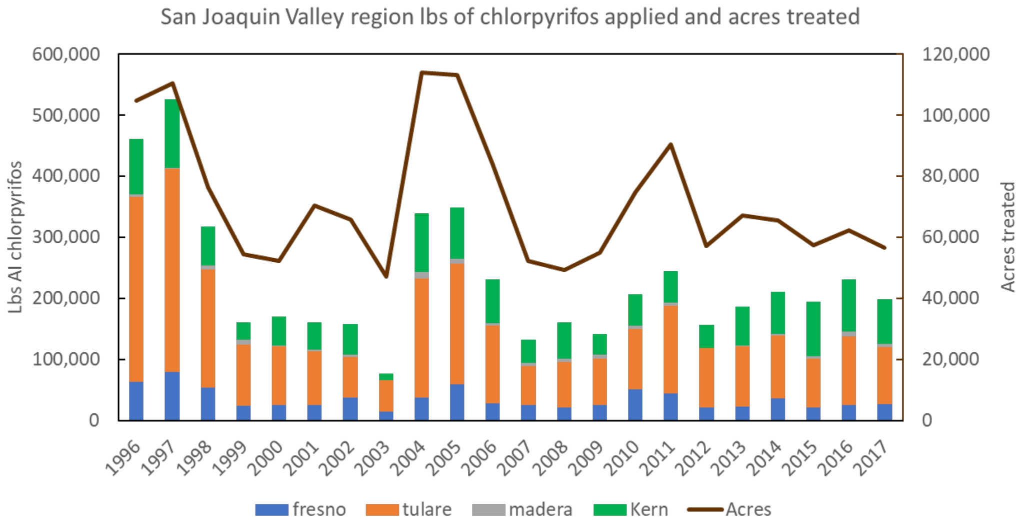


Figure 9. Foliar treatments of chlorpyrifos in citrus: San Joaquin Valley, 1996-2017, pounds AI applied and acres treated

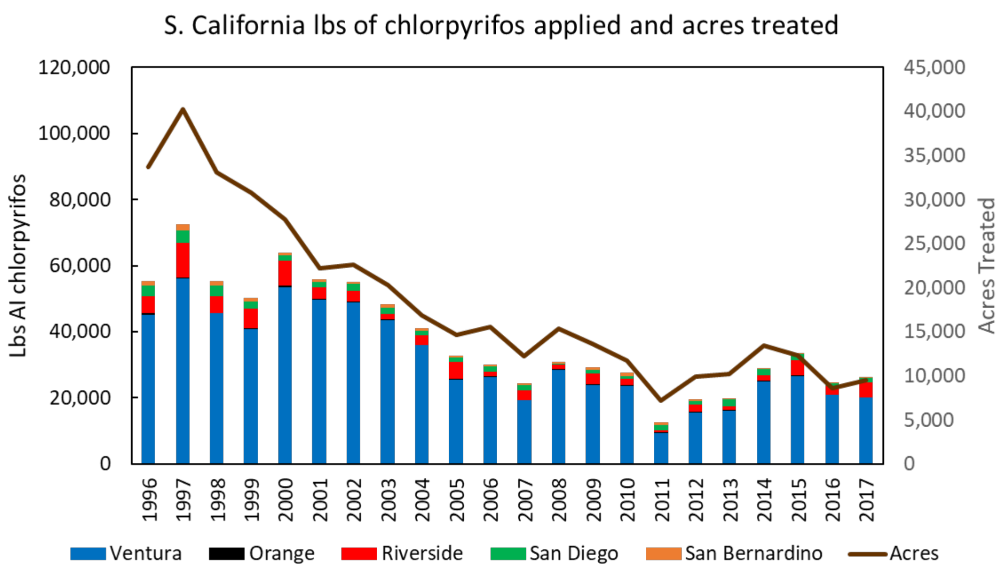


Figure 10. Foliar treatments of chlorpyrifos in citrus: southern California, 1996-2017, pounds AI applied and acres treated

Other Considerations

Weather extremes. Changes in weather can radically alter the dynamics of pest control in citrus. The drought/heat conditions of 2012-2017 dramatically increased pest populations due to both tree stress and by adding additional generations of some pests. California red scale and mite outbreaks occurred around the state, necessitating an increase in insecticide treatments. Chlorpyrifos played an important role in containing California red scale and outbreaks in the San Joaquin Valley (Fig. 3) and broad mites in Ventura County (Fig. 4).

Invasive pests. Invasive pests generally arrive without natural enemies to control them and effective insecticides are needed for eradication and control efforts. When glassy-winged sharpshooter, *Homalodisca vitripennis*, first appeared in California, chlorpyrifos was an important tool to reduce its numbers in citrus until registration of neonicotinoids was achieved. Chlorpyrifos, also plays a role in reducing Asian citrus psyllid, *Diaphorina citri*, populations in California and helping to slow the spread of huanglongbing disease.

Resistance management. As for other pests and other commodities, one consequence of eliminating the use of chlorpyrifos is that there will be fewer modes of action for resistance management.

Maximum Residue Levels (MRLs). A high percentage of citrus fruit from California is exported as fresh fruit. The top five export countries for oranges are South Korea, Canada, Japan, Hong Kong and China. The top five export countries for lemons are Japan, Canada, South Korea, Australia and Hong Kong. Not all of these export countries have fully established maximum residue levels (MRLs) or the levels that are established are below the US tolerances established (Table 4). If fruit is treated near harvest, growers will not use an insecticide that has a significantly lower or unestablished MRL (for example buprofezin, cryolite cyantraniliprole), because they run the risk of the fruit being rejected if that level is exceeded. In addition, growers do not know which market their fruit will be exported to, and they need to make decisions about treatments many months before harvest. Chlorpyrifos is one of the few insecticides that has MRLs established that are equal to or below the MRLs for all export markets. If the alternatives for a particular pest do not include an AI with established MRLs, then growers will have significant issues managing those pests for exported crops. The only alternative AIs with established MRLs for all of the top six export markets are flupyradifurone, pyriproxyfen, and spinosad.

Economic Analysis

This section presents the expected change in costs to citrus due to the withdrawal of chlorpyrifos. This cost only includes the change in pesticide material costs. In the absence of any anticipated effect on yields or changes in application costs, changes in pesticide material cost are the expected changes in gross revenues. The estimated change in costs does not reflect any increase in the number of applications due to one application of chlorpyrifos addressing multiple pests while more than one alternative would be required to address them.

Table 18: *Representative Products and Cost per Acre: Citrus*

AI	Representative product	Material cost ($)
(s)-cypermethrin	Mustang	3.80
abamectin	Agri-Mek SC Miticide/Insecticide	17.26
abamectin	Clinch Ant Bait	11.93
acetamiprid	Assail 70WP Insecticide	64.35
beta-cyfluthrin	Baythroid XL	16.40
buprofezin	Centaur WDG Insect Growth Regulator	74.05
carbaryl	Sevin Brand XLR Plus Carbaryl Insecticide	150.93
chlorantraniliprole	Altacor	43.46
chlorpyrifos*	Lorsban Advanced	28.23
cryolite	Prokil Cryolite	39.51
diflubenzuron	Micromite 80WGS	57.97
dimethoate	Drexel Dimethoate 4EC	10.54
fenbutatin-oxide	Dupont Vendex 50WP Miticide	64.19
fenpropathrin	Danitol 2.4 EC Spray	30.65
fenpyroximate	Fujimite SC Miticide/Insecticide	44.41
flupyradifurone	Sivanto 200 SL	44.99
imidacloprid	Admire Pro	27.42
malathion	Malathion 8 Aquamul	12.08
metaflumizone	Altrevin Fire Ant Bait Insecticide	25.29
naled	Dibrom 8 Emulsive	2.15
pyriproxyfen	Esteem 0.86 EC Insect Growth Regulator	87.14
pyriproxyfen	Esteem Ant Bait	24.93
spinetoram	Delegate WG	57.39
spinosad	Success	32.84
spirotetramat	Movento	87.18
sulfur	Sulfur 6L	60.35
thiamethoxam	Actara	21.70

*Target AI

Table 18 presents representative products for each active ingredient used on citrus in 2015–17 and their costs per acre. The material cost per acre is the product of the average use rate (lbs/ac) over this period and the price per pound. The material cost per acre ranges from $2.15 for naled to $150.93 per acre for carbaryl. Growers consider other factors in addition to price per acre when deciding which insecticides to use, as discussed above.

Table 19. Average Annual Acreage Shares of Alternative Insecticides with and without Chlorpyrifos: Citrus, 2015–2017

AI	Chlorpyrifos available (%)	Chlorpyrifos withdrawn (%)
(s)-cypermethrin	3.93	4.16
abamectin	12.59	13.32
acetamiprid	1.73	1.84
beta-cyfluthrin	7.31	7.74
buprofezin	0.99	1.05
carbaryl	0.48	0.51
chlorantraniliprole	1.96	2.07
cryolite	0.40	0.42
diflubenzuron	2.65	2.81
dimethoate	0.52	0.55
fenbutatin-oxide	0.14	0.15
fenpropathrin	3.98	4.21
fenpyroximate	1.97	2.09
flupyradifurone	0.26	0.28
imidacloprid	9.35	9.89
malathion	0.53	0.56
metaflumizone	0.40	0.43
naled	0.01	0.01
pyriproxyfen	5.78	6.12
spinetoram	13.70	14.49
spinosad	1.62	1.71
spirotetramat	11.04	11.68
sulfur	1.00	1.05
thiamethoxam	12.17	12.88
Total	94.52	100

Note: Three-year average from 2015-2017.

Table 19 shows the average acreage shares for each alternative AI used on citrus, with and without chlorpyrifos being available. Averaged over the three-year period 2015–2017 when chlorpyrifos was available, it was used on 5.5% of citrus acres treated with chlorpyrifos or an alternative AI. Total acres treated with insecticides do not correspond to total acres of citrus grown because some growers may have used multiple AIs on the same orchard.

To represent the use of alternative AIs if chlorpyrifos was withdrawn, their use is scaled up in proportion to their acreage shares, as discussed in the methods section. The four most common alternative AIs were spinetoram, abamectin, thiamethoxam, and spirotetramat, together accounting for 49.3% of total citrus acres treated with insecticides, which is projected to increase to 52.2% of acres treated without chlorpyrifos.

Table 20: Costs per Acre for Chlorpyrifos and the Composite Alternative: Citrus

AI	Material cost ($)	Cost increase for switching to composite alternative (%)
Chlorpyrifos	28.23	49.9
composite alternative	42.32	-

Table 20 shows the average per acre costs for chlorpyrifos as well as the cost of the composite alternative, whose price we use as a representative pesticide cost if chlorpyrifos was withdrawn. For citrus, switching to the alternative would lead to an increase in material cost. Chlorpyrifos users will incur a per acre cost increase of $14.09, or 49.9%.

Table 21. Change in Treatment Cost due to the Withdrawal of Chlorpyrifos: Citrus, 2015–2017

Year	Cost with chlorpyrifos ($)	Cost without chlorpyrifos ($)	Change in cost ($)	Change in cost (%)
2015	1,984,828	2,975,005	900,177	49.9
2016	2,016,605	3,022,636	1,006,030	49.9
2017	1,908,925	2,861,236	952,312	49.9

Table 21 reports the expected change in costs due to the withdrawal of chlorpyrifos. For citrus, costs are expected to increase by approximately 50% for a single application on acreage that would have been treated with chlorpyrifos. The total value of this cost increase ranges from $900,177 in 2015 to $1,006,030 in 2016. Compared to the $2.2 billion total value of the citrus industry, the change in insecticide cost due to the removal of chlorpyrifos is small, representing around 0.05% of the total value. However, the cost increase is not spread across all acreage, and a relatively small share of treated acres were treated with chlorpyrifos. On an acre that would have been treated with chlorpyrifos, the cost increase ($14.09) is 0.24% of 2016-17 gross revenue for navel oranges ($5,790), 0.23% of 2016-17 gross revenue for Valencia oranges ($6,078), 0.16% of 2016-17 gross revenues for mandarin ($9,011), 0.09% of 2016-17 gross revenues per acre for lemon ($15,269) and 0.16% of 2016-17 gross revenues per acre for grapefruit ($8,901).

No yield losses are expected from the withdrawal of chlorpyrifos if the alternatives are used, so there is no expected change in gross returns to citrus acres in production in this analysis. However, unchecked earwigs and ant damage to young, non-bearing citrus could slow the growth of the citrus and delay the beginning of commercial production. This could reduce the total fruit output from the tree over the course of its life. Here we limit attention to single-year losses on bearing acreage, which excludes the scenario above. Alternative AIs use the same application method as citrus. Therefore, the expected change in material costs is the expected change in net revenues for citrus. If the proportions of alternative AIs used change over time, these figures may over- or underestimate the costs of the policy, depending on whether the alternative AIs shifts towards products with a lower or higher cost per acre. If multiple treatments with alternative AIs are required to control multiple pests, while a single application of chlorpyrifos would have done so, then these costs are an underestimate.

Conclusions

Pest management costs in citrus are expected to increase by around $1 million per year. These cost increases are small on a percentage basis, only around 0.09% to 0.24% of gross revenues per acre, depending on the crop. However, they do not take into account potential future costs of ACP, for which chlorpyrifos is an important part of the management program. Citrus is vulnerable to endemic and invasive pest species, and chlorpyrifos is especially useful because it is broad spectrum, effective, and relatively compatible with current pest management strategies. Importantly, chlorpyrifos is a key ACP management tool in the late fall because it can be used close to harvest due to its well-established MRLs. In addition to ACP, the loss of chlorpyrifos will most strongly affect California red scale and citricola scale management in the San Joaquin Valley, bud mite management in in Ventura and statewide management of earwigs and ants in nonbearing citrus. Significant earwig and ant damage on young trees could delay production, a cost not covered in this analysis.

Cotton

California cotton generated over $475 million in gross revenues in 2017, accounting for 7.0% of the national total. California exported $377 million in cotton, which was 8.2% of total US export value in 2017 (CDFA 2018A). Roughly 75% of California cotton was exported. While cotton was only the 18th most valuable agricultural commodity in the state, it was the 11th most important agricultural commodity for export.

California produces two species of cotton: Acala/Upland (*Gossypium hirsutum*) and Pima/extra-long staple (*G. barbadense*). Pima is a premium, extra-long staple cotton with longer fibers than Upland cotton, and it commands a higher price. Of the 304,000 acres planted to cotton in 2017, 216,000 acres (71.1%) were planted to Pima and 88,000 acres (28.9%) to Upland cotton varieties. California's cotton production is concentrated geographically. The three largest cotton-producing counties in 2017—Kings (38.9% of production value), Fresno (27.1%), and Merced (14.1%)—accounted for 80.1% of state production. Figure 5 depicts the geographic location of California cotton production. As discussed in the methods section, the figure is generated using PUR data. The PUR does not differentiate between the two types of cotton.

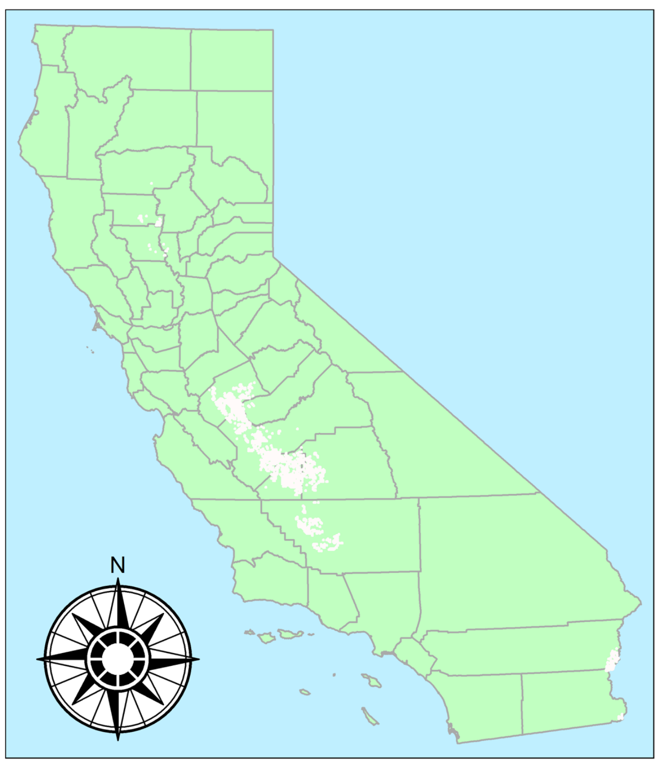


Figure 11: California cotton production: 2017

Notably, there has been significant change in California cotton production in recent years. Pima cotton acreage, Upland cotton acreage, and total cotton acreage all varied considerably over the ten-year period from 2008 to 2017. Figure 12 plots planted acreage by year from 2008-2017. Planted acreage for Pima cotton dipped to 119,000 acres in 2009, peaked at 274,000 acres in 2011 during this ten-year period, only to fall again to 117,000 acres in 2015. Planted acreage for Upland cotton mirrored this same pattern, dropped to 71,000 acres in 2009, reaching 182,000 acres in 2011, and falling to 47,000 acres in 2015. Overall, planted acreage has recently increased since bottoming out in 2015. In 2017, 216,000 acres were planted in Pima cotton and 88,000 in Upland cotton. To the extent that treated acres are proportionate to planted acres, losses estimated using 2015 data will be small relative to losses estimated using data from other years.

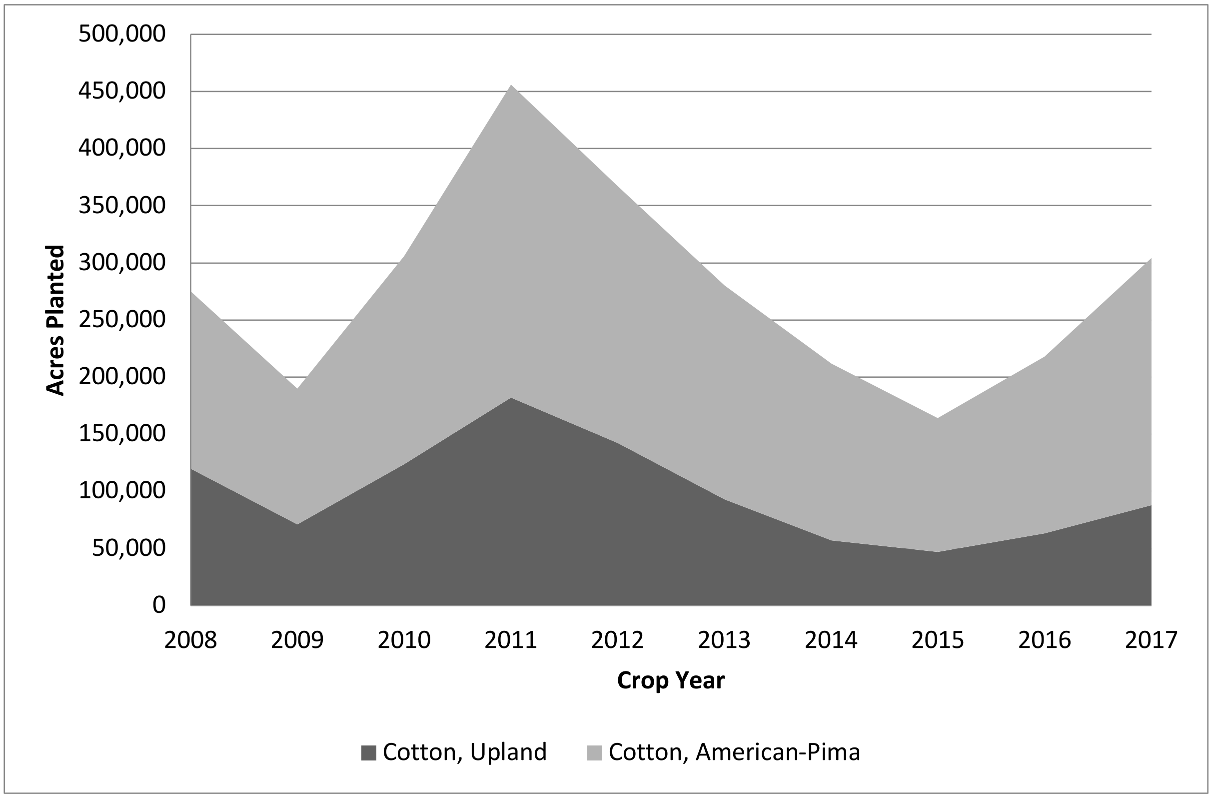


Figure 12. Acres planted in Upland and Pima cotton: California, 2008-2017

IPM Overview

California cotton is attacked by a variety of pests, of which nine were identified by Goodell & Berger (2014) as being treated with chlorpyrifos: cotton aphid, sweet potato whitefly, brown stink bug, cutworms, beet armyworms, and pink bollworm. Two are considered critical with no or few alternatives for management for specific parts of the season: cotton aphid and sweet potato whitefly. Two more pests of concern do have alternatives: lygus, which is a perennial pest, and brown stink bug, which is a sporadic but possibly emerging pest. Pests rarely occur in isolation but are present simultaneously in the fields or occur in quick succession. Because cotton lint is used to make fabrics, quality is almost as important as yield, both because of the end product's quality and effect of quality on ease of processing.

Similar to alfalfa, cotton has a long history with integrated pest management. Cotton was one of the first seven crops that the UC Statewide IPM Program chose to focus on in the 1970s, and IPM practices have been widely adopted in cotton.

Chlorpyrifos has been an important element of the integrated pest management in cotton, made more so by the restriction and removal of products such as carbofuran, endosulfan, aldicarb, and methamidophos, which were used historically to manage key cotton pests. These restrictions led to an increase in chlorpyrifos use until new permit conditions made chlorpyrifos difficult to use starting in January 2018.

Target Pests

Cotton aphid (*Aphis gossypii*).

Cotton aphid, like other aphids, feed by sucking sap from plant phloem tissues. Excess sugars are excreted in honeydew. In cotton, honeydew can fall on exposed lint leading to sticky cotton and thereby reducing quality and marketability. Significant effects on quality can lead to substantial losses in terms of economic returns, even in the absence of effects on yield. The problem of sticky cotton is not limited to aphid (or whitefly) management costs—if a region repeatedly produces sticky cotton, cotton mills may demand a discounted price for the cotton lint or may stop buying from that region (Frisvold et al. 2007). Due to problems with whiteflies in the 1990s, Arizona experienced these price discounts and some mills stopped buying cotton from the region. California producers most recently had problems with sticky cotton in the early 2000s (Cline 2002). Reputation is important for California's cotton industry because producers are known for producing high-quality cotton that commands a price premium over cotton from much of the rest of the United States and other parts of the world.

Chlorpyrifos has been crucial for late-season management of cotton aphids (Goodell and Berger 2014). No alternative chemicals work as well for late season control. Alternatives in the early season include imidacloprid, acetamiprid, flonicamid, thiamethoxam, methomyl, flupyradifurone, and acephate. Early season management often coincides with lygus management. The neonicotinoids imidacloprid and thiamethoxam – as well as clothianidin and dinotefuran – are currently being re-evaluated by DPR owing to their risk to bees and may not be available as post-emergent alternatives in the future (Troiano et al. 2018). Although neonicotinoids usually work for early season control, they do not work as well in the late season once leaves have a waxy coating. Acetamiprid, a neonicotinoid, is an effective aphid material and is widely used, but it has a 28-day PHI which can make it difficult to use late season in addition to efficacy issues. Naled sometimes is used for mid/late season aphids, most of the time mixed with another insecticide such as chlorpyrifos or acetamiprid. Flupyradifurone is another alternative material with good activity against aphids, although its use has likely been hampered (thus far) by price and lower efficacy with aerial applications later in the season. Chlorpyrifos is often tank mixed with another insecticide in late-season use, including acetamiprid, naled, or bifenthrin. One issue with alternatives to chlorpyrifos very late in the season is efficacy of materials when applied as an aerial application, which is standard in many areas. Products with chlorpyrifos have a fuming action, which helps reach sucking insects on the bottom of leaves and deep within the canopy. Coverage is a substantial issue late in the season.

In recent years (2017-2018), sulfoxaflor has been used under a Section 18 registration for lygus control during the growing season, likely making applications of other materials (chlorpyrifos and alternatives) unnecessary for late-season aphids. A Section 3 label for sulfoxaflor products is currently not available for cotton.

Non-chemical management practices can limit aphid populations. Planting and harvesting as early as possible and avoiding excessive fertilization and late-season irrigation can be helpful, but are somewhat weather dependent. Natural enemies can keep aphid populations low earlier in the year so conservation of natural enemies, mainly by avoiding broad-spectrum insecticides early in the season and through mid-season, is an important component of a system-level approach to pest management. Some cultivars are more resistant to aphids than others, but this information is not always available to growers when selecting cultivar, or varieties are chosen for agronomic reasons. Resistance is also relative between varieties and truly resistant varieties are not available. Varieties with smooth leaves tend to host lower aphid populations than those with hairy leaves.

Sweetpotato whitefly (*Bemesia tabaci* biotype B). Sweetpotato whitefly causes similar problems to cotton aphid. High populations can reduce yield, and their excreted honeydew reduces the quality and value of the cotton lint. As discussed, a single grower's sticky cotton lint can become a problem for an entire cotton region, having rippling effects across a growing area and in subsequent years for selling the crop.

Sweetpotato whitefly is known to develop resistance to insecticides that are regularly used. Best management practices are to use cultural and biological methods of control and only resort to chemical control when those are no longer effective. Cultivar selection and conservation of natural enemies, particularly in the early season, are helpful. Additionally, sweetpotato whitefly management benefits from a regional pest management approach in which cotton is planted at least half a mile upwind of other whitefly hosts, adjacent crops are promptly cleaned up, and nearby fields are kept clean of weeds in winter and spring.

Chlorpyrifos is mostly used in combination to provide quick control of ballooning adult populations in mid- to late-season (Goodell and Berger 2014). Buprofezin, spiromesifen, and pyriproxyfen selectively target eggs and/or nymphs when populations are low in the early- to mid-season but are not effective alternatives to chlorpyrifos in the late season. Neonicotinoids (dinotefuran and thiamethoxam) can be effective early- to mid-season, but as described for aphids, do not work well late season. As mentioned above, the neonicotinoids clothianidin, dinotefuran, imidacloprid, and thiamethoxam are currently under review (Troiano et al. 2018). Acetamiprid is used throughout much of the season and is used later in the season than the other neonicotinoids, though there is a 28-day PHI for this AI that can be an issue around harvest. Other late-season alternatives are bifenthrin, fenpropathrin, oxamyl, naled, and acephate. Bifenthrin and fenpropathrin can be mixed with an organophosphate. Similarly, chlorpyrifos is often tank mixed with other insecticides in late-season use, including acetamiprid, naled, buprofezin, or bifenthrin.

Lygus bug (*Lygus hesperus*) is the key pest in the San Joaquin Valley, the main cotton-growing region in California. Lygus often migrate into cotton from other habitats, including safflower and alfalfa. They are a pest throughout much of the season, attacking floral buds, damaging anthers, and reducing yield primarily by causing squares to drop. Damage can be somewhat mitigated by providing the crop extra water and delaying harvest, although this is often not possible. Lygus is a key pest because the broad-spectrum insecticides frequently used to control its populations can affect non-target natural enemies, resulting in secondary pest outbreaks.

Chlorpyrifos is not often used to control lygus, except in tank mixes for other insects (Goodell and Berger 2014). Tank mixes may be used when lygus occurs with aphids later in the season. Other insecticides that can be used to control lygus are beta-cyfluthrin, clothianidin, bifenthrin, flonicamid, novaluron, dimethoate, acephate, indoxacarb, oxamyl, and lambda-cyhalothrin, with flonicamid heavily relied upon. Clothianidin and imidacloprid – along with dinotefuran and thiamethoxam – are currently being re-evaluated by DPR for their risk to bees and may not be available as alternatives. Acetamiprid is sometimes used for lygus (sometimes mixed with a pyrethroid), generally later in the season and often also targeting aphids and/or whiteflies. Novaluron provides partial control as does indoxacarb. Bifenthrin and lambda-cyhalothrin are broad spectrum and disrupt natural enemies, which are important for the control of other pests in the cotton system. In years with particularly heavy lygus pressure requiring multiple and frequent applications to control influxes of adults, the maximal seasonal use of a material (e.g., flonicamid) may be used, eliminating the material's availability for late-season aphid or whitefly use.

Brown stink bug (*Euschistus servus*). Brown stink bug is a relatively new and possibly emerging pest. It appeared in Riverside County and in Arizona as a pest in 2012 and 2013. Managing the brown stink bug initially disrupted IPM system in cotton. It feeds on seeds, causing misshapen bolls, rendering them unharvestable because they cannot release their lint. The brown stink bug can also vector bacterial diseases that cause cotton boll rot, though that has not yet been a significant issue in the area this pest occurs in California (South East region). In states across the south, boll rot and cotton staining caused by this pest can be a substantial issue. This pest has not become a problem yet in the main cotton growing region of the San Joaquin Valley.

In Arizona, grower experience indicates that chlorpyrifos has not been very effective at controlling the brown stink bug. Brown stink bug is not on the label for chlorpyrifos in California. Alternatives include bifenthrin (with and without zeta-cypermethrin), and acephate. Insecticides that have efficacy against brown stink bug are broad-spectrum pesticides and will disrupt natural enemies. Research in Arizona indicated that applications of broad-spectrum materials with some activity against brown stink bug were not economically worthwhile, in part because of disruption of natural management of other pests.

Cutworms (*Agrotis spp*). Cutworms cause damage to cotton by chewing young plants off at or near ground level. Cutworms are not a key pest in the system and damage is usually limited to certain parts of a field, although they often reoccur in the same location for several years due to overwintering and movement patterns of the pest.

Maintaining good field sanitation practices, such as removing residue over the winter and weed management, is a good way to keep cutworms from becoming a problem. Having a bare field for 3-4 weeks before planting minimizes cutworms. However, that is not always possible when conservation tillage is used to manage soil erosion. When there is an outbreak of cutworms that is causing significant damage, chlorpyrifos is the most common treatment. The alternatives are acephate, which requires application in-furrow at planting in advance of an outbreak and so is only useful for recurring problems, and indoxacarb, which is not labeled for cutworms.

Beet armyworm (*Spodoptera exigua*). Beet armyworms are often present around cotton fields but only occasionally become a problem. They can destroy cotton seedlings and cause boll damage to older plants. They often start out on nearby weeds and then move into the cotton crop. Beet armyworms can feed on a variety of crops, including alfalfa, beets, beans, and many vegetables, as well as commons weeds, such as pigweed and nettleleaf goosefoot. This pest is mostly kept below damaging levels by natural enemies and weather conditions. When natural enemies are disrupted and weather conditions are favorable, populations can balloon.

Monitoring for beet armyworms in weedy field margins helps keep them from moving into cotton crops. Chlorpyrifos is not commonly used to control beet armyworms, but it can be important when other pests are co-occurring. Alternatives are esfenvalerate, bifenthrin, chlorantraniliprole, novaluran, *Bacillus thuringiensis*, methoxybenzamide, methomyl, and spinosad. Chlorantraniliprole, methoxyfenozide, and spinosad are all effective and do not impact natural enemies. Conserving natural enemies and maintaining margins clean of weeds are effective strategies for beet armyworm, along with other cotton pests. Additionally, transgenic Pima cotton is not susceptible to beet armyworms.

Pink bollworm (*Pectinophora gossypiella*). Pink bollworm is a potentially severe pest that has been successfully managed in California. Larvae cause damage by burrowing into the cotton bolls, leading to yield and quality loss. In 2018, it was formally announced that pink bollworm had been eradicated.

In California, pink bollworm has been the target of area wide management programs. Growers in the San Joaquin have a host-free time during the year when there is no cotton and, therefore, nowhere for pink bollworm to overwinter and subsequently infest the next year's crop. Bt cotton has had a large impact on this pest and reduced the need for insecticides. Releasing sterile males and using mating disruption have contributed to a decline of pink bollworm populations. Although chlorpyrifos was previously important for managing pink bollworm, growers will not need to worry about controlling pink bollworm unless it is reintroduced.

Chlorpyrifos Use: 2015-2017

Chlorpyrifos use in cotton increased during 2015-2017 (Figure 13), largely driven by the increase in total cotton acres. Late-season usage peaks in late August or September are typically applications for late-season aphid and whitefly infestations.

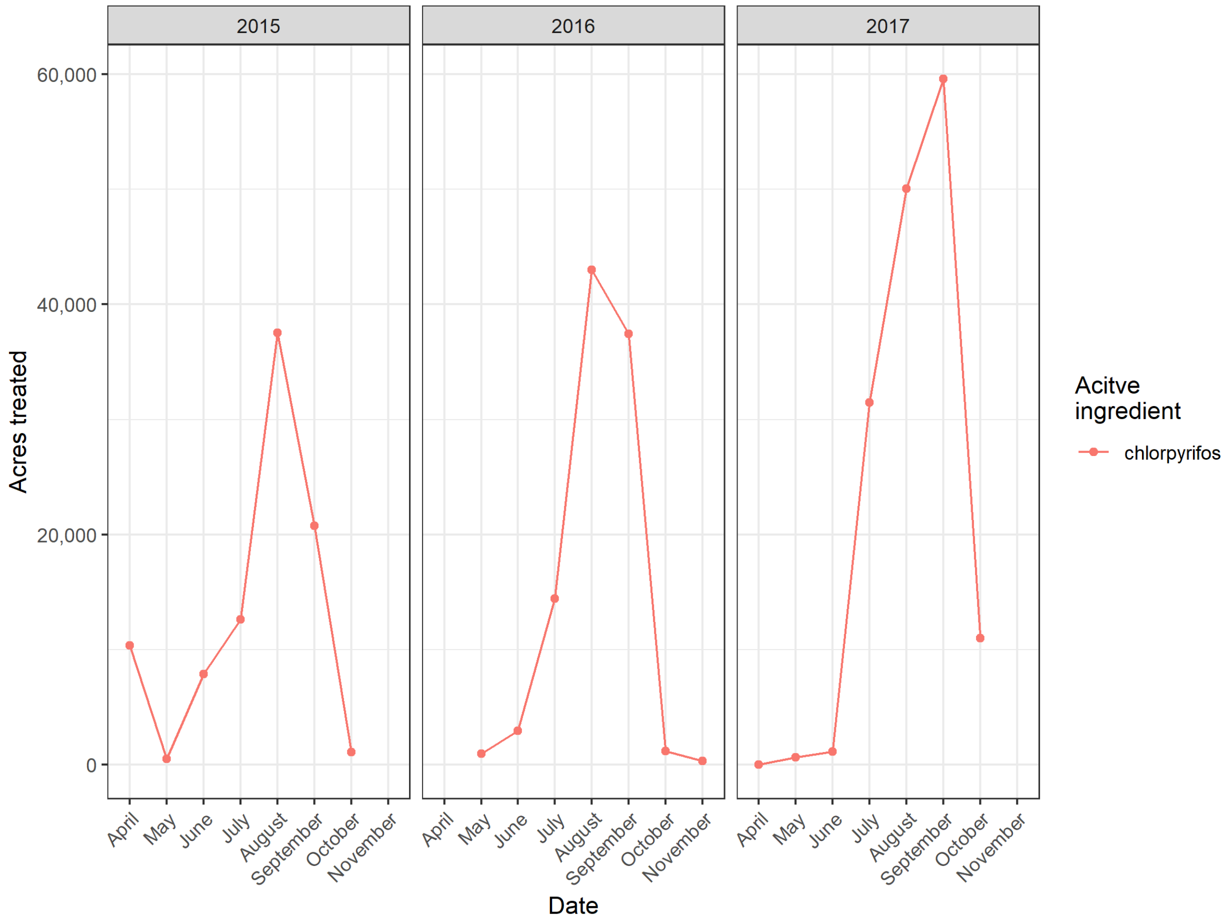


Figure 13: Monthly use of chlorpyrifos: cotton, 2015-2017

Although chlorpyrifos was still regularly used through 2017 (153,881 acres treated of a total 304,000 acres planted in 2017), several of the alternatives were more widely used (Table 22). Flonicamid was applied to 457,574 acres and acetamiprid to 220,987 in 2017 - some acres planted were treated more than once.

Table 22. Annual Use of Chlorpyrifos and Alternative Active Ingredients: Cotton, 2015-2017

Active ingredient	----------Pounds applied----------				-------------Acres treated--------------				Use rate (lbs/ac)
	2015	2016	2017	Total	2015	2016	2017	Total	
acephate	46,759	26,089	30,318	103,166	49,266	28,690	34,921	112,877	0.91
acetamiprid	10,410	13,479	19,077	42,967	123,443	155,534	220,987	499,964	0.09
beta-cyfluthrin	850	1,037	915	2,802	33,316	41,807	36,883	112,006	0.03
bifenthrin	9,319	11,663	15,963	36,945	95,057	113,859	164,258	373,174	0.10
chlorantraniliprole	30	48	275	353	734	983	6,043	7,760	0.05
chlorpyrifos*	85,773	95,958	152,079	333,809	90,743	100,210	153,881	344,834	0.97
clothianidin	2,984	4,003	7,453	14,440	31,415	42,557	80,486	154,457	0.09
dimethoate	25,549	41,612	47,208	114,370	53,088	84,825	112,075	249,987	0.46
esfenvalerate	10	144	39	194	425	3,355	1,399	5,179	0.04
fenpropathrin	1,951	1,816	752	4,519	7,063	6,528	2,415	16,007	0.28
flonicamid	23,404	27,106	39,702	90,212	262,422	304,963	457,574	1,024,959	0.09
imidacloprid	6,815	11,460	18,563	36,838	85,155	142,188	217,730	445,073	0.08
indoxacarb	4,537	3,762	10,340	18,639	40,941	39,116	110,863	190,920	0.10
lambda-cyhalothrin	1,794	1,627	3,449	6,870	48,217	44,166	97,469	189,852	0.04
methomyl	6,862	NA	24	6,886	10,166	NA	45	10,211	0.67
methoxyfenozide	656	256	4,033	4,945	6,984	1,891	36,635	45,510	0.11
novaluron	6,082	8,850	12,084	27,017	91,159	122,343	167,494	380,996	0.07
oxamyl	5,446	1,103	36,533	43,081	5,664	1,146	38,844	45,654	0.94
spinosad	57	1	6	64	1,018	37	130	1,185	0.05
thiamethoxam	1,782	1,485	3,084	6,352	28,677	23,798	51,734	104,209	0.06

*Target AI

Economic Analysis

This section presents the estimated change in net returns to California cotton in the event of the withdrawal of chlorpyrifos. Both gross revenues and pest management costs may be affected. In this analysis, we take into consideration the possibility that substantial yield losses may occur if there is a sticky cotton problem due to aphids and sweetpotato whitefly not being effectively controlled. Accordingly, we address possible Pima cotton gross revenue losses under three possible yield loss scenarios (0%, 25%, and 50%) and address possible Upland cotton gross revenue losses under three possible yield loss scenarios (0%, 15%, and 30%), each for two own-price elasticities of demand.[3] Yield loss scenarios at the high end reflect a particularly severe year for aphids and/or whiteflies where pest managers are not able to bring these pests under control, which would not occur every year. A 0% loss scenario represents a scenario in which growers are

[3] The own-price elasticity of demand describes the expected change in the quantity demanded when the price of a good changes.

able to use alternative materials to manage aphids and whiteflies and prevent sticky cotton, thereby maintaining a full yield of marketable cotton that is not subject to quality-based price reductions. The range of losses for Upland cotton is lower than Pima because Pima is more likely than Upland to face issues with sticky cotton and yield losses. This is largely because of the longer growing season required for Pima cultivation and thus expanded exposure period to honeydew-producing pests as well as Pima's higher susceptibility to aphids and whiteflies.

For both Pima and Upland cotton, the total change in net returns related to chlorpyrifos withdrawal is the expected change in gross revenue due to yield losses plus the expected change in pesticide material costs. We report the expected change in pesticide materials for Pima and Upland cotton separately; however, the PUR does not differentiate between the two types of cotton so we must apportion the expected change in pesticide material costs across the two varieties. To apportion the expected change in pesticide material costs by type of cotton, we make two assumptions: (i) we assume treated acreage is divided in proportion to harvested acreage in CDFA (2018) (for example in 2017 we assume 71.2% of treated acreage was Pima and 28.8% was Upland, based on harvested acreage of 215,000 and 87,000, respectively), and (ii) we assume the bundle of alternatives is the same for both Pima and Upland. The total expected change in pesticide material costs, which is the sum of expected pesticide material costs across varieties, does not depend on the validity of these two assumptions. However, these two assumptions are relevant for the breakdown of the expected change in pesticide material costs reported below: if the division of pesticide material costs is higher in one variety than the other, then the pesticide material costs will be correspondingly lower in the other variety.

Table 23 presents representative products for each active ingredient used on cotton in 2015–2017 and their costs per acre. Cost per acre is the product of the average use rate (lbs/ac) over this period and the price per pound. The representative product for chlorpyrifos costs $7.98 per acre, while the alternatives range from $0.71 to $45.93 per acre. Growers consider factors other than price per acre when deciding which insecticides to use, as discussed above.

Table 23. Representative Products and Price per Acre: Cotton

Active ingredient	Representative product	Total cost ($)
(s)-cypermethrin	Mustang	3.8
acephate	Acephate 97UP Insecticide	14.1
acetamiprid	Assail 30SG Insecticide	22.7
beta-cyfluthrin	Baythroid XL	10.9
bifenthrin	Bifenture EC Agricultural Insecticide	4.9
buprofezin	Courier 40SC Insect Growth Regulator	36.8
chlorantraniliprole	Dupont Coragen Insect Control	29
chlorpyrifos	Lorsban Advanced	8
clothianidin	Belay Insecticide	13.6
dimethoate	Dimethoate 400	6.6
esfenvalerate	Asana XL	4.3
fenpropathrin	Danitol 2.4 EC Spray	24.8
flonicamid	Carbine 50WG Insecticide	16.7
flupyradifurone	Sivanto Prime	45.9
imidacloprid	Wrangler Insecticide	2.8
indoxacarb	Dupont Steward EC Insecticide	27.9
lambda-cyhalothrin	Warrior II	7.4
methomyl	Du Pont Lannate SP Insecticide	29
methoxyfenozide	Intrepid 2F	13.5
naled	Dibrom 8 Emulsive	9.5
novaluron	Diamond 0.83EC	12.4
oxamyl	Dupont Vydate C-LV Insecticide/Nematicide	15.9
pyriproxyfen	Knack Insect Growth Regulator	0.7
spinosad	Success	16.1
spiromesifen	Oberon 4SC Insecticide/Miticide	21.5
sulfoxaflor	Transform	19.9
thiamethoxam	Centric 40WG	13.1

Table 24 shows the average acreage shares for each alternative AI used on cotton, with and without chlorpyrifos being available. Averaged over the three-year period 2015–17, chlorpyrifos was used on 6.3% of cotton acres treated with chlorpyrifos or an alternative AI. With withdrawal, chlorpyrifos is unavailable and we assume the use of alternative AIs would be scaled up in proportion to their acreage shares, as discussed in the methods section. Three alternatives accounted for 36.3% of all acreage treated with chlorpyrifos or an alternative AI over the 2015–2017 period: flonicamid, acetamiprid, and sulfoxaflor.

Table 24. Average Annual Acreage Shares of Alternative Insecticides with and without Chlorpyrifos: Cotton, 2015–2017

Active ingredient	Chlorpyrifos available (%)	Chlorpyrifos withdrawn (%)
acephate	2.1	2.2
acetamiprid	9.1	9.7
beta-cyfluthrin	2.0	2.2
bifenthrin	6.8	7.3
buprofezin	2.3	2.5
chlorantraniliprole	0.1	0.2
clothianidin	2.8	3.0
cypermethrin	2.2	2.3
dimethoate	4.6	4.9
esfenvalerate	0.1	0.1
fenpropathrin	0.3	0.3
flonicamid	18.7	19.9
flupyradifurone	2.6	2.8
imidacloprid	8.1	8.7
indoxacarb	3.5	3.7
lambda-cyhalothrin	3.5	3.7
methomyl	0.3	0.3
methoxyfenozide	0.8	0.9
naled	3.4	3.7
novaluron	6.9	7.4
oxamyl	0.8	0.9
pyriproxyfen	1.3	1.4
spinosad	0.0	0.0
spiromesifen	0.9	0.9
sulfoxaflor	8.5	9.1
thiamethoxam	1.9	2.0
Total	93.7	100.0

Note: Three years average from 2015-2017.

Table 25 compares the average per acre costs for chlorpyrifos and the composite alternative, whose cost we use as a representative material cost if chlorpyrifos were withdrawn. Switching to an application of the composite alternative would increase material costs by $7.06 per acre (88.4%) on acres previously using chlorpyrifos.

Table 25. Costs per Acre for Chlorpyrifos and the Composite Alternative: Cotton

Active ingredient	Total cost ($)	Cost increase for switching to composite alternative (%)
chlorpyrifos	7.98	88.4
composite alternative	15.04	-

Change in pesticide material costs. The total annual change in material (and treatment) costs for Pima and Upland cotton combined was $0.6 million in 2015, $0.7 million in 2016, and $1.1 million in 2017. In order to evaluate total changes in pesticide material costs for the two types of cotton, we assume that treated acreage is divided between the two in the same proportion as harvested acreage reported in CDFA (2018). The composite alternative remains the same for the two types because the PUR data do not distinguish between the two. Table 26 reports the annual change for Pima cotton. It ranged from $0.5 million in 2015 to $0.8 million in 2017. Table 27 reports the change in treatment costs due to the withdrawal of chlorpyrifos for Upland cotton, which ranged from $0.2 million in 2015 to $0.3 million in 2017. The differences in changes in annual treatment costs correspond to the differences in annual acreage.

Insecticide material costs are anticipated to increase because most of the alternative AIs cost more than chlorpyrifos. For example, the three most common AIs in the composite alternative bundle cost significantly more on a per acre basis than chlorpyrifos ($7.98): flonicamid ($16.70), acetamiprid ($22.70), and sulfoxaflor ($19.90).

Table 26. Change in Treatment Costs due to the Withdrawal of Chlorpyrifos: Pima Cotton, 2015–2017

Year	Chlorpyrifos available($)	Chlorpyrifos withdrawn ($)	Change in cost ($)	Change in cost (%)
2015	518,760	977,321	458,561	88.4
2016	570,415	1,074,637	504,222	88.4
2017	874,642	1,647,787	773,146	88.4

Table 27. Change in Treatment Costs due to the Withdrawal of Chlorpyrifos: Upland Cotton, 2015–2017

Year	Chlorpyrifos available ($)	Chlorpyrifos withdrawn ($)	Change in cost ($)	Change in cost (%)
2015	205,715	387,558	181,843	88.4
2016	229,648	432,646	202,999	88.4
2017	353,925	666,779	312,854	88.4

All material cost calculations are based on the cost per acre of the composite alternative, which is based on 2015-2017 insecticide use patterns. Note that, if the proportions of alternative AIs used change over time, these figures may over- or underestimate the costs of the policy, depending on whether the bundle of alternative AIs shifts towards products with a lower or higher cost per acre.

Change in gross revenues: Pima cotton. Table 28 reports the estimated change in gross revenues for Pima cotton due to the withdrawal of chlorpyrifos assuming a 25% yield loss on all acreage treated with chlorpyrifos each year, and perfectly elastic demand. The percentage reduction in total gross revenue for Pima cotton ranges from 1.6% (2017) to 1.8% (2015). Because price is unaffected by a change in quantity when demand is perfectly elastic, this loss is composed of a 25% yield loss on acres treated with chlorpyrifos.

In order to evaluate the impact on gross revenue in dollar terms, we use three base prices centered on the 2018 national price, which was $1.38/lb.[4] The range of prices encompasses prices for the three base years and mirrors the use of a single set of current pesticide prices for computing costs in the three base years. We use the national price because the California price has been redacted since 2015 (CDFA 2018a). As stated previously, we assume that the share of treated acres in Pima cotton is the same as the share of harvested cotton acres.

Based on these parameters, the absolute magnitude of the gross revenue change depends on the market-clearing price for Pima cotton: under a low price scenario (15% below 2018 national price), gross revenue changes range from -$3.7 million to -$5.6 million; under an intermediate price scenario (2018 national price), from -$4.3 million to -$6.6 million; and under a high price scenario (15% above 2018 national price), from -$5.0 million to -$7.6 million. The magnitude of gross revenue losses is significantly larger than the losses due to increased treatment costs (less than $1 million) presented in Table 26, regardless of the price scenario.

Table 28. Change in Gross Revenue due to 25% Yield Loss on Chlorpyrifos-treated Acreage from Withdrawal of Chlorpyrifos: Pima Cotton, Perfectly Elastic Demand, 2015–2017

Year	Gross revenue with chlorpyrifos available ($)	Gross revenue with chlorpyrifos withdrawn ($)	Change in gross revenue ($)	Change in gross revenue (%)
		--- Low Price: ($1.173/lb.) ---		
2015	203,285,592	199,591,024	-3,694,568	-1.8
2016	282,704,730	277,999,443	-4,705,287	-1.7
2017	354,838,365	349,190,292	-5,648,073	-1.6
		--- 2018 Price: ($1.380/lb.) ---		
2015	239,159,520	234,812,970	-4,346,550	-1.8
2016	332,593,800	327,058,169	-5,535,631	-1.7
2017	417,456,900	410,812,108	-6,644,792	-1.6
		--- High Price: ($1.587/lb.) ---		
2015	275,033,448	270,034,915	-4,998,533	-1.8
2016	382,482,870	376,116,894	-6,365,976	-1.7
2017	480,075,435	472,433,925	-7,641,510	-1.6

Table 29 reports the estimated change in gross revenues for Pima cotton due to the withdrawal of chlorpyrifos assuming a 50% yield loss and perfectly elastic demand. The percentage change in gross revenue ranges from 3.2% to 3.6%. The absolute magnitude of the gross revenue change depends on the market-clearing price for Pima cotton: under a low price scenario (15% below 2018 price), gross revenue changes range from -$7.4 million to -$11.3 million; under an intermediate price scenario (2018 national price), from -$8.7 million to -$13.3 million; and under

[4] Obtained from https://quickstats.nass.usda.gov

a high price scenario (15% above 2018 price), from -$10.0 million to -$15.3 million. The magnitude of gross revenue losses is significantly larger than the losses due to increased material costs (less than $0.4 million) presented in Table 26, regardless of the price scenario.

Table 29. Change in Gross Revenue due to 50% Yield Loss on Chlorpyrifos-treated Acreage from Withdrawal of Chlorpyrifos: Pima Cotton, Perfectly Elastic Demand, 2015–2017

Year	Gross revenue with chlorpyrifos available ($)	Gross revenue with chlorpyrifos withdrawn ($)	Change in gross revenue ($)	Change in gross revenue (%)
		--- Low Price: ($1.173/lb.) ---		
2015	203,285,592	195,896,457	-7,389,135	-3.6
2016	282,704,730	273,294,157	-9,410,573	-3.3
2017	354,838,365	343,542,219	-11,296,146	-3.2
		--- 2018 Price: ($1.380/lb.) ---		
2015	239,159,520	230,466,420	-8,693,100	-3.6
2016	332,593,800	321,522,537	-11,071,263	-3.3
2017	417,456,900	404,167,317	-13,289,583	-3.2
		--- High Price: ($1.587/lb.) ---		
2015	275,033,448	265,036,383	-9,997,065	-3.6
2016	382,482,870	369,750,918	-12,731,952	-3.3
2017	480,075,435	464,792,414	-15,283,021	-3.2

The gross revenue losses for Pima cotton reported above assume a worst-case scenario where demand is perfectly elastic, so there is no increase in price when the quantity produced declines. Perfectly elastic demand corresponds to a case where California production is a small share of total market production and thus had little influence on the market-clearing price. This assumption is conservative: California accounted for 90% of national Pima cotton production in 2017 (USDA NASS 2019) and the U.S. accounted for 37% to 44% of world Pima cotton exports from 2016-2018 (USDA FAS 2019). Given the large share of California Pima cotton on the national and international markets, reductions in California's supply of Pima cotton would likely increase the market-clearing price.

The magnitude of the price change depends on the own-price demand elasticity; however, estimates of California Pima cotton own-price demand elasticity are not available in the literature. In the economic literature, estimates of the own-price demand elasticity for cotton for a variety of time periods and regions vary significantly (see the Appendix C for a summary). (Russo et al. 2008) estimate the own-price demand elasticity for (all) California cotton over the period 1970 to 2002 as -0.95. That is, if price increases by 1%, the total quantity demanded would decrease by 0.95%. Because California Pima cotton is viewed as a highly distinct product and commands a much larger domestic market share than California Upland cotton, it may be the case that this own-price elasticity of demand estimate overestimates the decline in the quantity demanded due to a 1% price increase.

If we apply this elasticity estimate applied to California Pima cotton today, recognizing that it was estimated for all cotton, not Pima cotton specifically, and the two types of cotton are not interchangeable, the effect of the price increase resulting from lower supply would offset the effect of production losses. For example, at the 2018 national price ($1.380/lb.), a 25% yield loss on 2017 Pima cotton acreage treated with chlorpyrifos would increase price to $1.405/lb., resulting in a gross revenue increase of $0.2 million for the industry as a whole. A 50% yield loss on 2017 acreage would increase price to $1.430/lb., resulting in a gross revenue increase of $0.2 million for the industry as a whole. (A full set of estimates are included in Appendix C.) Critically, while the benefit of the price increase would be obtained on all cotton production, the cost of the decrease in the production would only be borne by affected acreage that must replace chlorpyrifos with an alternative. The yield reduction is substantially larger than the price increase, so there is still a decline in net returns although it is slightly reduced.

Change in gross revenues: Upland cotton. We follow the same procedure for estimating gross revenue losses for Upland cotton. Results based on perfectly elastic demand are reported here, and results based on an own-price elasticity of demand of -0.95 are included in Appendix C.

Table 30 reports the estimated change in gross revenues for Upland cotton due to the withdrawal of chlorpyrifos assuming a 15% yield loss on all acreage treated with chlorpyrifos each year, and perfectly elastic demand. Total gross revenues for Upland cotton decline by 1% to 1.1%. Because price is unaffected by a change in quantity when demand is perfectly elastic, this loss is composed of a 15% yield loss on Upland cotton acres treated with chlorpyrifos.

In order to evaluate the impact on gross revenue in dollar terms, we use three base prices centered on the 2018 national price, which was $0.725/lb.[5] The range of prices encompasses prices for the three base years and mirrors the use of a single set of current pesticide prices for computing costs in the three base years. As with Pima cotton, we use the national Upland cotton price because the California price has been redacted since 2015 (CDFA 2018).

Based on these parameters, the absolute magnitude of the gross revenue change depends on the market-clearing price for Upland cotton: under a low price scenario (15% below 2018 national price), annual gross revenue changes range from -$0.5 million to -$0.7 million; under an intermediate price scenario (2018 national price), from -$0.6 million to -$0.8 million; and under a high price scenario (15% above 2018 national price), from -$0.7 million to -$1.0 million.

Gross revenue losses are modestly larger than the losses due to increased treatment costs ($0.2 million to $0.3 million) presented in Table 27 in absolute terms, although on a percentage basis they are significantly higher in some of the scenarios. This differs from the results for Pima cotton due to the substantially lower price of Upland cotton, the lower range of potential yield losses,

[5] Obtained from https://quickstats.nass.usda.gov

and with the assumption that the composite alternative is identical for the two types of cotton, which in turn is due to the fact that the PUR data do not differentiate between the two types of cotton.

Table 30. Change in Gross Revenue due to 15% Yield Loss on Acreage Treated with Chlorpyrifos from Withdrawal of Chlorpyrifos: Upland Cotton, Perfectly Elastic Demand, 2015–2017

Year	Gross revenue with chlorpyrifos available ($)	Gross revenue with chlorpyrifos withdrawn ($)	Change in gross revenue ($)	Change in gross revenue (%)
		--- Low Price: ($0.616/lb.) ---		
2015	48,814,395	48,282,095	-532,300	-1.1
2016	72,479,628	71,755,825	-723,803	-1.0
2017	69,537,034	68,872,928	-664,106	-1.0
		--- 2018 Price: ($0.725/lb.) ---		
2015	57,428,700	56,802,465	-626,235	-1.1
2016	85,270,150	84,418,617	-851,533	-1.0
2017	81,808,275	81,026,974	-781,301	-1.0
		--- High Price: ($0.834/lb.) ---		
2015	66,043,005	65,322,835	-720,170	-1.1
2016	98,060,673	97,081,410	-979,263	-1.0
2017	94,079,516	93,181,020	-898,496	-1.0

Table 31 reports the estimated change in annual gross revenues for Upland cotton due to the withdrawal of chlorpyrifos assuming a 30% yield loss and perfectly elastic demand. The percentage change in gross revenue ranges from -1.9% to -2.2%. The magnitude of the gross revenue change depends on the market-clearing price: under a low price scenario (15% below 2018 price), gross revenue changes range from -$1.1 million to -$1.4 million; under an intermediate price scenario (2018 national price), from -$1.3 million to -$1.7 million; and under a high price scenario (15% above 2018 price), from -$1.4 million to -$2.0 million. Gross revenue losses are somewhat larger than the losses due to increased treatment costs ($0.2 million to $0.3 million) presented in Table 27 in absolute terms, although on a percentage basis they are significantly higher in some of the scenarios.

California Upland cotton tends to be of higher quality than Upland cotton produced elsewhere in the U.S., so the national price is likely to understate the price actually received by California growers. To the extent that the national price understates the unreported California price, the above figures also underestimate losses for California Upland cotton. The quality difference also suggests that the price of California Upland cotton may increase when the quantity produced decreases. We present loss calculations based on the own-price elasticity of demand for all California cotton estimated by Russo, Green and Howitt (2008) in Appendix C. Because California

Pima cotton is viewed as a highly distinct product and commands a much larger domestic market share than California Upland cotton, it may be the case that this own-price elasticity of demand estimate overstates the increase in price that would result from a decrease in California Upland cotton production. Thus, the calculations in Appendix C may underestimate losses.

Table 31. Change in Gross Revenue due to 30% Yield Loss on Acreage Treated with Chlorpyrifos from Withdrawal of Chlorpyrifos: Upland Cotton, Perfectly Elastic Demand, 2015–2017

Year	Gross revenue with chlorpyrifos available ($)	Gross revenue with chlorpyrifos withdrawn ($)	Change in gross revenue ($)	Change in gross revenue (%)
		--- Low Price: ($0.616/lb.) ---		
2015	48,814,395	47,749,796	-1,064,599	-2.2
2016	72,479,628	71,032,022	-1,447,605	-2.0
2017	69,537,034	68,208,823	-1,328,211	-1.9
		--- 2018 Price: ($0.725/lb.) ---		
2015	57,428,700	56,176,230	-1,252,470	-2.2
2016	85,270,150	83,567,085	-1,703,065	-2.0
2017	81,808,275	80,245,674	-1,562,601	-1.9
		--- High Price: ($0.834/lb.) ---		
2015	66,043,005	64,602,665	-1,440,340	-2.2
2016	98,060,673	96,102,147	-1,958,525	-2.0
2017	94,079,516	92,282,525	-1,796,992	-1.9

Conclusions

Cotton has two pests with few currently viable alternatives to chlorpyrifos for management: cotton aphid and sweet potato whitefly. For these pests, chlorpyrifos fills a unique niche for late season treatment. Provided that alternatives paired with non-chemical management tools can control these and other pests so that there is no yield loss, the annual cost of the withdrawal of chlorpyrifos would be relatively small, owing to the relatively small acreage treated with chlorpyrifos and the relatively low costs of chlorpyrifos and the composite alternative, totaling $0.6 million to $1.1 million. This increase in cost is entirely due to the higher cost of the composite alternative. No changes in application costs are considered. The increase in pest management costs per acre is less than 1% of 2017 gross revenues per acre for both Pima cotton ($1,955.73) and Upland cotton ($889.74).

If late season aphids and whiteflies cannot be controlled with alternatives, then there is the risk of California cotton becoming unmarketable due to cotton stickiness. Pima cotton is more susceptible than Upland to aphids and whiteflies and has a longer growing season, making managing heavy infestations of those insects on Pima without chlorpyrifos more difficult. Both types, however, could realize substantial yield losses if chlorpyrifos is withdrawn, given the alternatives currently available, which could lead to gross revenue losses. Accounting for yield losses of 25% (Pima) and 15% (Upland) in addition to the increase in pesticide material costs results in annual net revenue losses of up to $8.5 million when 2018 national average prices are used.

The magnitude of gross revenue changes depends on a number of factors, including price, yield, treated acreage, level of yield loss, and the own-price elasticity of demand. Under a worst-case scenario of perfectly elastic demand—where California's production has no influence on the market-clearing price of Pima cotton—annual gross revenues for Pima would decline by 1.6% to 1.8% if yield losses were 25% on acreage treated with chlorpyrifos, corresponding to annual gross revenue reductions of $3.7 million to $7.6 million, given the parameters used. If yield losses were 50%, annual gross revenues would decline 3.2% to 3.6%, corresponding to annual gross revenue reductions of $7.4 million to $15.3 million. For Upland cotton, annual gross revenues would decline by 1.0% to 1.1% if yield losses were 15% on acres treated with chlorpyrifos, corresponding to annual gross revenue losses of $0.5 million to $1.0 million. If Upland cotton yield declined by 30% on acres treated with chlorpyrifos, annual gross revenues would decline by 1.9% to 2.2%, corresponding to annual gross revenue losses of $1.1 million to $2.0 million.

Perfectly elastic demand is likely to be an overly conservative assumption for Pima cotton because California is responsible for a large share of national production and global exports. Indeed, demand may be sufficiently inelastic so that yield losses lead to price increases that more than offset production losses, resulting in a net increase in revenue. While California's Upland cotton is known for higher quality than cotton produced elsewhere in the U.S., the responsiveness of price to a change in production is likely less.

An issue not covered in this analysis is the cost of increasing problems with insecticide resistance. In lygus, aphid, and whitefly management, chlorpyrifos is often rotated with other AIs to decrease the chance of the pests developing resistance. Without chlorpyrifos, growers would rely more heavily on the other AIs, some of which, e.g., neonicotinoids, are in the same group. This could increase the prevalence of insecticide resistance, which would decrease efficacy of alternative materials and increase management costs. This is particularly a concern for aphids in cotton. In addition, because the same active ingredients are used to target multiple pest species throughout the season, rotating materials is challenging and will be more challenging without chlorpyrifos.

Grape

Among U.S. states, California is the top grape producer with 82.9% of national bearing acreage, 84.4% of national production by volume, and 89.6% of national production by value in 2017 (NASS 2018). Grape is one of California's top five economically important crops. In 2017, California produced 6.5 million tons of grapes from 829,000 bearing acres (plus 51,000 non-bearing acres), corresponding to $5.8 billion in gross receipts (CDFA 2018a). California grape exports exceeded $2.5 billion in 2017, which was 12.2% of California's total agricultural export value, second only to almonds.

Wine, raisin, and table grapes are all produced in California. Grape production of all varieties occurs throughout the state. Figure 14 and Figure 15 map wine grape production (top) and table and raisin grape production (bottom). Table grape production was concentrated in Kern ($1,549 million), Tulare ($761 million), and Fresno ($378 million) counties, and was a top ten production value crop in five counties (the previous three plus Riverside and Madera) (CDFA 2018a). Raisin grape production was concentrated in Fresno ($270 million), Kern ($112 million), and Madera ($109 million) counties and was a top ten-production value crop in only these counties. Wine grape was a top ten-production value crop in 22 counties. The top three wine grape producing counties by value were Napa ($751 million), Sonoma ($578 million), and San Joaquin ($396 million). Revenues in Napa and Sonoma counties were driven by high value production, rather than by large acreage.

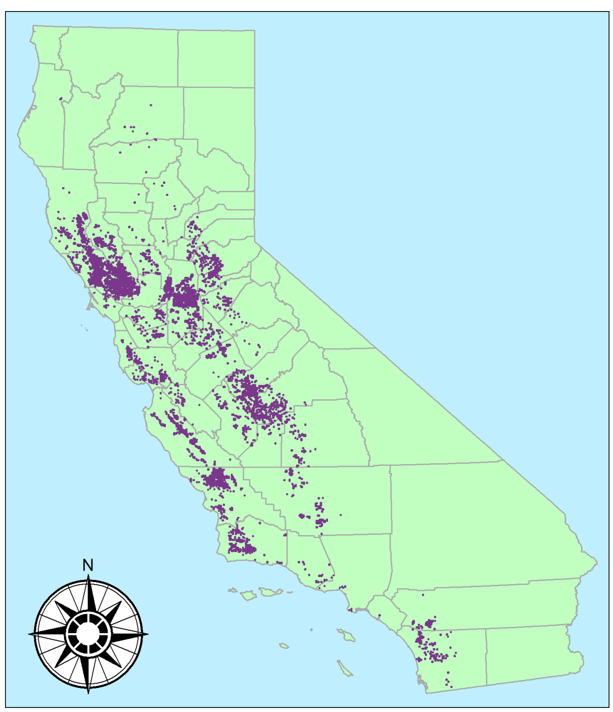


Figure 14. California wine grape production: 2017

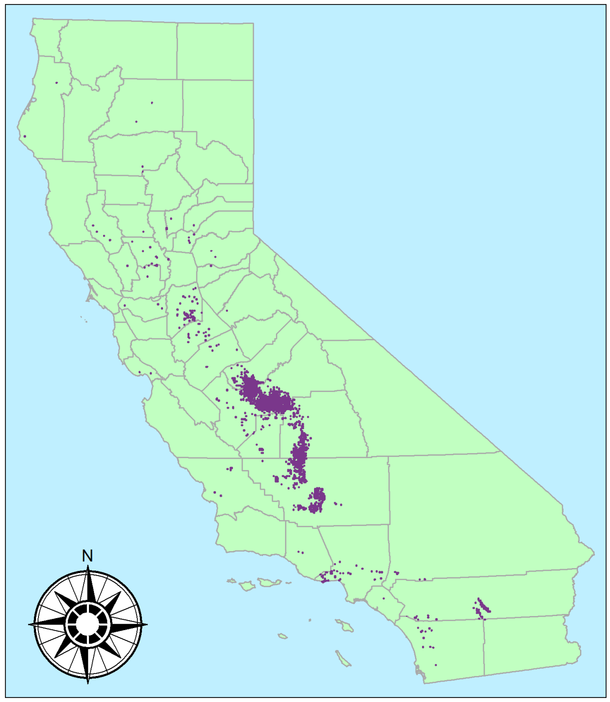


Figure 15. California raisin and table grape production: 2017

By bearing acreage, wine grape production accounted for 67.6% of total grape acreage in 2017, raisin grape 19.0%, and table grape the remaining 13.4% (CDFA 2018a). Table and raisin grape yields tended to be higher than wine grape; as a result, wine grape accounted for 61.9% of production tonnage, while raisin and table grape production accounted for 19.6 and 18.5% of tonnage, respectively. In 2017, table grape had the highest average value per ton at $1,330 per ton, followed by wine grape at $927 per ton. Raisin grape had a substantially lower value, at only $380 per ton. Wine grape was 64.2% of total production value, table grape 27.5%, and raisin grape 8.3%. Note there are many sub-categories within the three primary ones. For example, there were at least 30 white wine, 40 red wine, 60 table, and six raisin grape varieties reported with standing acreage in 2016 or 2017 (CDFA 2018c). The largest share of standing acreage by variety in 2017 were planted to chardonnay for white wine (53.4% of category total); cabernet sauvignon for red wine (30.1%); flame seedless for table (16.9%); and Thompson seedless for raisin (86.6%).

Additionally, grapes are used in a wide variety of products. In 2017, 4.2 million tons—or 64.6% of total production—were crushed for wine, concentrate, juice, vinegar or beverage brandy (CDFA 2018c, 2018d). Most table grapes were sold fresh (1.0 million of the total 1.2 million tons), most raisin grapes were dried (1.1 million of the 1.3 million tons), and virtually all wine grapes were crushed. However, 94,268 tons of raisin grapes and 131,884 tons of table grapes were crushed for wine in 2017 (CDFA 2018d), demonstrating that there is some movement across categories.

IPM Overview

For grape production, growers almost exclusively use chlorpyrifos to control vine mealybug (*Planococcus ficus)* and ants. Ant control is also part of controlling vine mealybug, hence essentially all chlorpyrifos use in grape is directly or indirectly for vine mealybugs.

Target Pests

Vine mealybug (*Planococcus ficus*). Vine mealybug attacks all grape types in California. Like all mealybugs, they feed by sticking their sucking mouthparts into plant phloem tissue to extract plant fluids, which reduces plant vigor. They also excrete honeydew, which can cause the growth of sooty mold on developing grapes. Vine mealybug is difficult to control because of its high reproduction potential, with multiple generations per year. Thus, vine mealybug populations can balloon late in the season as the grapes are maturing. Large mealybug populations are a serious drain on vines. Adding to the problem, vine mealybug feeds within the almost mature grape bunches, making them hard to kill with contact insecticide. To manage this pest, growers use a series of treatments that include multiple insecticides at various times of year. For severe infestations, chlorpyrifos is used as a delayed dormant spray, when the vines have no leaves, either before or after the growing season. There is no replacement for the delayed dormant part of the treatment program. Haviland et al. (2011) found that a combination of spirotetramat and buprofezin was the only treatment which significantly reduced vine mealybug damage while Van Steenwyk et al. (2016c) found that sequential use of spirotetramat and flupyradifurone was effective. Regulation of buprofezin in other countries makes it difficult to use wine grapes for export. Although they are not drop-in alternatives, acetamiprid, buprofezin, clothianidin, flupyradifurone, imidacloprid, and spirotetramat use would likely increase in the absence of chlorpyrifos. Including chlorpyrifos, these AIs are part of the current management program for vine mealybug, although the full set is only likely used against severe infestations.

Without chlorpyrifos, growers will likely increase the number of times they treat with several alternative products in addition to maintaining the in-season vine mealybug treatment program. Specifically, for hard-to-control vine mealybug infestations that had previously been targeted with chlorpyrifos, an extra application of both imidacloprid and spirotetramat would be applied. For non-chemical control, mating disruption products with the active ingredient lavandulyl senecioate can decrease the need for chemical controls. Mating disruption has not been widely used to date, though use has been increasing. Mealybugs are attacked by a variety of natural enemies, although they cannot fully control vine mealybug (Daane et al. 2012, Walton et al. 2012). The most useful one, *Anagyrus pseudococci*, can be released in vineyards to supplement control (Daane et al. 2012), however, the California supply of *A. pseudococci* has been unreliable, making it difficult for growers to use.

Ants. A variety of ants can be found in grapes, including Argentine ants (*Linepithema humile*), native grey ants (*Formia sp*.), pavement ants (*Tetramorium caespitum*), and southern fire ants (*Solenopsis xyloni*). Southern fire ants and pavement ants are protein feeding ants while Argentine ants and native gray ants are sugar feeding ants. Although ants are not a direct threat to the grape crops, they disrupt grape IPM by guarding vine mealybugs and interfering with biological control. Biological control agents have difficulty attacking mealybugs with ants present

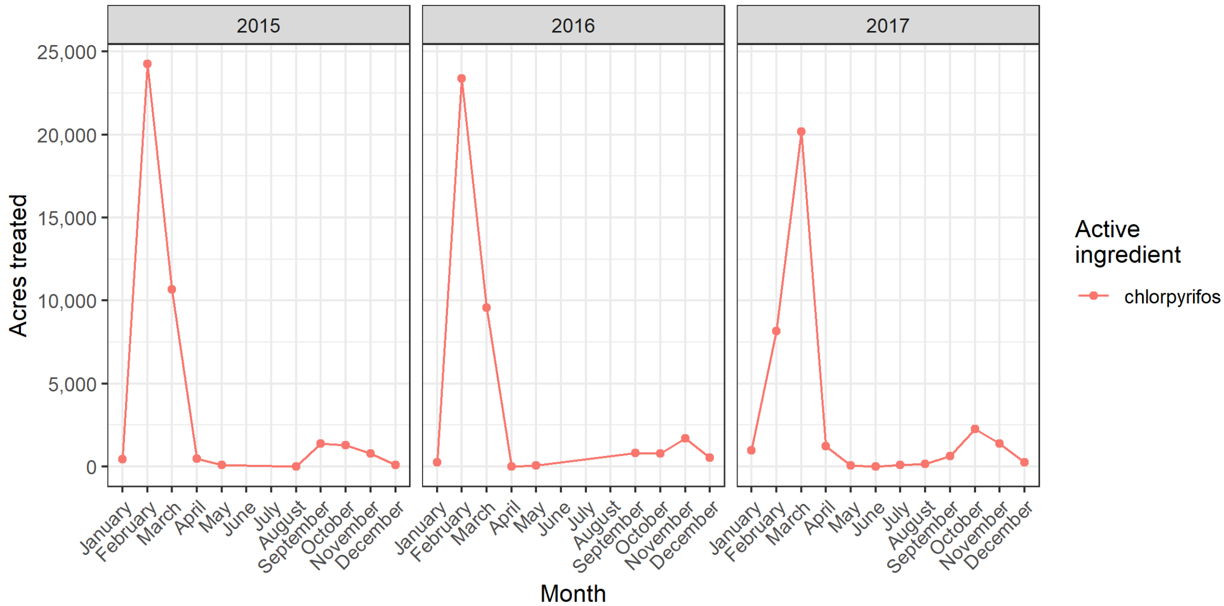
(Daane et al. 2007, Mgocheki and Addison 2009). Chlorpyrifos applications for ant control were conventionally done in-season. The more recent permit conditions have confined chlorpyrifos use to the dormant season. Sprays to control ants during the dormant season are ineffective as ants are not active when temperatures are cold. Thus, it is unlikely that growers will treat with chlorpyrifos or any other material during the dormant season. However, as chlorpyrifos is currently used only in the dormant phase of grape production and the most effective time to treat for ants is during the growing season, any ant control from current chlorpyrifos use is likely insubstantial. It is unlikely that growers would add a different treatment for ants in the dormant phase. Essentially, as chlorpyrifos is not currently effective in controlling ants due to seasonal offset, its use would not be replaced with a different ant control. During the growing season, ants can also be managed with bait products, of which several are available. For the sugar feeding ants, there are disodium tetraborate and s-methoprene baits. For protein feeding ants, baits with abamectin, pyriproxyfen, and metaflumizone are available. Several cultural methods can help but are not widely used outside of organic grape production. Tilling can disrupt ant nests, which can reduce populations. Planting cover crops that produce lots of nectar, such as vetch, can redirect ants away from the mealybugs.

Although imidacloprid is also being evaluated for potential regulatory restrictions, this analysis assumes that imidacloprid is available. If regulations change to disallow imidacloprid use, the use of spirotetramat will likely increase even more, increasing the risk of resistance and further reducing the efficacious pest management options available to growers.

Chlorpyrifos Use: 2015-2017

Data available on pesticide use differentiates only between wine and other grape types, not between raisin and table grapes (or varieties within a category). Chlorpyrifos use patterns differ seasonally between wine grape and other grapes with use peaking in October and March, respectively (Figure 16). Despite these differences, the goal in both crops is to control vine mealybug during the time grape vines are dormant.

(a) Table/raisin grape



(b) Wine grape

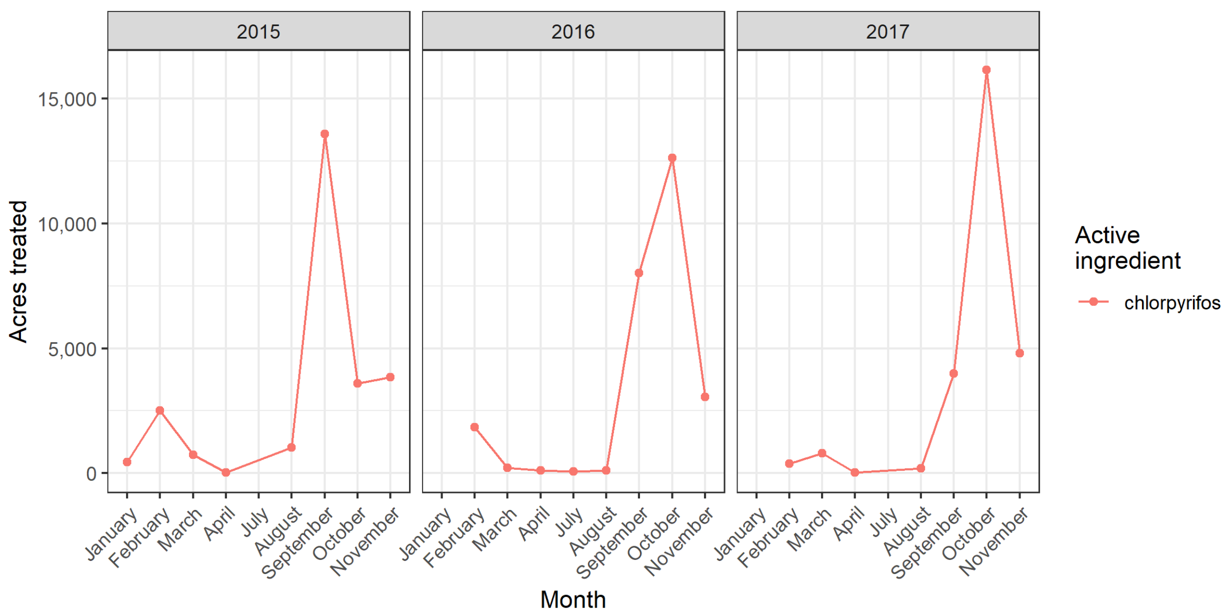


Figure 16. Monthly use of chlorpyrifos for (a) raisin/table grape and (b) wine grape (bottom panel), 2015-2017

Figure 16, Table 32, and Table 33 overstate the current use of chlorpyrifos because new permit conditions starting in 2018 and 2019 have severely restricted use relative to the baseline considered here. Even in the data available, chlorpyrifos was applied to fewer cumulative acres from 2015-2017 than spirotetramat, imidacloprid, and buprofezin.

Table 32. Annual Use of Chlorpyrifos and Alternative AIs: Raisin/Table Grape, 2015-2017

AI	---------Pounds applied---------				-------------Acres treated------------				Use rate (lbs/ac)
	2015	2016	2017	Total	2015	2016	2017	Total	
acetamiprid	1,144	1,215	1,462	3,822	13,473	13,459	15,527	42,458	0.09
buprofezin	36,856	33,043	36,505	106,405	68,237	60,098	67,447	195,782	0.54
chlorpyrifos*	71,466	65,842	59,824	197,132	39,505	37,084	35,424	112,013	1.76
clothianidin	2,240	2,268	2,349	6,858	21,153	23,171	23,704	68,027	0.10
flupyradifurone	17	128	615	759	95	750	3,436	4,281	0.18
imidacloprid	36,431	40,331	50,470	127,232	177,897	170,900	157,071	505,868	0.25
lavandulyl senecioate	338	278	541	1,157	4,563	5,819	31,022	41,404	0.03
spirotetramat	16,146	15,831	16,481	48,458	145,800	142,693	148,309	436,801	0.11

*Target AI

Table 33. Annual Use of Chlorpyrifos and Alternative AIs: Wine Grape, 2015-2017

AI	---------Pounds applied---------				-------------Acres treated------------				Use rate (lbs/ac)
	2015	2016	2017	Total	2015	2016	2017	Total	
acetamiprid	1,489	960	1,345	3,795	18,513	14,415	17,425	50,352	0.08
buprofezin	13,157	17,965	16,838	47,960	20,264	27,633	22,579	70,475	0.68
chlorpyrifos*	46,811	47,545	49,416	143,772	25,767	26,032	26,340	78,138	1.84
clothianidin	3,226	3,146	3,944	10,315	21,689	21,868	28,428	71,985	0.14
flupyradifurone	203	273	649	1,125	1,137	1,605	4,616	7,357	0.15
imidacloprid	85,634	70,595	79,861	236,091	257,177	236,088	258,765	752,030	0.31
lavandulyl senecioate	148	727	607	1,483	3,607	11,874	43,737	59,218	0.03
spirotetramat	18,502	20,968	23,211	62,680	164,122	189,934	202,373	556,429	0.11

*Target AI

Economic Analysis

This section presents the expected change in net revenues to grape production under a potential withdrawal of chlorpyrifos. Based on consultation with UCCE personnel, we assume that no yield loss occurs. In the absence of any anticipated yield effects, gross revenues will not change as a result of the policy scenario. To prevent yield loss, we assume that the alternatives would increase in use proportionally to their current use, and that for heavy infestations the representative products for two AIs, imidacloprid and spirotetramat, would need to be applied twice, increasing costs. Changes in costs considered here include the change in insecticide material costs and changes in application costs when an alternative treatment requires a different application method (and/or multiple applications). We report costs separately for raisin/table and wine grape production because of differences in pest management. Table 34 and Table 35 present representative products for each active ingredient used for raisin/table and wine grape production in 2015–2017, their material cost per acre for a single application, and their cost per acre when used as a substitute for chlorpyrifos.

The material cost per acre for a single application is calculated as the product of the average use rate (lb/ac) over this period and the price per pound of the representative product. Differences in the cost per acre for representative products between the two PUR categories of grape are due to different average use rates over the period. There is substantial variation in the cost per acre across AIs, ranging from $14.51 to $63.08 for raisin and table grapes and from $15.18 to $64.05 per acre for wine grape. Chlorpyrifos has the lowest cost per acre for both grape categories, so any substitution of alternative pesticides will increase growers' pest control costs. For both grape categories, the highest cost per acre AI is spirotetramat.

The cost of switching to these AIs is only the difference in material costs. The majority of active ingredients would be applied the same number of times with the same application method as chlorpyrifos. There are two exceptions: imidacloprid and spirotetramat. Both must be applied twice when replacing a single application of chlorpyrifos, requiring an additional fixed application cost per acre as well as extra material costs. In addition, imidacloprid is applied through drip irrigation systems before August and by air blast in August–December. We assume that applications by drip irrigation incur no application cost, which lowers the cost of switching from chlorpyrifos. The net effect, averaging total material and application costs and total acreage across the three years, is that imidacloprid used to replace chlorpyrifos will cost $47.37 per acre for raisin and table grapes and $58.37 per acre for wine grape while spirotetramat used to replace chlorpyrifos will cost $151.15 per acre for raisin and table grapes and $153.10 per acre for wine grape. This calculation is discussed further in the methods section.

Table 34. Representative Products and Costs per Acre: Raisin/Table Grape

AI	Representative product	Material cost per acre for single application ($/ac)	Cost per acre as substitute ($/ac)
acetamiprid	Assail 30SG Insecticide	23.77	23.77
buprofezin	Applaud 70 DF Insect Growth Regulator	34.94	34.94
chlorpyrifos	Lorsban Advanced	14.51	-
clothianidin	Belay Insecticide	14.68	14.68
flupyradifurone	Sivanto 200 SL	49.43	49.43
imidacloprid	Macho 2.0 FL	22.72	47.37
lavandulyl senecioate	Checkmate VMB-F	48.39	48.39
spirotetramat	Movento	63.08	151.15

Table 35. Representative Products and Costs per Acre: Wine Grape

AI	Representative product	Material cost per acre for single application ($/ac)	Cost per acre as substitute ($/ac)
acetamiprid	Assail 30SG Insecticide	19.90	19.90
buprofezin	Applaud 70 DF Insect Growth Regulator	43.75	43.75
chlorpyrifos	Lorsban Advanced	15.18	-
clothianidin	Belay Insecticide	20.87	20.87
flupyradifurone	Sivanto 200 SL	42.62	42.62
imidacloprid	Macho 2.0 FL	28.36	58.37
lavandulyl senecioate	Checkmate VMB-F	42.38	42.38
spirotetramat	Movento	64.05	153.10

Table 36 and Table 37 show the average acreage shares for each chlorpyrifos alternative used on each category of grape, both with and without chlorpyrifos being available. Averaged over the three-year period 2015–2017, chlorpyrifos was used on 8.0% of raisin and table grape acres and 4.8% of wine grape acres treated with chlorpyrifos or an alternative AI.

With the withdrawal of chlorpyrifos, chlorpyrifos would become unavailable and the alternative AIs would be scaled up in proportion to their acreage shares, as discussed in the methods section. The main alternative AIs are imidacloprid and spirotetramat, together accounting for 67.1% of raisin and table grape acres treated acreage and 79.8% of wine grape acres treated in the 2015–2017 period. Total acres treated may not correspond to total acres of each category of grape grown because one vineyard may be treated with chlorpyrifos or an alternative more than once.

Table 36. Average Annual Acreage Shares of Alternative Insecticides with and without Chlorpyrifos: Raisin/Table Grape, 2015–2017

AI	Chlorpyrifos available (%)	Chlorpyrifos withdrawn (%)
acetamiprid	3.0	3.3
buprofezin	13.9	15.1
clothianidin	4.8	5.3
flupyradifurone	0.3	0.3
imidacloprid	36.0	39.1
lavandulyl senecioate	2.9	3.1
spirotetramat	31.1	33.8
Total	92.0	100

Note: Three years average from 2015-2017.

Table 37. Average Annual Acreage Shares of Alternative Insecticides with and without Chlorpyrifos: Wine Grape, 2015-2017

AI	Chlorpyrifos available (%)	Chlorpyrifos withdrawn (%)
acetamiprid	3.1	3.2
Buprofezin	4.3	4.5
clothianidin	4.4	4.6
flupyradifurone	0.4	0.5
imidacloprid	45.9	48.2
lavandulyl senecioate	3.2	3.4
spirotetramat	33.9	35.6
Total	95.2	100

Note: Three years average from 2015-2017.

Table 38 and Table 39 show the average per acre costs for chlorpyrifos as well as the cost of the composite alternative, whose price we use as a representative pesticide cost if chlorpyrifos was withdrawn. For both grape types, switching to the alternative would lead to increases in material and application costs due to the extra applications required when using imidacloprid or spirotetramat. Chlorpyrifos users will incur a per acre cost increase on table or raisin grape of $63.53, or 437.7%, and an increase on wine grape of $72.70, or 479.1% in order to replace one application of chlorpyrifos.

Table 38. Costs per Acre for Chlorpyrifos and the Composite Alternative: Raisin/Table Grape, 2015-2017

AI	Material cost ($)	Net app cost ($)	Total cost ($)	Cost increase for switching to composite alternative (%)
chlorpyrifos	14.51	0	14.51	437.7
composite alternative	68.85	9.19	78.04	-

Table 39. Costs per Acre for Chlorpyrifos and the Composite Alternative: Wine Grape, 2015-2017

AI	Material cost ($)	Net app cost ($)	Total cost ($)	Cost increase for switching to composite alternative (%)
chlorpyrifos	15.18	0	15.18	479.1
composite alternative	78.18	9.70	87.88	-

Table 40 and Table 41 report the estimated change in cost under withdrawal. For raisin and table grapes, pesticide costs, including changes in material and application costs, increased by 437.7% on acreage that must be treated with a chlorpyrifos alternative, with total annual losses ranging from $2.3 million to $2.5 million. Costs for wine grape increase by 479.1%, with total annual losses in the neighborhood of $1.9 million. The magnitude of these changes is driven by the large price difference between chlorpyrifos products and the alternatives that account for a large share of non-chlorpyrifos treated acreage. While large in absolute terms, the cost increases relative to gross revenues per affected acre are small on a percentage basis. The cost increase was 2.1% of 2017 gross revenues for raisin grapes, 0.4% for table grapes, and 0.3% for wine grapes based on yields and prices reported in CDFA (2018).

Note that if the proportions of alternative AIs used changes over time, these figures may over- or underestimate the costs of the policy, depending on whether the bundle of alternative AIs shifts towards products with a lower or higher cost per acre.

Table 40. Change in Treatment Costs due to the Withdrawal of Chlorpyrifos: Raisin/Table Grape, 2015–2017

Year	Chlorpyrifos available ($)	Chlorpyrifos withdrawn ($)	Change in cost ($)	Percent change (%)
2015	573,405	3,082,955	2,509,550	437.7
2016	538,273	2,894,063	2,355,790	437.7
2017	514,176	2,764,504	2,250,328	437.7

Table 41. Change in Treatment Costs due to the Withdrawal of Chlorpyrifos: Wine Grape, 2015-2017

Year	Chlorpyrifos available ($)	Chlorpyrifos withdrawn ($)	Change in cost ($)	Percent change (%)
2015	391,011	2,264,467	1,873,456	479.1
2016	395,037	2,287,783	1,892,746	479.1
2017	399,714	2,314,867	1,915,153	479.1

Conclusions

The primary use of chlorpyrifos on grape is as part of a multi-AI, multi-application vine mealybug management program. Chlorpyrifos is used as a delay dormant spray – before or after the growing season – for severe infestations. There is no replacement for the dormant part of the treatment program. In cases where chlorpyrifos would have been used to manage a heavy vine mealybug infestation, one application would likely be replaced by an application each of two more expensive alternatives. Withdrawal of chlorpyrifos for table, raisin, and wine grape production would result in a $4.2 million to $4.3 million annual increase in insecticide costs, based on 2015-2017 use. In percentage and absolute value terms these increases in pest management costs are large but translated to a per affected acre basis they are small.

Walnut

California accounts for all national walnut production and is the second largest walnut producer in the world, second only to China. For 2017-18, California accounted for 28.1% of world production and 58.7% of world export value (USDA FAS 2018). Gross receipts for walnut totaled nearly $1.6 billion in 2017, which was the seventh largest agricultural commodity by production value (CDFA 2018a). Over 86.0% of this production value, nearly $1.4 billion, was exported, making walnut California's fifth most important export agricultural commodity by value. Walnut was a top three agricultural export commodity to six of the top ten agricultural export markets in 2017: European Union, Japan, India, United Arab Emirates, Turkey, and Vietnam. There were 335,000 acres of bearing walnut orchards standing in 2017, plus 65,000 acres of non-bearing acreage. The three largest walnut producing counties, San Joaquin ($317 million), Butte ($255 million), and Glenn ($184 million), accounted for 47.2% of state production in 2017. Walnut is a top four agricultural commodity by value in ten counties (San Joaquin, Colusa, Glenn, Butte, Sutter, Tehama, Solano, Yuba, Lake, and Placer), the second most important agricultural commodity in two of these counties (Glenn and Sutter), and the top agricultural commodity in four (Butte, Tehama, Solano, and Yuba). In 2017, seven of ten walnuts were sold shelled, the remainder marketable in-shell.

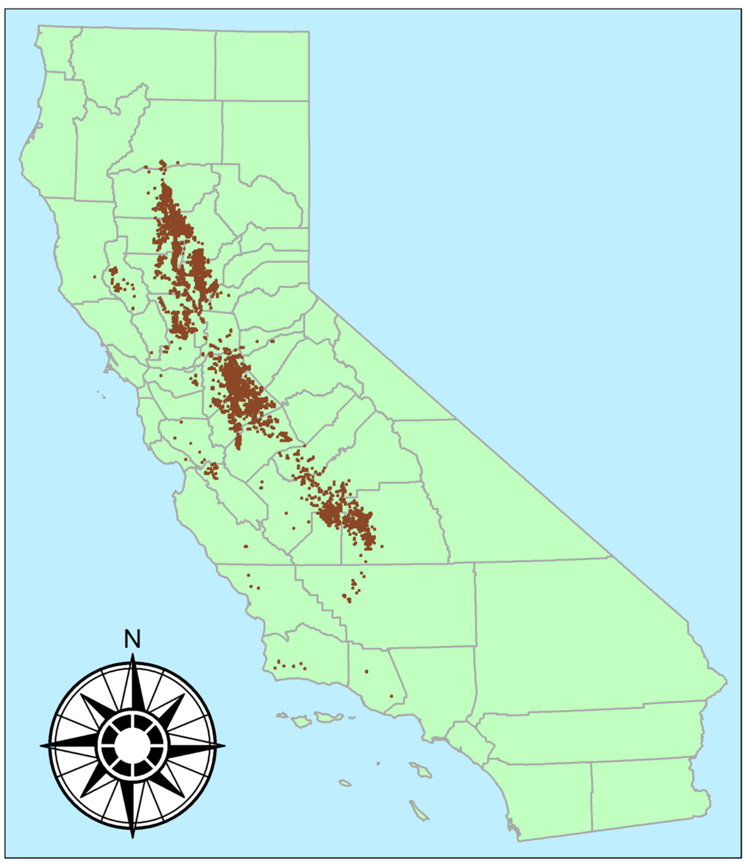


Figure 17. California walnut production: 2017

IPM Overview

California walnut is attacked by a number of primary and secondary insect pests. Primary pests, which attack the nuts and directly damage the marketable crop, are: navel orangeworm, codling moth, and walnut husk fly. Secondary pests, which attack the foliage, twigs and small limbs and can cause damage to the tree through leaf drop and reduced tree vigor, are: walnut and dusky-veined aphid, twospotted spider mite, European fruit lecanium, frosted scale, and Pacific flatheaded and other borers. Generally, primary pests are treated every year, while secondary pests require less frequent treatment.

In walnut production, chlorpyrifos is used to control codling moth, walnut husk fly, walnut and dusty-veined aphid, and to a lesser extent the Pacific flatheaded and other borers. Chlorpyrifos controls a wide complex of insect pests, so it is often used to control multiple pests at the same time, depending on the timing of control for each pest. For example, it is possible to control codling moth with a mid- to late-May spray or early to mid-June spray while simultaneously controlling walnut and dusky veined aphid. Similarly, chlorpyrifos can be used to control both walnut husk fly and codling moth during July and August.

Target pests

Codling moth (*Cydia pomonella*). Codling moth has three generations per year in walnut, starting from late-March to mid-April. Damage from the first generation causes small nuts to drop from the tree. Later generations feed on the nut meat, making nuts unmarketable. Additionally, nuts damaged by codling moth can be a breeding substrate for navel orangeworm, another primary pest of walnut. Codling moth populations can be monitored using pheromone traps, which allows treatments to be timed more accurately. Treatments can consist of insecticide and/or mating disruption. Natural enemies do not effectively control codling moth. *Trichogramma platneri,* a small parasitic wasp, can be purchased and released into orchards. *Trichogramma* releases can be helpful when done in conjunction with mating disruption but are often not economically feasible. There are multiple alternatives to chlorpyrifos for codling moth: chlorantraniliprole, permethrin, esfenvalerate, acetamiprid, beta-cyfluthrin, bifenthrin, spinetoram, diflubenzuron, cyantraniliprole, phosmet, methoxyfenozide, emamectin benzoate, carbaryl, spinosad spray, spinosad bait, and lambda-cyhalothrin.

Walnut husk fly (*Rhagoletis completa*). Walnut husk fly infestation causes nut shell staining, which cannot be removed by bleaching. Infested nuts cannot be sold in shell, greatly reducing their value. Early season infestation can also lead to adhering husk, shriveled kernel, and mold. The alternatives to chlorpyrifos for walnut husk fly are: acetamiprid, bifenthrin, *Burkholderia*, clothianidin, fenpropathrin, imidacloprid, lambda-cyhalothrin, phosmet, and spinosad (Van Steenwyk et al. 2016; Van Steenwyk et al. 2018).

Walnut aphid (*Chromaphid juglandicola*) and dusky-veined aphid (*Callaphis juglandis*). Walnut aphid and dusky-veined aphid are secondary pests on walnut. Large populations can reduce tree vigor and nut size, causing loss of yield quantity and quality. Aphids produce honeydew, encouraging the growth of sooty mold. Black sooty mold makes nuts more sensitive to sunburn.

Integrated pest management research in walnut has established economic injury levels for aphids, which informs growers on when insecticide applications may be necessary. Both aphid species overwinter as eggs on the walnut trees. Eggs hatch in the spring, aphids settle onto the new walnut leaves, and have multiple generations over the summer. Walnut aphid was a significant pest prior to the introduction of the parasitic wasp *Trioxys pallidus* in the 1970s, which brought it under statewide control. Dusky-veined aphids are not a host for *T. pallidus*. However, they are preyed upon by a variety of generalist natural enemies such as lacewings and lady beetles. In many orchards, aphids can be kept below injury levels by biological control agents. However, broad-spectrum insecticides, like pyrethroids, applied to control codling moth and walnut husk fly, can disrupt natural enemies and cause aphid outbreaks. Alternatives to control aphids are: acetamiprid, cyantraniliprole, clothianidin, flupyradifurone, flonicamid, and sulfoxaflor (Van Steenwyk et al. 2016). Sulfoxaflor is currently not registered for use in walnut though registration is expected in late 2019.

Pacific flatheaded borer (*Chrysobothris mali*) and related borers (*Dicerca horni*, *Chrysobothris wintu*, and *Chrysobothris analis*). Pacific flatheaded borer and related borers are mainly a problem for newly planted or young trees, especially sunburned trees. The borers excavate cavities in the wood and can girdle young trees, causing tree death. Sunburn can be managed by painting trunks with white latex paint. The white latex paint can be mixed with chlorpyrifos to control borers. The only known alternative is carbaryl.

Chlorpyrifos Uses: 2015-2017

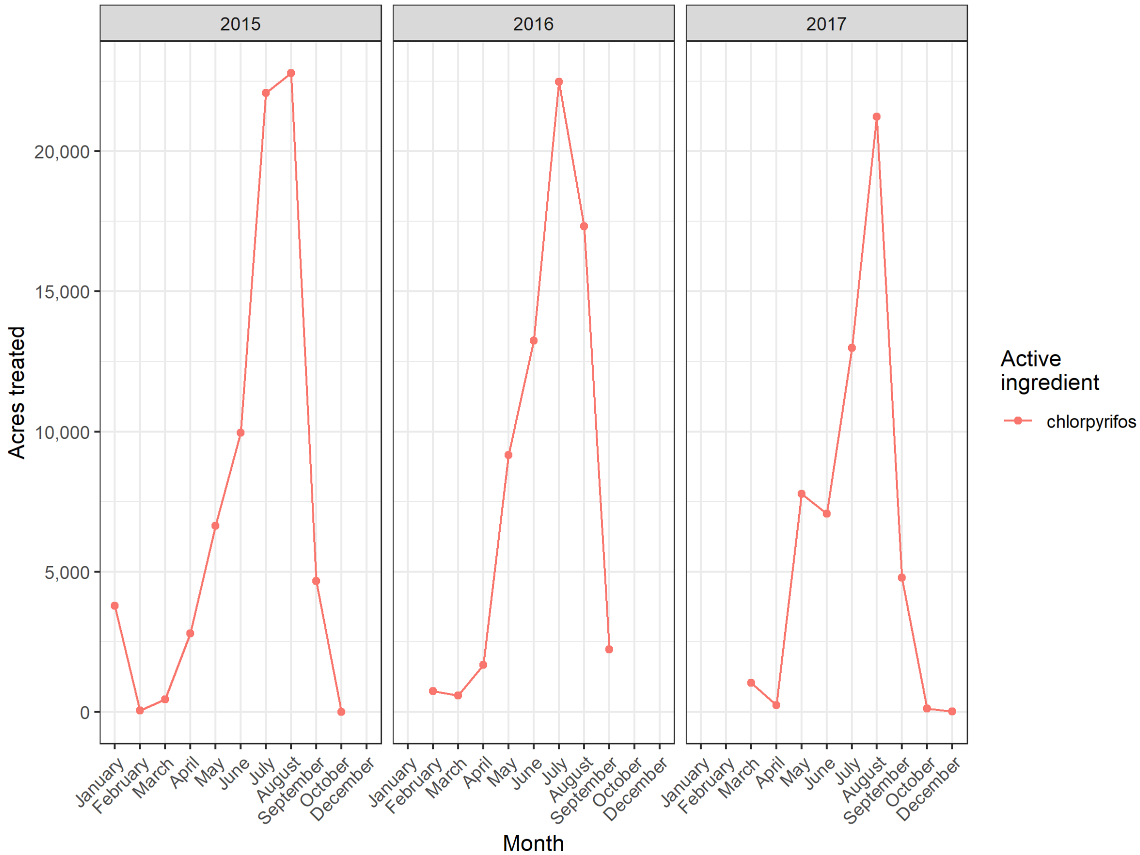


Figure 18. Monthly use of chlorpyrifos: walnut, 2015-2017

From 2015-2017, chlorpyrifos use consistently peaked in July and August (Figure 18). This is when the second flight of codling moth is starting and when the walnut husk fly needs to be managed to prevent damage. Specific use varies by orchard location and local pest problems, but the trend of the highest use being in July and August remains consistent.

Table 42: Annual Use of Chlorpyrifos and Alternative AIs: Walnut, 2015-2017

AI	-------Pounds applied-------				------------Acres treated------------				Use rate (lbs/ac)
	2015	2016	2017	Total	2015	2016	2017	Total	
acetamiprid	11,472	11,891	13,636	36,998	92,864	90,355	104,055	287,274	0.13
beta-cyfluthrin	420	417	447	1,283	18,958	19,238	20,099	58,295	0.02
bifenthrin	14,187	17,588	20,527	52,301	100,489	115,550	130,987	347,026	0.15
Burkholderia sp	NA	NA	9,081	9,081	NA	NA	1,099	1,099	8.26
carbaryl	663	348	124	1,134	1,009	191	164	1,363	0.83
chlorantranili-prole	8,234	9,607	15,514	33,355	92,305	111,559	184,491	388,355	0.09
chlorpyrifos*	133,270	125,761	103,278	362,309	73,234	67,444	55,266	195,945	1.85
clothianidin	446	398	398	1,242	5,242	4,841	4,075	14,158	0.09
cyantraniliprole	152	2	NA	153	1,976	10	NA	1,986	0.08
diflubenzuron	279	578	304	1,161	997	2,318	1,691	5,007	0.23
emamectin benzoate	33	59	28	120	2,383	4,234	2,073	8,689	0.01
esfenvalerate	1,339	1,762	2,209	5,311	19,421	27,835	30,908	78,163	0.07
flupyradifurone	4	9	5	18	21	55	24	100	0.18
imidacloprid	6,625	5,771	7,259	19,656	82,216	68,964	85,965	237,145	0.08
lambda-cyhalothrin	2,256	1,855	4,075	8,186	62,664	51,951	108,510	223,124	0.04
methoxyfenoz-ide	17,890	18,539	28,553	64,982	65,962	71,223	104,626	241,811	0.27
permethrin	5,966	5,881	7,272	19,119	24,942	24,377	29,953	79,272	0.24
phosmet	6,500	3,336	3,749	13,584	2,096	1,145	1,380	4,621	2.94
spinetoram	2,311	2,581	2,531	7,422	35,245	41,919	44,085	121,249	0.06
spinosad	155	223	332	710	1,850	2,878	3,398	8,126	0.09

*Target AI

Economic Analysis

This section presents the expected change in costs to walnut due to the withdrawal of chlorpyrifos. This cost consists of the change in pesticide material costs on acres previously treated with chlorpyrifos. We anticipate no change in application costs. No yield loss is anticipated. In the absence of any anticipated yield effects, gross revenues will not change.

Table 43: Representative Products and Costs Per Acre: Walnut

AI	Representative product	Price/acre ($)
acetamiprid	Assail 30SG Insecticide	34.01
beta-cyfluthrin	Baythroid XL	9.60
bifenthrin	Brigade WSB Insecticide/Miticide	37.95
burkholderia sp	Venerate	125.95
carbaryl	Sevin Brand XLR Plus Carbaryl Insecticide	12.44
chlorantraniliprole	Altacor	41.66
chlorpyrifos	Lorsban Advanced	15.25
clothianidin	Belay Insecticide	12.77
cyantraniliprole	Exirel	519.18
diflubenzuron	Dimilin 2L	358.24
emamectin benzoate	Proclaim	32.72
esfenvalerate	Asana XL	7.86
flupyradifurone	Sivanto 200 SL	50.05
imidacloprid	Admire Pro	5.02
lambda-cyhalothrin	Warrior II	7.50
methoxyfenozide	Intrepid 2F	332.94
permethrin	Permastar Ag Agricultural Insecticide	37.42
phosmet	Imidan 70-W	59.42
spinetoram	Delegate WG	41.45
spinosad bait	GF-120	19.63
spinosad spray	Success	27.08

Table 43 presents representative products for chlorpyrifos and alternative AIs used on walnut in 2015–2017 and their material costs per acre. The material cost per acre is the product of the average use rate (lb/ac) over this period and the price per pound. The cost per acre ranged from $5.02 per acre for imidacloprid to $519.18 per acre for cyantraniliprole. Growers consider other factors in addition to cost per acre when deciding which insecticides to use, as discussed above.

Table 44: Average Annual Acreage Shares of Alternative Insecticides with and without Chlorpyrifos: Walnut, 2015–2017

AI	Chlorpyrifos available (%)	Chlorpyrifos withdrawn (%)
acetamiprid	12.3	13.5
beta-cyfluthrin	2.5	2.7
bifenthrin	14.9	16.3
burkholderia sp	0.1	0.2
carbaryl	0.1	0.1
chlorantraniliprole	16.7	18.2
clothianidin	0.6	0.7
cyantraniliprole	0.1	0.1
diflubenzuron	0.2	0.2
emamectin benzoate	0.4	0.4
esfenvalerate	3.4	3.7
flupyradifurone	0.0	0.0
imidacloprid	10.2	11.1
lambda-cyhalothrin	9.6	10.5
methoxyfenozide	10.4	11.3
permethrin	3.4	3.7
phosmet	0.2	0.2
spinetoram	5.2	5.7
spinosad bait	0.8	0.8
spinosad spray	0.6	0.7
Total	91.7	100.0

Note: Three years average from 2015-2017.

Table 44 shows the average acreage shares for each alternative AI used on walnut, with and without chlorpyrifos being available. Averaged over the three-year period 2015-2017, chlorpyrifos was used on 8.3% of walnut acres treated with chlorpyrifos or an alternative AI. Note that total acres treated with insecticides may not correspond to total acres of walnut grown since some growers may have used multiple AIs on the same orchard. To evaluate costs if chlorpyrifos was withdrawn, the use of alternative AIs is scaled up in proportion to their acreage shares, as discussed in the methods section. There are five alternatives that were applied to more than ten percent of acres treated with insecticide over the 2015–2017 period. From largest to smallest acres treated, they are: chlorantraniliprole, bifenthrin, acetamiprid, methoxyfenozide, and imidacloprid. Together these alternatives account for 64.5% of acres treated with insecticides in the 2015–2017 period.

Table 45: Costs Per Acre for Chlorpyrifos and the Composite Alternative: Walnut

Active ingredient	Price/acre ($)	Cost Increase for Switching (%)
chlorpyrifos	15.25	320.6
composite Alternative	64.14	-

Table 45 shows costs per acre for chlorpyrifos and the composite alternative, whose cost we use as a representative material cost if chlorpyrifos were withdrawn. For walnut, switching to the composite alternative would increase material costs by $48.89 per acre, or 320.6%, on acres previously using chlorpyrifos.

Table 46: Change in Treatment Costs due to the Withdrawal of Chlorpyrifos: Walnut, 2015–2017

Year	Chlorpyrifos available ($)	Chlorpyrifos withdrawn ($)	Change in cost ($)	Percent change (%)
2015	1,116,821	4,697,446	3,580,625	320.6
2016	1,028,527	4,326,075	3,297,548	320.6
2017	842,806	3,544,915	2,702,109	320.6

Table 46 reports the change in costs due to the withdrawal of chlorpyrifos. Application costs on acres that previously used chlorpyrifos are estimated to increase by approximately one third, leading to total annual costs increasing by $2.7 million to $3.6 million. The magnitude of this change is driven by the large price difference between chlorpyrifos products and the alternatives that account for a large share of non-chlorpyrifos treated acreage. For walnut, the cost per acre of chlorpyrifos, averaged across 2015–2017 was $15.25 per acre while the use-weighted cost of the alternatives was $64.14 per acre.

Conclusions

In walnut, pest management costs are expected to increase by around $2.7 million to $3.6 million. The expected cost of alternative materials is $64.14 per acre compared to $15.25 per acre for chlorpyrifos, a 320.6% increase. Gross revenue for walnut was $4,758 per acre in 2017, totaling $1.6 billion across all acres. The $48.89 per acre increase in treatment costs corresponds to one percent of gross revenues on acreage affected by withdrawal. Note that, over the three-year period of 2015–2017, chlorpyrifos was used on an average of 8.3% of insecticide-treated walnut acreage. As with other crops, the analysis does not evaluate the possible impact of resistance developed due to fewer modes of action available to growers.

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Appendix A: 2017 Chlorpyrifos Use

Table 47. Top Twenty Crops Using Chlorpyrifos by Acres Treated in 2017 – Lbs Used, Acres Treated

Crop*	Lbs applied	Acres treated
Cotton	152,079	153,881
Alfalfa	75,642	153,607
Almond	186,885	103,447
Citrus	227,092	67,636
Grape	109,241	61,764
Walnut	103,278	55,266
Sugarbeet	30,024	38,310
Wheat	5,157	12,328
Corn (Forage - Fodder)	7,117	8,491
Corn, Human Consumption	4,670	5,100
Peach	6,101	3,964
Pecan	5,086	3,636
Onion, Dry	3,253	3,425
Brassica	2,945	2,846
Sweet Potato	5,221	2,593
Asparagus	1,550	2,393
Strawberry	1,660	1,734
Nectarine	9,017	1,667
Sorghum/Milo	1,009	1,136

*The following crops are groupings: Citrus – orange, grapefruit, tangerine, lemon, lime, pomelo; Grape – table, raisin, wine grape; Wheat – wheat fodder, wheat; Brassica - bok choy, broccoli flower, broccoli, Brussels Sprouts, cabbage = 13007, cauliflower, gai lon, Napa cabbage, Cole crop, collard, kale, mustard, must greens, rapini, swiss chard

Table 48. Chlorpyrifos use by crop and county

Crop*	County	Pounds Applied	Acres Treated	Acres Harvested
Cotton	Kings	102,717	101,792	237,600
	Fresno	37,118	38,689	158,510
	Kern	6,525	6,815	64,980
	Tulare	2,389	2,881	43,400
	Glenn	1,451	1,553	7,140
	Merced	984	1,247	59,400
	Colusa	459	463	.
	Sutter	344	344	.
	Madera	91	97	1,930
	Sum of Others	0	0	29,581
	State Total	152,079	153,881	602,541

Crop*	County	Pounds Applied	Acres Treated	Acres Harvested
Alfalfa	Kern	12,850	29,619	72,900
	Tulare	9,804	23,010	50,000
	Imperial	15,581	22,749	196,400
	Fresno	8,975	14,742	37,850
	Kings	6,617	12,683	22,900
	Riverside	2,640	10,197	46,100
	Siskiyou	3,787	8,067	31,400
	Merced	3,668	8,061	58,100
	Lassen	2,249	4,794	27,600
	Modoc	1,983	4,579	.
	Glenn	1,750	3,592	11,000
	Stanislaus	1,546	2,248	21,400
	Colusa	1,127	2,038	6,480
	Sutter	562	1,994	4,140
	San Joaquin	909	1,897	45,500
	Los Angeles	640	1,380	.
	Solano	579	1,209	28,400
	Shasta	103	207	3,500
	Yolo	91	181	26,000
	Tehama	77	170	1,630
	Contra Costa	64	128	1,770
	Butte	22	38	470
	Sacramento	19	25	14,600
	Sum of Others	0	0	34,057
	State Total	75,642	153,607	742,197
Almond	Fresno	62,926	34,123	228,000
	Kern	37,718	20,324	214,000
	Madera	30,011	15,580	135,000
	Tulare	21,997	14,876	67,400
	Merced	10,637	5,987	109,000
	Kings	10,717	5,754	27,500
	Stanislaus	7,853	4,207	188,000
	Solano	2,304	1,146	17,800
	Sutter	780	391	12,300
	Yolo	527	344	30,000
	Butte	448	241	39,600
	Tehama	418	222	11,600

Crop*	County	Pounds Applied	Acres Treated	Acres Harvested
	Colusa	160	81	61,200
Almond	San Joaquin	101	59	74,200
	Yuba	85	43	1,590
	Glenn	152	43	52,600
	Contra Costa	33	18	.
	Sacramento	19	10	275
	Sum of Others	0	0	3,453
	State Total	186,885	103,447	1,273,518
Citrus	Tulare	94,041	24,030	131,580
	Kern	72,902	22,276	64,460
	Fresno	26,629	8,809	56,530
	Ventura	20,653	5,762	19,023
	Riverside	4,561	2,612	16,085
	Madera	4,976	1,457	3,000
	Imperial	376	1,092	6,332
	San Diego	1,350	926	12,207
	San Luis Obispo	547	240	1,600
	Stanislaus	767	204	514
	Orange	85	84	.
	San Bernardino	60	68	2,120
	Santa Barbara	73	50	1,290
	Glenn	45	13	.
	Tehama	23	8	.
	Butte	7	6	212
	Sum of Others	0	0	3,419
	State Total	227,092	67,636	318,372
Grape	Kern	50,570	28,837	115,600
	Tulare	21,065	13,109	58,150
	Merced	10,036	5,341	13,600
	Fresno	9,303	4,690	164,000
	San Joaquin	8,003	4,266	98,100
	Madera	3,702	1,990	62,700
	Riverside	2,365	1,259	9,730
	Stanislaus	1,706	908	.
	Kings	1,194	657	6,306
	Sacramento	527	281	35,300
	Sonoma	368	201	60,000

Crop*	County	Pounds Applied	Acres Treated	Acres Harvested
	Monterey	345	184	44,300
Grape	Contra Costa	24	26	2,550
	San Luis Obispo	21	11	42,200
	San Benito	9	5	4,380
	Sum of Others	0	0	129,011
	State Total	109,241	61,764	845,927
Walnut	Sutter	18,109	9,315	30,700
	San Joaquin	15,764	8,395	67,500
	Butte	12,542	6,541	49,800
	Yuba	11,020	5,661	16,200
	Glenn	9,165	4,773	31,100
	Stanislaus	8,310	4,434	36,600
	Tulare	7,348	4,036	42,900
	Colusa	4,670	2,602	18,500
	Yolo	3,719	2,583	14,800
	Solano	3,677	1,931	13,700
	Tehama	3,294	1,767	24,700
	Kings	1,801	990	16,700
	Fresno	1,657	840	8,420
	Merced	1,447	809	6,370
	Lake	397	312	3,650
	Calaveras	130	140	794
	Madera	99	65	2,100
	Shasta	100	50	1,300
	Amador	23	13	120
	Sonoma	4	10	.
	Sum of Others	0	0	8,142
	State Total	103,278	55,266	394,096
Sugar beet	Imperial	30,024	38,310	24,900
Corn (Fodder - Forage)	Kings	2,625	2,859	48,100
	Tulare	1,987	2,602	151,000
	Fresno	887	1,226	24,900
	Stanislaus	943	1,075	92,500
	San Joaquin	394	389	35,300
	Sacramento	168	179	7,720
	Merced	42	85	89,400

Crop*	County	Pounds Applied	Acres Treated	Acres Harvested
Corn (Fodder - Forage)	Kern	49	52	.
	Sutter	23	24	.
	Sum of Others	0	0	22,938
	State Total	7,117	8,491	471,858
Wheat, all**	Kern	2,310	4,889	16,300
	Fresno	1,671	3,688	25,600
	Merced	572	2,266	12,900
	Imperial	264	575	23,400
	Tulare	139	296	20,000
	Siskiyou	105	294	9,230
	Madera	54	216	3,600
	Modoc	39	96	.
	Kings	3	8	18,000
	Sum of Others	0	0	117,690
	State Total	5,157	12,328	246,720

Note: Pounds Applied and Acres Treated data were obtained from PUR database; Acres Harvested data were obtained from the 2017 County Agricultural Commissioners' Crop Report published by NASS

*The following crops are groupings: Citrus – orange, grapefruit, tangerine, lemon, lime, pomelo; Grape – table, raisin, wine grape; Wheat – wheat fodder, wheat; Brassica - bok choy, broccoli flower, broccoli, Brussels Sprouts, cabbage = 13007, cauliflower, gai lon, Napa cabbage, Cole crop, collard, kale, mustard, must greens, rapini, swiss chard

** Wheat and Wheat (Forage - Fodder) codes from PUR were combined into Wheat, all to match NASS classification

Missing cells (.) indicate Acres Harvested values that were too low to be reported individually by NASS; these values are included in the Sum of Others calculations

Appendix B: Mode of Action for all Alternatives

Table 49. Mode of Action for Alternatives

Active Ingredient	Mode of Action Classification
(s)-cypermethrin	3A
abamectin	6
acephate	1B
acetamiprid	4A
Bacillus thuringiensis ssp	11A
beta-cyfluthrin	3A
bifenthrin	3A
buprofezin	16
burkholderia sp strain a396 cells and fermentation	UNB
carbaryl	1A
chlorantraniliprole	28
chlorpyrifos	1B
clothianidin	4A
cryolite	8C
cyantraniliprole	28
cypermethrin	3A
diflubenzuron	15
dimethoate	1B
emamectin benzoate	6
esfenvalerate	3A
fenbutatin-oxide	12B
fenpropathrin	3A
fenpyroximate	21A
flonicamid	29
flupyradifurone	4D
imidacloprid	4A
indoxacarb	22A
lambda-cyhalothrin	3A
lavandulyl senecioate	NA
malathion	1B
metaflumizone	22B
methomyl	1A
methoxyfenozide	18
naled	1B
novaluron	15

oxamyl	1A
permethrin	3A
phosmet	1B
pyriproxyfen	7C
spinetoram	5
spinosad	5
spiromesifen	23
spirotetramat	23
sulfoxaflor	4C
sulfur	UN
thiamethoxam	4A
zeta-cypermethrin	3A

Appendix C: Cotton

This appendix provides data regarding Pima cotton production and exports in the U.S and California, reports own-price demand elasticity estimates regarding cotton from the existing literature, and presents a table including all changes in gross revenues estimated for a demand elasticity of 0.95 that are summarized in the text in the main chapter.

Production. On average, California's Pima cotton acreage was 84% of national acreage and production averaged 89% of national production in 2016-2018 (Table 50).

Table 50. Pima Cotton Acreage and Production: California and U.S., 2016-2018

Year	**-----------------Acreage---------------- (1,000 acres)**			**---------------Production-------------- (1,000 bales)**		
	CA	U.S. total	CA share	CA	U.S. total	CA share
2016	154	187.8	82%	502	568.9	88%
2017	215	250.4	86%	630	699.5	90%
2018	209	247.5	84%	718	794	90%

Data source: USDA NASS (2018)

Exports. U.S. is a major exporter of extra-long staple cotton in the world market. National export data reported in Table 51 were collected from three sources: The International Cotton Advisory Committee (ICAC), United States Department of Agriculture (USDA) World Agricultural Supply and Demand Estimates (WASDE), and USDA Foreign Agricultural Service (FAS). The three sources disaggregate cotton in different ways. ICAC and USDA WASDE report export quantities for all extra-long staple or Pima cotton. Both sources report a market share averaging 57%. USDA FAS only reports Pima cotton with staple length greater than 1 3/8 inches. It reports a U.S. market share ranging from 37% to 44% of world exports in 2016-2018.

Table 51. Exports of Extra Long-Staple (ELS) Cotton: 2016-2018

Source	**---------U.S. exports--------- (1,000 MT)**			**--------U.S. shares------ (%)**			**--------World exports------ (1,000 MT)**		
	2016	2017	2018	2016	2017	2018	2016	2017	2018
ICAC	133.99	135.95	142.05	58%	56%	56%	232.90	242.05	252.94
USDA WASDE	133.77	138.56	141.61	57%	57%	56%			
USDA FAS	85.98	88.75	112.39	37%	37%	44%			

Own-price demand elasticity of cotton. Table 52 summarizes previous studies regarding the own-price demand elasticity of cotton. These studies utilize different methods, data from different time periods and, most importantly, different types of demand for cotton. Estimation methods include Almost Ideal Demand System (AIDS), Seemingly Unrelated Regressions (SUR), Generalized Least Squares (GLS) and Ordinary Least Squares (OLS). Note that there are no estimates for California Pima cotton specifically.

Table 52. Own-Price Demand Elasticity Estimates: Cotton

Estimates	Elasticity	Data periods	Method	Source
U.S. export demand	-1.7	1820-1859	AIDS SUR	Irwin 2003
U.S. export demand	-1.62	1959-1983	Armington GLS	Duffy et al. 1990
U.S. export demand	-1.14	1960-1981	Armington OLS	Babula 1987
	-1.02	1960-1981	Armington SUR	
U.S. export demand in Japan	-0.91	1972-1998	AIDS	Chang and Nguyen 2002
CA domestic demand	-0.68	1970-2002	OLS	Russo et al. 2008
	-0.95	1970-2002	SUR	

The most recent study is Russo et al. (2008), which focused on the demand of California cotton particularly. Based on those two considerations we chose to use their result. We chose -0.95, which they obtained using seemingly unrelated regression because that model simultaneously estimated the demand for other major California crops that compete with cotton in growers' acreage allocation decisions, while the OLS model did not take this into account.

Change in net returns with imperfectly elastic demand. Table 53 reports the estimated change in gross revenues for Pima cotton due to the withdrawal of chlorpyrifos assuming a 25% yield loss on affected acreage and an own-price demand elasticity of -0.95. (It corresponds to Table 28 in the text.) Table 54 reports the same changes assuming a 50% yield loss. In both tables, there is a small increase in gross revenues, which offsets the increased material costs presented in Table 26. Critically, while all cotton production benefits from the increase in price, affected acres incur a net loss due to the withdrawal of chlorpyrifos because all of the reduction in quantity occurs on those acres.

Table 53. Change in Gross Revenue due to 25% Yield Loss on Acreage Treated with Chlorpyrifos from Withdrawal of Chlorpyrifos: Pima Cotton, Own-Price Demand Elasticity = -0.95, 2015–2017

Year	Price after yield loss ($/lb.)	Gross revenue with chlorpyrifos ($)	Gross revenue chlorpyrifos withdrawn ($)	Change in gross revenue ($)	Percent change (%)
		--- **Low Base Price: ($1.173/lb.)** ---			
2015	1.198	203,285,592	203,413,909	128,317	0.1
2016	1.195	282,704,730	282,876,815	172,085	0.1
2017	1.194	354,838,365	355,050,055	211,690	0.1
		--- **2018 Base Price: ($1.380/lb.)** ---			
2015	1.409	239,159,520	239,310,481	150,961	0.1
2016	1.406	332,593,800	332,796,253	202,453	0.1
2017	1.405	417,456,900	417,705,947	249,047	0.1
		--- **High Base Price: ($1.587/lb.)** ---			
2015	1.620	275,033,448	275,207,054	173,606	0.1
2016	1.617	382,482,870	382,715,691	232,821	0.1
2017	1.616	480,075,435	480,361,839	286,404	0.1

Table 54. Change in Gross Revenue due to 50% Yield Loss on Acreage Treated with Chlorpyrifos from Withdrawal of Chlorpyrifos: Pima Cotton, Own-Price Demand Elasticity = -0.95, 2015–2017

Year	Price after yield loss ($/lb.)	Gross revenue with chlorpyrifos ($)	Gross revenue chlorpyrifos withdrawn ($)	Change in gross revenue ($)	Percent change (%)
			--- Low Base Price: ($1.173/lb.) ---		
2015	1.222	203,285,592	203,371,626	86,034	0.0
2016	1.218	282,704,730	282,852,527	147,797	0.1
2017	1.216	354,838,365	355,036,406	198,041	0.1
			--- 2018 Base Price: ($1.380/lb.) ---		
2015	1.438	239,159,520	239,260,736	101,216	0.0
2016	1.433	332,593,800	332,767,679	173,879	0.1
2017	1.430	417,456,900	417,689,889	232,989	0.1
			--- High Base Price: ($1.587/lb.) ---		
2015	1.654	275,033,448	275,149,847	116,399	0.0
2016	1.648	382,482,870	382,682,831	199,961	0.1
2017	1.645	480,075,435	480,343,373	267,938	0.1

Table 55. Change in Gross Revenue due to 15% Yield Loss on Acreage Treated with Chloropicrin from Withdrawal of Chlorpyrifos: Upland Cotton, Own-Price Demand Elasticity = -0.95, 2015–2017

Year	Price after yield loss ($/lb.)	Gross revenue with chlorpyrifos available ($)	Gross revenue with chlorpyrifos withdrawn ($)	Change in gross revenue ($)	Change in gross revenue (%)
			--- Low Base Price: ($0.616/lb.) ---		
2015	0.623	48,814,395	48,836,301	21,906	0.04
2016	0.623	72,479,628	72,510,114	30,486	0.04
2017	0.622	69,537,034	69,565,310	28,277	0.04
			--- 2018 Base Price: ($0.725/lb.) ---		
2015	0.733	57,428,700	57,454,472	25,772	0.04
2016	0.733	85,270,150	85,306,016	35,866	0.04
2017	0.732	81,808,275	81,841,542	33,267	0.04
			--- High Base Price: ($0.834/lb.) ---		
2015	0.843	66,043,005	66,072,642	29,637	0.04
2016	0.843	98,060,673	98,101,919	41,246	0.04
2017	0.842	94,079,516	94,117,773	38,257	0.04

Table 56. Change in Gross Revenue due to 30% Yield Loss on Acreage Treated with Chloropicrin from Withdrawal of Chlorpyrifos: Upland Cotton, Own-Price Demand Elasticity = -0.95, 2015–2017

Year	Price after yield loss ($/lb.)	Gross revenue with chlorpyrifos available ($)	Gross revenue with chlorpyrifos withdrawn ($)	Change in gross revenue ($)	Change in gross revenue (%)
		--- Low Price: ($0.616/lb.) ---			
2015	0.630	48,814,395	48,845,987	31,592	0.06
2016	0.629	72,479,628	72,525,383	45,756	0.06
2017	0.629	69,537,034	69,580,234	43,201	0.06
		--- 2018 Price: ($0.725/lb.) ---			
2015	0.742	57,428,700	57,465,867	37,167	0.06
2016	0.740	85,270,150	85,323,980	53,830	0.06
2017	0.740	81,808,275	81,859,099	50,824	0.06
		--- High Base Price: ($0.834/lb.) ---			
2015	0.853	66,043,005	66,085,747	42,742	0.06
2016	0.851	98,060,673	98,122,577	61,905	0.06
2017	0.851	94,079,516	94,137,964	58,448	0.06