Economic and pest management evaluation of nitroguanidine-substituted neonicotinoid insecticides: nine 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, the University of California, and the University of California Cooperative Extension

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Executive Summary

The California Department of Pesticide Regulation (DPR) released a risk determination document for four nitroguanidine-substituted neonicotinoid (NGN) insecticides in 2018: clothianidin, dinotefuran, imidacloprid, and thiamethoxam (Troiano et al. 2018). Our report uses economic data and pesticide use data from 2015-2017 to analyze the economic and pest management implications of a scenario in which NGNs determined to be high risk for specific uses are cancelled for a set of focal crops, including almond, cherry, citrus, cotton, grape, pistachio, strawberry, tomato, and walnut. These crops accounted for 42.1% of the value of California's agricultural production and 60.1% of its agricultural exports in 2017 (CDFA 2018a; UCAIC 2018).

Originally some NGN uses on tree nuts were determined to be high risk but DPR's January 2019 amendment revised their status to low risk (Darling 2019). At DPR's request, tree nuts were still included as focal crops and the economic impacts of cancelling those NGN uses were evaluated. Overall, net return losses for the crops considered totaled $165 million in 2015, $205 million in 2016, and $203 million in 2017, assuming the price of strawberries did not increase as a result of a decline in production (Table ES-1). Net return losses occur if gross revenues decline as a result of decreased yield or if costs increase. Here, the costs considered are the treatment costs of replacing NGNs with alternative active ingredients, including material and application costs.

In 2016 and 2017 about two-thirds of the losses were due to strawberry and in 2015 about half were. There is an estimated yield and gross revenue reduction for strawberry, which accounts for the bulk of the net return losses, although strawberry treatment costs increase. Total losses and the share owing to strawberry decline if the price of strawberry increases in response to a decrease in production. For crops other than strawberry, net return losses were due only to increases in treatment costs because yield and quality reductions are not anticipated to occur as a result of replacing high-risk NGN uses with alternatives. Loss estimates do not include losses owing to the more rapid development of resistance to remaining active ingredients by pests for which NGNs are part of the current management program. Chlorpyrifos would have been considered an alternative for multiple crop/pest combinations in this report, but due to the pending cancellation of all chlorpyrifos products, it was omitted here.

Table ES-1. Estimated Total Net Returns Losses by Crop and Year ($1,000s)

Crop	2015	2016	2017
Almond	29	26	9
Cherry	42	51	40
Citrus	3,061	3,342	3,230
Cotton	1,432	2,262	3,564
Grape			
Raisin and table	7,409	7,179	6,713
Wine	14,795	14,147	15,617
Pistachio	7,588	7,838	8,784
Strawberry*			
Price constant	87,889	135,422	136,615
Price increases	74,681	116,086	117,037
Tomato			
Fresh market	5,015	6,179	4,571
Processing	36,920	27,853	22,735
Walnut	1,327	1,105	1,378
Total			
Strawberry price constant	**165,631**	**205,084**	**203,256**
Strawberry price increases	**152,404**	**185,794**	**183,678**

*Strawberry was the only crop for which a yield loss is anticipated. Estimated total net returns losses in strawberry include the estimated cost of yield loss calculated with the price of strawberries remaining constant (price constant) or the price of strawberries increasing (price increases). Estimates assume that all acreage treated with imidacloprid would sustain a yield loss if imidacloprid was cancelled.

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 (CDFA 2018a; UC AIC 2018). Clothianidin was determined initially to be high risk only before and during bloom while imidacloprid was high risk all year (Troiano et al. 2018). Clothianidin is more commonly used, although neither is applied to a substantial share of almond acreage; in 2017, NGNs were only applied to just under 38,000 out of over 1.3 million acres planted. The insects most commonly targeted with these NGNs are leaffooted bugs, stink bugs, and San Jose scale. There are effective (sometimes more effective) alternative AIs for each pest. Our analysis estimates the change in net returns if clothianidin was cancelled for use in January through April (pre-bloom/bloom) and imidacloprid was cancelled completely. No yield losses are anticipated when available alternatives are used, so changes in insecticide material and application costs determine the change in net returns. Taking these costs into account, during the pre-bloom/bloom period, switching to the alternatives would lead to an 11.5% increase in cost on acres using imidacloprid and a 15.6% decrease in cost on acres using clothianidin. In the post-bloom period, switching to the alternative would lead to a 22.0% increase in cost on acres using imidacloprid. Based on acres treated annually for the years 2015-2017, the increase in treatment costs for acres treated with NGNs when alternatives must be used is 6.5% to 13.6% of the cost of using NGNs on those acres, depending on the year. The total change in costs to almond from the restrictions on NGNs is small, less than $100,000. This is due to the off-setting effects of the reduction in treatment costs for some alternatives and the small acreage treated with NGNs.

Cherry. In 2017, gross revenues were $330 million for sweet cherry and exports were $99 million (CDFA 2018a; UCAIC 2018). All four NGNs are registered in cherry; however, only imidacloprid and thiamethoxam are regularly used and only imidacloprid is considered high risk for cherry. Imidacloprid is mainly used against black cherry aphid, cherry leafhopper, and mountain leafhopper. No yield losses are anticipated when available alternatives are used, so changes in insecticide material and application costs determine the change in net returns. If imidacloprid is cancelled for use in cherry the treatment cost on acres that must use alternatives instead would increase from 34.9% based on 2016 use to 35.0% for 2015 and 2017. The absolute value of this cost increase is less than $100,000 owing to the small acreage treated with imidacloprid.

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 (CDFA 2018a; UCAIC 2018). NGNs are used to manage glassy-winged sharpshooter, citricola scale, citrus leafminer, Fuller rose beetle, and Asian citrus psyllid (ACP), and to treat harvested citrus before it is shipped to combat the spread of insect pests. Two NGNs are registered in California citrus, imidacloprid and thiamethoxam, but only imidacloprid was determined to be high risk (Troiano et al. 2018). Switching to alternatives would lead to a cost increase of 69% over the cost of applying imidacloprid. The cost increase is small in dollar terms, however, leading to a total cost increase ranging from $3.1 to $3.3 million on acreage treated with imidacloprid. No yield losses from the cancellation of NGNs are anticipated due to the availability of alternatives, with one critical caveat. Apart from the estimated cost increases considering the current pest management situation, citrus could sustain significant losses from invasive species in the future. Citrus is vulnerable to invasive pest species, and imidacloprid is especially useful for invasive species management because it is broad spectrum, effective, and relatively compatible with current pest management strategies in most citrus regions. Currently, citrus faces significant potential losses due to a specific invasive, Asian citrus psyllid (ACP). Without the use of imidacloprid, it is likely that the deadly bacteria spread by ACP will spread at a much faster rate in the state, putting the entire industry into jeopardy.

Cotton. Cotton generated $475 million in gross revenues and $377 million in exports in (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. All four NGNs evaluated in this study are registered and used in cotton and were classified as high risk. Lygus, aphids, whiteflies, mites, and thrips are targeted by the NGNs. Preventing secondary pest outbreaks and rotating AIs to reduce the risk of resistance are both important concerns. There are alternatives to the NGNs, and no yield losses are anticipated when they are used, so changes in insecticide material and application costs determine the change in net returns. The percent change in costs ranges from 33.7% in 2015 to 38.1% in 2016, with associated annual losses that ranged from over $1.4 million to over $2.2 million. The magnitude of these changes is driven by treated cotton acreage, which is a substantial share of harvested acreage, and the large insecticide material cost differences between imidacloprid, the most widely used NGN and its most-used alternatives.

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 use NGN products against leafhoppers and grape phylloxera. Vine mealybug is a problem in all grape-growing areas and can be especially severe in warmer areas, such as the southern San Joaquin Valley. Raisin and table grape are more concentrated in the warmer growing areas than wine grape, and, as such, tend to have more problems with vine mealybug. There are alternatives for leafhoppers and mealybugs, but they are more expensive. Phylloxera management does not have good alternatives for neonicotinoids. No yield losses are anticipated when available alternatives are used, so changes in insecticide material and application costs determine the change in net returns. PUR data separate grape into two categories, grape, including table and raisin, and wine grape. For table and raisin grape, the percent change in costs on affected acreage ranges from 103.3% in 2017 to 106.8% in 2015, depending on the NGN. The associated total cost increase on affected acres summing over all NGNs would be $6.7 million to $7.4 million. For wine grape, the percent change in costs ranges from 136.4% in 2015 to 137.6% in 2016 and 2017. The associated total cost increase for would be $14.8 million to $15.6 million The magnitude of these changes is driven by the large treated grape acreage, the large share of treated acres that are treated with NGNs currently, and the large price differences between the NGNs and their most-used alternatives.

Pistachio. Pistachio was California's ninth largest agricultural commodity by value of production in 2017, with gross revenues of $1 billion (CDFA 2018a). The value of exports was $1.5 billion, with the quantity of pistachios exported equal to 78% of the quantity produced (UCAIC 2018). Imidacloprid is the only NGN initially considered high risk in pistachio. It is largely used for control of mealybug and scale, the most common of which is Gill's mealybug. There are effective alternatives for these pests, but they cost more per acre than imidacloprid. No yield losses are anticipated when available alternatives are used, so changes in insecticide material and application costs determine the change in net returns. The total cost of replacing imidacloprid applications with alternatives is expected to increase dramatically, by 245.2% increase. The absolute value of the increase ranged from $7.6 million to $8.8 million, depending on the year. The magnitude of these changes is driven by the large treated pistachio acreage, the large share of treated acres that are treated with imidacloprid currently, and the large price differences between imidacloprid and its most-used alternatives.

Strawberry. In 2017, strawberry was California's fourth largest agricultural commodity by value of production, with gross revenues of over $3 billion (CDFA, 2018a). 2017 exports were $415 million (UCAIC 2018). Two NGNs are registered for and applied to control sucking insect pests in California strawberry: imidacloprid and thiamethoxam. Both were designated as high risk

(Troiano et al. 2018). Insect pests target by the NGNs are aphids, leafhoppers, lygus bug, root weevils and grubs, and whiteflies. The importance of these insects may vary by region and year. Cancellation of imidacloprid and thiamethoxam in strawberry would result in a $1.7 million to $2.1 million increase in insecticide costs. Although imidacloprid is not nearly as widely used as thiamethoxam for strawberry, it is the main driver of the cost increase because one application would likely be replaced by three applications of more expensive alternatives. There is also an estimated decrease in gross revenues because there are no equally efficacious alternatives for controlling whitefly. Reduced gross revenues are the primary driver of net revenue losses in strawberry: the estimated annual reduction ranged from $86.2 million to $134.9 million. Combining the increase in treatment costs and decrease in gross revenues, net returns declined by $87.9 million to $136.6 million.

Tomato. Tomato was California's eighth largest commodity by value of production in 2017, with gross revenues of $1.1 billion (CDFA 2018a). Exports were $686 million (UCAIC 2018). Tomatoes in California are grown for two markets: fresh and processed. California is the largest producer of processing tomato and the second largest producer of fresh tomato in the U.S., behind only Florida. NGNs are used for aphids, flea beetles, leafhoppers, leafminers, Lygus, potato psyllid, stink bugs, thrips, and whiteflies. The importance of these insects varies by region, year, and market. In addition to the direct efficacy and cost considerations of using alternatives to NGNs, secondary pest outbreaks and resistance management are key considerations in tomato. Owing to the systemic nature of the NGNs, they can be applied once at planting and provide good control through the season. Without them, growers would likely apply multiple applications of alternative active ingredients, greatly increasing the treatment cost on affected acres. The result would be a 364.7% to 423.5% increase in total treatment costs for fresh tomato and a 352.2% to 358.8% increase for processing tomato. No yield losses are anticipated when available alternatives are used, so changes in insecticide material and application costs determine the change in net returns. In absolute terms, the total annual cost ranged from $4.6 million to $6.2 million. For processing tomato, the total annual cost ranged from $22.7 million to $36.9 million.

Walnut. By value of production, walnut was the seventh largest agricultural commodity in California with gross revenues totaling $1.6 billion in 2017 (CDFA 2018a). Exports totaled $1.4 billion, with the quantity exported equal to 65% of the quantity produced (UCAIC 2018). There are two NGN insecticides registered for use on walnut: clothianidin and imidacloprid. They are used mostly against aphids and walnut husk fly with minor use against scale insects. Clothianidin was determined initially to be high risk only before and during bloom while imidacloprid was high risk all year (Troiano et al. 2018). Accordingly, our analysis estimates the change in cost of pest management if clothianidin were unavailable January through April and imidacloprid was completely unavailable. No yield losses are anticipated when available alternatives are used, so changes in insecticide material and application costs determine the change in net returns. Insecticide material and application costs for applications using alternative active ingredients compared to applications using NGNs increase by 42.4% to 4.2.8% under the policy. The change in costs ranges from $1.1 million to $1.3 million.

Caveats. There are a number of caveats regarding the estimates in this report. Here we mention the most significant general ones, while crop-specific ones are included in the individual crop analyses. First, the net revenue loss estimates are not comprehensive estimates for California agriculture; the crops examined account for only 42.1% of California's agricultural production. Second, the analysis uses data from 2015-2017, the three most recent years of data available. There may have been notable changes in pesticide use since then that could affect the number of impacted acres and/or change the cost of using target NGNs versus alternative AIs. Third, growers' land allocation decisions across crops could change the use of specific pesticide AIs. Fourth, new regulations may change the availability of alternative AIs due to cancellations of uses or new restrictions on use, such as approved application methods. There is also the possibility that new AIs or new uses of existing AIs could be registered. Fifth, invasive species may increase the cost of the cancellation of the target NGNs. Finally, the development of pest resistance to AIs can increase the cost of cancellation by reducing the number of modes of action available. Even if there are efficacious alternatives for a target NGN for the management of a specific pests, using alternatives may limit their availability for controlling other pests and ultimately increase pest management costs and/or reduce yields.

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Introduction

Neonicotinoids are a class of systemic insecticides that attack insects' central nervous system, blocking nicotinic acetylcholine receptors (Le Goff and Giraudo 2019). They are effective against many sucking and some chewing insects and have become widely used since their introduction in the mid-1990s as alternatives to organophosphates and carbamates (Jeschke and Nauen 2008; Cimino et al. 2016; Le Goff and Giraudo 2019). They have comparatively low toxicity to mammals but are toxic to many insects, including bees as well as pests. Nitroguanidine-substituted neonicotinoid (NGN) insecticides are a subset of the neonicotinoid insecticide class that have been determined to be most harmful to bees (Troiano et al. 2018). There are four NGN active ingredients (AIs): clothianidin, dinotefuran, imidacloprid, and thiamethoxam. They are registered on a wide variety of crops in California. This report evaluates the effect on net revenues of the cancellation of the high risk uses of these NGNs on nine crops: almond, cherry, citrus, cotton, grape, pistachio, strawberry, tomato and walnut. These crops accounted for 42.1% of the value of California's agricultural production and 60.1% of its agricultural exports in 2017 (CDFA 2018a; UCAIC 2018).[1]

Food and Agricultural Code (FAC) section 12838 required the California Department of Pesticide Regulation (DPR) to issue a determination on its reevaluation of the NGNs, which it PR completed in July 2018 (Troiano et al. 2018). The risk determination report provides detailed designations of whether uses of the four NGNs at full label rates on different crops are high risk or low risk to bees. Risk included risks to the colony as a whole from sub-lethal exposure (Troiano et al. 2018).

In January 2019, DPR posted an addendum (Darling 2019) to the Troiano et al. (2018) risk determination report. The addendum revised the risk determination for several crop groups including tree nuts and one NGN in stone fruit. Stone fruit still had 2/4 registered NGNs in the high risk designation and, as such, was kept in the analysis. As analyses for tree nuts were already underway and they represent substantial acreage in California and could still potentially be impacted by neonicotinoid regulations, these analyses were completed and are included in this report at DPR's request. Table 1 shows the original and revised risk determinations for the nine focal crops included in this analysis.

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[1] Grape juice included in raisin and table grape exports.

Table 1. Risk Determinations for Focal Crops

	Imidacloprid	Thiamethoxam	Clothianidin	Dinotefuran
grape	**c**	high	**b**	high
almond	low*		**a**	
walnut	low*		**a**	
citrus	high	low		
strawberry	high	high	**c**	high
cotton	**b**	high	high	high
tomato	high	**c**	high	high
cherry	high	low*	**c**	low
pistachio	low*			

Gray boxes – not registered
*High risk designation revised downward in January 2019 DPR addendum
a – Applications after bloom designated low risk
b – Soil applications designated low risk
c – No risk assessment data on the listed crop/AI combination but crop group has high risk designation, so AI designated high risk. However at least one other crop in this group designated low risk based on crop-specific information.

Within each focal crop, NGNs that were designated as high risk (Table 1) were included as target NGNs. The complete list target NGNs by crop is in Table 2.

Table 2: Target Nitroguanidine-substituted Neonicotinoids by Focal Crop

	Imidacloprid	**Thiamethoxam**	**Clothianidin**	**Dinotefuran**
grape	X	X	X	X
almond	X		X	
walnut	X		X	
citrus	X			
strawberry	X	X	X	X
cotton	X	X	X	X
tomato	X	X	X	X
cherry	X	X	X	
pistachio	X			

Under FAC section 12838, DPR has two years to identify and adopt measures necessary to protect pollinator health. As part of that effort, on in October 2018 personnel from the Office of Pesticide Consultation and Analysis (OPCA) in the California Department of Food and Agriculture (CDFA) met with DPR personnel to discuss potential changes to the availability of NGNs. This report evaluates the potential economic impacts of a specific possible change driven by DPR's risk determination document: cancellation of specific AIs for specific uses that were designated as high risk. 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 economic effects on

California agriculture of regulations regarding pesticides under consideration by DPR, which is OPCA's mandate as specified in FAC Section 11454.2.

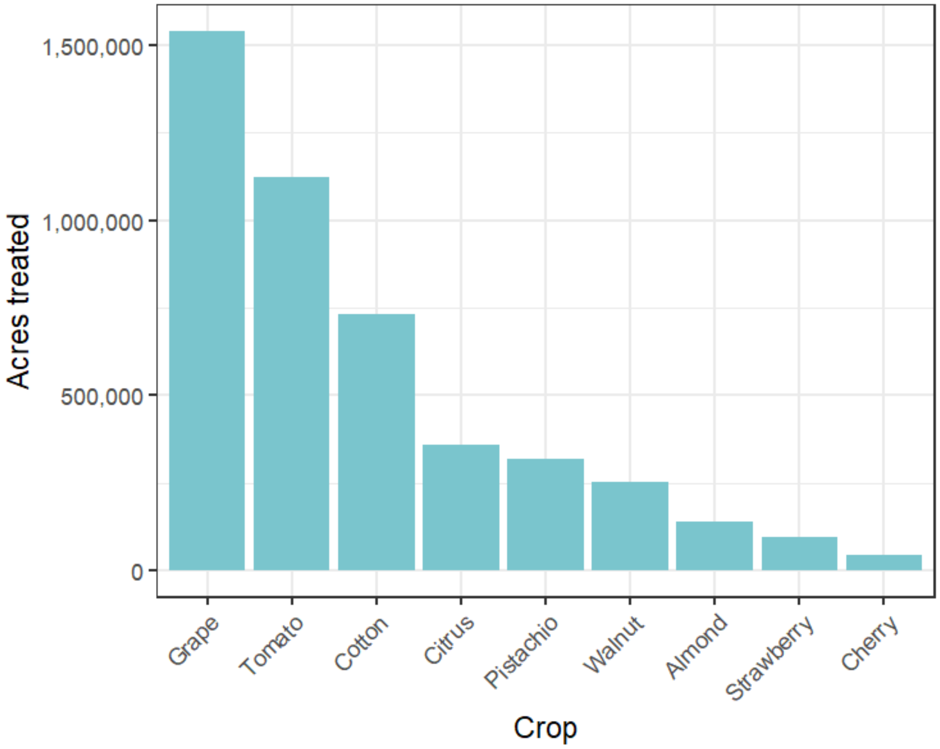

Figure 1. Total acres treated with nitroguanidine substituted neonicotinoids by focal crop: 2015-2017

For the nine focal crops, this report will provide a discussion of the importance of NGN insecticides for pest management, identify situations where NGNs are of key importance, i.e., alternative AIs are not economically viable or efficacious, and analyze the economic impact of the potential cancellation of the target NGNs. In pistachio and walnut, one NGN would only be restricted while others would be cancelled. This is addressed in the crop sections.

Total acres treated with target NGNs for each focal crop over the three-year period 2015-2017 are plotted in Figure 1 using DPR's Pesticide Use Report (PUR) database. Crops were chosen on the basis of their use of the AI relative to total crop acreage and relative to the total use of that AI across crops, and their economic importance to California agriculture (see Crop Selection section). Each crop section includes basic economic information, the pests targeted by NGNs, the monthly and annual use of the target NGNs, and an economic analysis of the impact of canceling specific uses of the NGNs.

Considerations Across All Crops

There are several issues that are common across crops: the restricted use and proposed cancellation of chlorpyrifos, resistance management, secondary pest infestations, and regional differences that lead to differences in the relative efficacy of the NGNs and available alternatives. The crop analyses identify instances in which one or both of these are particularly important; however, neither one is entirely absent for any crop.

Restriction and cancellation of chlorpyrifos. Chlorpyrifos was listed as a toxic air contaminant by the California Department of Pesticide Regulation in 2018, which lead to a proposal from DPR in May 2019 to cancel all chlorpyrifos products within two years. While chlorpyrifos can serve as substitutes for NGNs in some cases, chlorpyrifos is excluded as an alternative in this analysis because it may not be available. However, this report restricts attention to evaluating the economic impacts of canceling NGNs for specific uses based on acres treated with NGNs. Economic impacts of canceling chlorpyrifos are not considered directly.

Resistance management. Resistance is when insects become less susceptible or immune to a specific insecticide through a change that is heritable. Resistance is a major problem facing growers. It decreases the effectiveness of the insecticide, thereby increasing the cost of insect management and/or reducing yield due to more insect damage.

How insecticides kill insects – their modes-of-action (MoA) – is important because insects can quickly evolve resistance to one MoA if it is heavily used (Le Goff and Giraudo 2019). Insecticides are classified based on MoA by the Insecticide Resistance Action Committee (IRAC)[2]. 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 rotate what is applied in a given location. There are guidelines available to growers and PCAs about how to rotate insecticides to reduce the risk of resistance.

Neonicotinoids, including the four NGNs addressed here, are often used in rotation with insecticides with other MoAs, particularly for pests that are known to developed or have already developed resistances to some AIs. In these situations, there are chemistries other than neonicotinoids that are effective against these pests, however, if NGNs are no longer available in California, there would be fewer AIs in rotation. 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.

Secondary outbreaks. Virtually all crops have primary and secondary pests. Primary pests attack direct damage to the marketable crop and require regular management. Secondary pests cause indirect damage by reducing plant vigor, causing leaf drop, or generally hindering production. Primary pests require annual application of some control measures, while secondary pests 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 a common situation with spider mites. They can be well controlled by natural enemies but when a broader

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[2] https://www.irac-online.org/

spectrum insecticide is used in the field, like pyrethroids, killing the natural enemies, mite populations will explode very rapidly. This is called a 'secondary pest outbreak.'

As a result, pest managers take into account how an application targeting one pest will affect populations of other pests when selecting what insecticide to use. NGNs play an important role in preventing secondary pest outbreaks because they are less harmful to natural enemies than alternatives including organophosphates, carbamates, and pyrethroids. Removing the NGNs could increase the use of insecticides beyond direct replacement of the NGN if secondary pest outbreaks necessitate more treatments. This cost is not captured in the economic analyses, but it could be substantial. Additionally, it could make the problem of rapidly developing resistance worse.

Caveats

There are a number of caveats regarding the estimates in this report. Here we mention the most significant ones. There are also crop-specific considerations included in the individual crop analyses. The first set of caveats regards methodology. The first regards the selection of crops analyzed. While they are economically important crops that apply the target NGNs to a substantial amount of acreage, they account for only 42.1% of the value of California's agricultural production. The loss estimates presented here are not comprehensive estimates for the entire production agriculture sector. A second caveat regards the use of historical data. 2015-2017 were the three most recent years of data available. There may have been notable changes in pesticide use since then that are not reflected in this analysis. Such changes could affect the number of impacted acres if there was a significant increase or decrease in the use of the target NGNs relative to the use of alternative AIs. Any redistribution of use across AIs could increase or decrease the cost of using target NGNs versus alternative AIs. Steggall et al. (2018) provide a more complete discussion of the development of the methodology and addresses the logic behind each major modeling decision.

A second set of caveats regards external factors that could substantially alter the results presented here. First, growers' land allocation decisions could change. Changes in crop acreage are likely to be associated with changes in the use of specific pesticide AIs, even though the AIs may not generally be applied to a large share of acreage. (A caution regarding interpretation is associated with this caveat: while estimated losses may appear small relative to gross revenues for a given commodity, the losses are not equally distributed across acreage and growers. Only acreage that was treated with NGNs during the 2015-2017 base period would have been impacted.)

Second, new regulations may change the availability of alternative AIs. We were able to include one regulatory action in this report; chlorpyrifos was excluded as an alternative due to the initiation of the cancellation process by DPR during the writing of this report as noted in the previous subsection. There is the potential for other regulatory actions, even in the near term; for example, beta-cyfluthrin is under review by DPR (https://www.cdpr.ca.gov/docs/registration/canot/2018/ca2018-04.pdf). Given the stage of the review process, it is included as an alternative. However, it may not be available. In general, the availability of existing alternative AIs may change due to cancellations of uses or new restrictions on use, such as approved application methods. There is also the possibility that new AIs or new uses of existing AIs could be registered in California.

A third set of caveats is that biological changes may occur. Invasive species may increase the cost of the cancellation of the target NGNs. For example, the cancellation of imidacloprid for citrus would remove a critical tool for the management of Asian citrus psyllid. New invasive species could affect citrus or other commodities. The development of pest resistance to AIs can also increase the cost of cancellation. Rotating AIs with different modes of action is a key tool for managing the development of resistance, as noted above. Even if there are efficacious alternatives for a target NGN for the management of a specific pests, using these alternatives may limit their availability for controlling other pests and ultimately increase pest management costs and/or reduce yields.

Methods

This section details the methods used for each crop in the following analysis, which are based on Steggall et al. (2018). The criteria used for crop selection are discussed first, followed by the data regarding pesticide use, the approach for preparation of the integrated pest management (IPM) discussion, and finally the components of the economic analysis.

Crop Selection

DPR used the federal Environmental Protection Agency's crop group categories to assign risk determinations. Accordingly, this report utilizes those categories to select crops for analysis. For each crop group, Table 3 reports the crop that treated the most acres with all NGNs – low risk and high risk – from 2015-2017 along with its total acres treated and ranking for that three-year period, the number of NGNs designated high risk as a proportion of the number registered, and whether or the crop is included in this analysis. If it is not, the reason is provided in the rightmost column. In some groups, additional crops are analyzed due to their substantial use of NGNs and/or their economic importance to California agriculture. In the tree nut group, pistachio was the top user but almond and walnut applied NGNs to substantial acreage and are economically important crops in California and were also included. Similarly, in the berry crop group, grape (wine, table, and raisin) was the top user and strawberry was also included due to its economic importance. Lettuce, Cole crops (Brussels sprout, cabbage, collard green, and kale), potato, and artichoke were determined to be low risk and not included. Cantaloupe had the most acreage treated in the cucurbit crop group but had only one high risk NGN and was not included. Nine crops were selected for analysis based on NGN use and economic importance. Their rankings in terms of acres treated with NGNs were 1, 2, 4, 5, 7, 8, 9, 11, and 17.

Table 3. Crop Selection Decision Information

Crop group	High risk NGNS/ registered NGNs	Crop with most acres treated 2015-2017	Acres treated 2015-2017 (rank)	Other crops included (rank)	Included in report	Explanation
1: Root and tuber vegetables	0/4	Potato	64,764 (14)	None	No	Low risk
3: Bulb vegetables	0/3	Artichoke	20,784 (24)	None	No	Small acreage and low risk
4: Leafy vegetables	0/4	Lettuce	827,402 (3)	None	No	Low risk
5: Cole crops	0/4	Aggregated	576,859 (6)	None	No	Low risk
6: Legume vegetables	0/3	Dried bean	26,703 (22)	None	No	Small acreage and low risk
8: Fruiting vegetables	3/3	Tomato	1,124,244 (2)	None	Yes	
9: Cucurbit vegetables	1/4	Cantaloupe	74,807 (13)	None	No	Low risk
10: Citrus fruit	1/2	Aggregated	822,564 (4)	None	Yes	
11: Pome fruits	2/3	Apple	6,255 (37)	None	No	Small acreage
12: Stone fruits	2/4*	Cherry	42,782 (17)	None	Yes	
13: Berry	4/4	Grape	1,539,802 (1)	Strawberry (11)	Yes	
14: Tree nuts	0/4**	Pistachio	317,807 (7)	Walnut (8), Almond (9)	Yes	Originally high risk, changed to low risk
15: Cereal grains	4/4	Wheat, fodder	478 (83)	None	No	Small acreage
19: Herbs and spices	0/1	Cilantro	7,367 (35)	None	No	Small acreage and low risk
20: Oilseed group	4/4	Cotton	730,708 (5)	None	Yes	
24: Tropical and subtropical fruit	3/3	Persimmon	392 (92)	None	No	Small acreage

* In the original risk determination, ¾ registered NGNs were classified as high risk.

**In the original risk determination, ¾ registered NGNs were classified as high risk. In the Addendum (Darling 2019), 4/4 NGNs were re-classified as low risk.

Pesticide Use Data

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

Regions. Table 4 presents the standard growing regions for California defined in the PUR.

Table 4. Growing Regions in California as Defined by the Pesticide Use Report Database

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, strawberry, and tomato are examined using crop-specific regions, which are presented in the crop sections.

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 generally what growers are targeting with the NGNs and alternative AIs, as well as a sense of the factors influencing variations in NGN use within and across years. One or more authors are experts in pest management for each crop and provided this information. They determined target pests based on their detailed knowledge of the crops they work with and by talking to other experts. They also provided lists of alternative AIs, which were used in the economic analyses, and information on intra-year and inter-year variations in use.

Maps

The maps presented in each crop section visually represent production of each crop spatially across California. With the exception of citrus, the maps 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.

Economic Analysis

We estimate the change in pest management costs for each crop based on the acres treated with NGNs, the available alternatives, and the costs per acre of the AIs (Steggall et al. 2018). The baseline total cost is established by multiplying the cost per acre for each target NGN by the acres treated with that target NGN. This is compared to the cost of the regulated scenario. In the regulated scenario we are evaluating, the target AI would no longer be available. To estimate the cost, we assign all the acres that had been treated with the target NGN to the alternative AIs in proportion to the acreage treated with the alternative AIs in 2015-2017 (Steggall et al. 2018). Below we provide the details for the general methods applied to all crops and then describe refinements designed to address crop-specific factors. If yield is anticipated to decline, then a change in gross revenues will affect net returns in addition to the change in pest management costs

Acres treated and pounds applied. The acres treated with each AI and the pounds of AI applied were extracted from the PUR database for each target and 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. Total acres treated with insecticides does not correspond to total acres planted or harvested because some acres may have been treated with multiple AIs or treated with the same AI more than once, while other acres may not have been treated with a target NGN or an alternative AI at all.

Selecting representative products. For each target pest, crop, and alternative AI, we identified a representative product to use in determining the cost of the cancellation of the NGNs determined to be high risk. 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. In two cases the formulation of the product was used when selecting the representative product. Specifically, in almond and pistachio, for one AI the most used product was not representative of the use type that would be an alternative for the NGNs. The top product was an ant bait but the pest under consideration was an aphid, which requires a formulation suitable for spraying or chemigation. In these cases, the top product that was the correct type was used as the representative product. In tomato, the most acres treated with spinetoram, were a pre-mix product that was not use for the target pests. In this case, the most used product that was used for the target pests was used instead.

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.

Material costs. The price for the representative products is standardized to cost per pound. For example, if the price is $10/oz, the standardized cost is $10/oz * 16 oz/lb, or $160/lb. Many products are aqueous, and, in order to convert these to pounds, we used the density of the products, provided in the PUR database product table, to convert 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 in the PUR database product table, to obtain the cost per pound of the AI. The cost of the AI per acre is the cost per pound multiplied by the average use rate (pounds of AI applied/acres treated) for that crop over the study period (Steggall et al. 2018).

Application costs. In some cases, alternatives may require a different application method, which can change the cost per acre of a treatment. Using cost studies and expert consultation, we estimated application costs for aerial spraying, ground spraying, chemigation, and side dressing (Table 5). Chemigation and side dress are assigned a zero cost based on the limited time needed for chemigation using already installed equipment and the simultaneous application of other products or other operations with side dress. Aerial application costs vary considerably and depend on multiple factors, including but not limited to the size of the field being treated, the type of aircraft being used, the rate of application, and the number of applicators in the area. We used 100 acres at 5 gallons per acre as the average to determine the cost. In cotton, strawberry, and tomato, most aerial applications are made with fixed wing aircraft. In almond, cherry, citrus, grape, pistachio, and walnut, helicopters are sometimes used, which increases the cost of aerial applications. To account for this, experts estimated a higher cost per acre in those crops where helicopters are more regularly used.

Table 5: Application Method Costs Per Acre

Application method	**Cost ($)**
Ground	25
Aerial including helicopters	27.5
Aerial mostly fixed wing	17.5
Chemigation	0
Side dressing	0

Application method is recorded in the PUR data. One key caveat is that while ground and aerial applications and fumigation are specified in the Pesticide Use Reports that comprise the PUR database, chemigation and side dressing are meant to go in a category called ‘Other’. ‘Other’ captures all methods that are not ground, aerial, or fumigation. For the focal crops and the representative products considered, chemigation and side dress are the only relevant options other than ground and aerial. As both of these practices have the same estimated cost of zero, they can be analyzed together.

When an AI can be applied to a crop using a variety of application methods, we calculate the average application cost per acre based on the frequency at which each application method is used across all applications of the AI to the crop. For example: if half of the applications of an AI on a crop are ground ($25/acre) and the other half are aerial including helicopters ($27.50/acre), the average application method cost would be $26.25/acre.

Net returns scenarios. In order to calculate the cost of the loss of the NGNs for each crop, we compare net returns under the status quo to net returns if high risk NGN uses are cancelled. In this study, the use of available alternatives will enable growers to avoid yield losses for all crops except strawberry. For strawberry, the reduction in gross revenues per acre as well as an increase in insecticide costs on acreage treated with a target NGN will affect net returns. For the remaining eight crops, the change in net returns reduces to the change in cost. The change in cost per acre has two components: the change in the material cost per acre and, when appropriate, the change in application costs. The total change in costs for each high-risk NGN is the acres currently treated with that NGN multiplied by the change in the cost per acre. The total change in cost for the crop is the sum of the total change in cost for all high-risk NGNs.

Identifying the change in cost per acre requires determining an alternative AI. In many instances more than one alternative is available and would likely be used on some acreage. Thus, following Steggall et al. (2018) we define a composite alternative: each AI is assigned to acres currently treated with high-risk NGNs in proportion to its share of total acres treated with all alternatives. For example, if there are 1,000 acres of a crop, 600 are treated with an NGN, 200 are treated with alternative A and 200 are treated with alternative B, then A and B are each assigned to treat 300 acres of the acres currently treated with an NGN. The cost per acre is reported as the weighted average of the costs of A and B. In this case, each AI accounts for half of the cost of the composite alternative. The total cost is this composite cost per acre multiplied by the 600 acres currently treated with an NGN. Costs will not change on acreage currently treated with a non-NGN AI.

Crop-specific considerations. Table 6 summarizes crop-specific refinements to the methodology in Steggall et al. (2018). These refinements address unique features of the crop and how it could be affected by the proposed cancellations.

As reported in the second column of Table 6, the analyses for four crops are conducted separately for subsets of their data: almond, grape, tomato, and walnut. These subsets account for possible differences in the use patterns (or other features) of the cancelled AI and its composite alternative. For grape and tomato, the subset is based on the type of product produced: table and raisin grapes versus wine grape, and fresh market versus processing tomatoes. The bundle of alternative AIs may be different, and acreage shares calculated separately, across these two subsets. For almond and walnut, the subset is based on the timing of the application: pre-bloom (January to April) and post-bloom (May to December). This is because one of the two NGNs under consideration for cancellation, clothianidin, was found to be high-risk only in the pre-bloom period and is available as an alternative AI post-bloom. Acreage shares are calculated separately for the two periods.

The third column of Table 6 reports other assumptions or features of the analysis unique to a specific crop. For almond and pistachio, pyriproxyfen bait was not considered an alternative AI. For walnuts, spinosad cost per acre was calculated separately for bait and spray because the use rate for a bait is orders of magnitude smaller than for spray. Citrus, strawberry, and tomato growing regions differ from the standard regions defined by the PUR and presented in Table 4.

Note that, for all but one focal crop – strawberry – the authors have assessed that the replacement of the cancelled NGN will have no adverse consequences on marketable yield and hence on gross revenues.

Table 6. Summary of Methodological Refinements by Crop

Crop	Subsets for defining representative product	Crop-specific considerations
almond	Pre-bloom/bloom, post-bloom	Excludes pyriproxyfen bait as an alternative AI
cherry		None
citrus	Aggregates orange, lemon, mandarin, grapefruit, and their hybrids	Regions are different from those defined in the PUR
cotton		None
grape	Table, wine	None
pistachio		Excludes pyriproxyfen bait as an alternative AI
strawberry		Regions are different from those defined in the PUR
tomato	Fresh market, processing	Multiple applications were used in the composite alternative, regions are different that those defined in the PUR
walnut	Pre-bloom/bloom, post-bloom	Different AI usage rates for spinosad bait and spray so they are treated separately as alternatives. Pyriproxyfen bait is excluded as an alternative AI

Almond

Almond is one of California's most economically important crops. Gross receipts for almond totaled $5.6 billion in 2017, second only to grape ($5.8 billion) in terms of production value (CDFA 2018a). There were one million acres of bearing almond orchards in 2017, plus 330,000 non-bearing acres.

Over 80% of the almond crop, nearly $4.5 billion, is exported, making almond California's most important export agricultural commodity by value. California accounts for all national production of almond and is by far the largest producer and exporter of almond in the world. For 2018-2019, the California almond crop was forecast to account for nearly 80% produced worldwide and more than 87% of almond exchanged through export markets (USDA FAS, 2018). 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.

Almonds are grown throughout the entirety of the Central Valley, from Redding in the north to Bakersfield in the south, with some additional isolated production closer to the coast near San Luis Obispo. 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 in three of these counties (Kern, Merced, and Tehama), and the top agricultural commodity in six (Fresno, Stanislaus, Madera, Colusa, Glenn, and Yolo). Figure 2 maps the distribution of California's 2017 almond production.

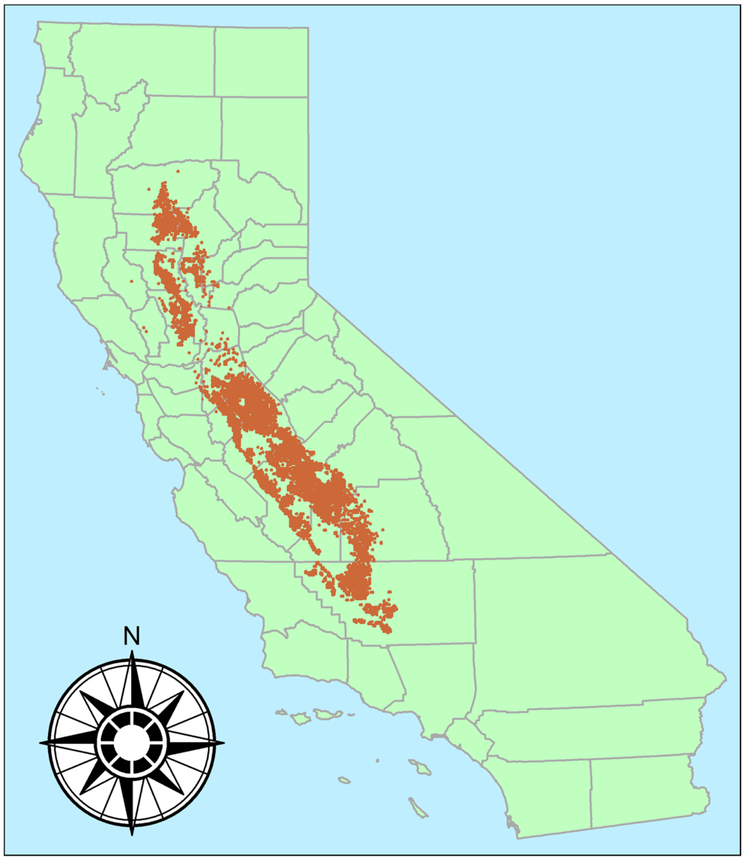

Figure 2. California almond production: 2017

IPM Overview

Given the broad geographic distribution of almond acreage in California, production of this crop occurs under a variety of agronomic and climatic conditions, which in turn leads to a diverse array of production practices and patterns of pesticide use. Almond production conditions can broadly be divided between the Sacramento Valley and San Joaquin Valley, although there are idiosyncrasies within each of these macro-regions, most importantly between the southern and northern San Joaquin Valley. Here, pesticide use will be evaluated statewide, which requires some generalization about key pests and their management.

Clothianidin and imidacloprid are the two NGNs used in almond, although neither has substantial use. Clothianidin is used more often, and approximately 85% of the time it is tank mixed as a secondary along with major AIs like abamectin and/or methoxyfenozide (or alternately chlorantraniliprole). Though clothianidin is considered an alternative AI for the control of plant bugs like LFB, it is not considered to be very effective. LFB and other plant bugs are more commonly and effectively controlled with pyrethroids. Finally, imidacloprid use is negligible (<1%). Imidacloprid can be used in the dormant period or in the spring. Dormant applications of imidacloprid are likely via drip irrigation targeting nematodes while spring applications target scale. Imidacloprid is not generally effective against nematodes. There are alternative AIs for the control of scale (e.g., oils, insect growth regulators (IGRs)) and nematodes (e.g., 1,3-dichloropropene, spirotetramat) in almond.

Target Pests

Leaffooted bugs. Three leaffooted bug species are sporadic pests of almond: *Leptoglossus zonatus* (most common), *L. clypealis*, and *L. occidentalis*. These leaffooted bugs overwinter as adults on host plants near almond orchards and migrate into orchards in April and May in search of food. These insects are not common pests, but in the right weather, large populations can emerge and cause significant damage. Adults feed on young nuts using piercing mouthparts, which can cause the forming nuts to abort, and on mature nuts, they cause black spots on the kernel or nut drop. Though clothianidin is used to treat leaffooted bugs in almond, it is not the main treatment and some alternatives are actually more effective. Alternatives include bifenthrin, lambda-cyhalothrin, abamectin, and esfenvalerate. Chlorpyrifos has historically been used to control leaffooted bugs, however, DPR issued a notice to cancel all chlorpyrifos products in May 2019. Accordingly, chlorpyrifos is not considered as an alternative in this analysis.

Stink bugs. Several stink bugs can be pests in almond: the green stink bug, *Acrosternum hilare* (most common), the redsholdered stink bug (*Thyanta pallidovirens* and *T. custator acerra*), and the Uhler stink bug (*Chlorochroa uhleri*). Stink bug populations develop around almond orchards, often in weedy field margins, and then migrate into the orchards as adults. Like leaffooted bugs, their piercing mouthparts damage the nuts. Stink bug damage appears in May – July. Clothianidin may be applied against them, usually in a tank-mix with bifenthrin or lambda-cyhalothrin. Acetamiprid tank-mixed with bifenthrin or lambda-cyhalothrin is the main alternative currently available. Chlorpyrifos would also have been considered an alternative before DPR issued the notice to ban in May 2019.

San Jose scale (*Diaspidiotus perniciosus*). Imidacloprid is occasionally used against scale in the spring. However, this is not common and more effective alternatives include pyriproxyfen, buprofezin, and carbaryl.

Nematodes. Growers report occasionally using chemigated imidacloprid against nematodes. This is rare and not effective. As such, alternative AI for management of nematodes are not considered in this analysis.

Target NGN Use: 2015-2017

Neonicotinoids were applied to under 30,000 out of over 1.3 million acres of almond orchards in 2017. In 2015, around 45,000 acres were treated with NGNs, a small fraction (3%) of the total almond acres planted. NGN use primarily consists of clothianidin but also includes a small number of acres treated with imidacloprid (Table 7). Clothianidin is mostly applied between March-May, with peak applications in April, consistent with when leaffooted bug would be entering orchards. No applications were reported during the pre-bloom period - Dec/Jan/Feb – in 2015-2017 (Figure 3).

Table 7: Annual Use of Target Nitroguanidine Substituted Neonicotinoids and Alternative Active Ingredients: Almond, 2015-2017

Active ingredient	**--------Pounds 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
acetamiprid	2,964	1,938	1,487	6,388	24,583	16,099	12,204	52,886	0.12
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
clothianidin*	5,434	2,868	3,476	11,778	55,257	29,364	35,943	120,564	0.1
esfenvalerate	17,799	16,487	13,139	47,425	289,583	251,052	204,092	744,728	0.06
imidacloprid*	1,032	750	304	2,085	8,546	7,060	1,776	17,383	0.12
lambda-cyhalothrin	8,597	8,162	12,915	29,674	249,256	232,080	344,502	825,837	0.04
pyriproxyfen	4,253	5,461	2,324	12,038	127,766	249,717	164,329	541,812	0.02

*Target NGN

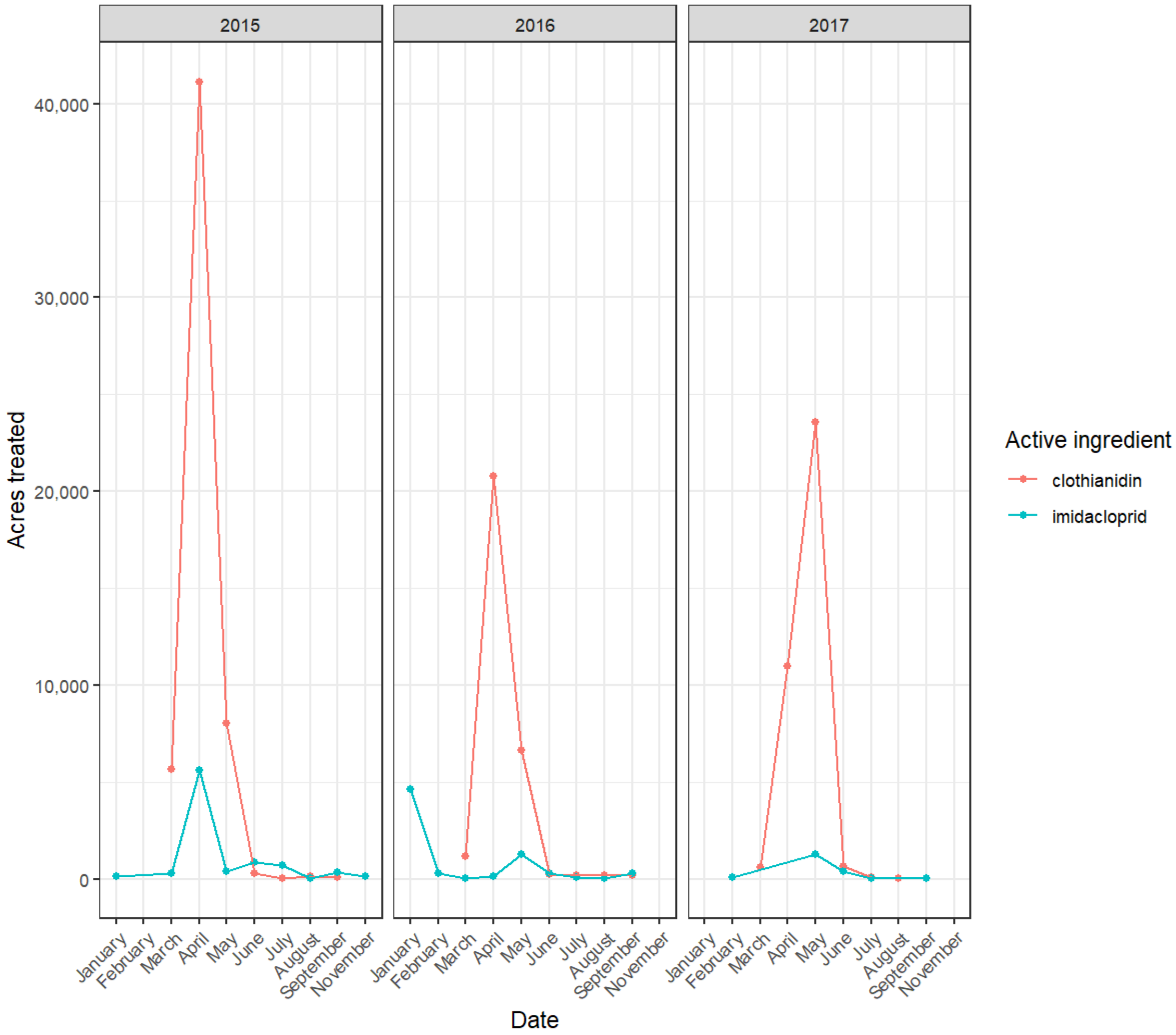

Figure 3. Monthly use of target nitroguanidine substituted neonicotinoids: almond, 2015-2017

Economic Analysis

This section presents the anticipated change in net returns to almond if the use of clothianidin and imidacloprid were restricted. Imidacloprid was originally classified by CDPR as high risk on almond at all times in the year, so we model a complete cancellation of this product for almond. Clothianidin, however, was originally classified as high risk for pre-bloom and bloom periods. The pre-bloom and bloom period occur from December to mid-March, so we model the cost of cancelling clothianidin in only those months. This cost includes the change in pesticide material and application costs. Because there is not anticipated to be a yield or nut quality decrease due to the availability of alternatives, gross revenues will not change as a result of cancellation.

Because the use rates may change between the pre-bloom/bloom and the post-bloom periods, we calculate separate costs per acre for each of these periods. Table 8 presents representative products and their costs for each NGN and alternative AIs used on almond during the pre-bloom/bloom period (December to March) and Table 9 presents them for the post-bloom period (April to November) from 2015 to 2017. The material cost is calculated as the product of the three-year average use rate (lbs/acre) and the price per pound of product. The application cost per acre is the average of the application cost of each method used for an AI, weighted by the share of that application method in the total acres treated with that AI. The total cost per acre for an AI is the sum of its material and application costs, which ranges from $26.44 to $71.39 in the pre-bloom/bloom period and from $25.51 to $84.22 during the post-bloom period.

Table 8: Representative Products and Costs Per Acre: Almond, December to March

Active ingredient	Representative product	Material cost ($)	Application cost ($)	Total cost ($)
abamectin	Abba Ultra Miticide/Insecticide	7.29	25.00	32.29
acetamiprid	Assail 30 SG Insecticide	31.15	25.01	56.16
bifenthrin	Bifenture EC Agricultural Insecticide	7.78	25.78	33.56
buprofezin	Centaur WDG Insect Growth Regulator	19.42	25.07	44.49
carbaryl	Sevin Brand XLR Plus Carbaryl Insecticide	1.44	25.00	26.44
clothianidin*	Belay Insecticide	14.53	25.04	39.57
esfenvalerate	Asana XL	7.52	24.97	32.49
imidacloprid*	Wrangler Insecticide	2.80	27.18	29.97
lambda-cyhalothrin	Warrior II	7.47	25.08	32.55
Pyriproxyfen**	Seize 35 WP Insect Growth Regulator	46.36	25.03	71.39

*Target NGN

** Ant bait is excluded because ants are not targeted by NGNs. Esteem Ant Bait (prodno = 45394), the only bait used on almond during the study period, is omitted.

Table 9. Representative Products and Costs Per Acre: Almond, April to November

Active ingredient	Representative product	Material cost ($)	Application cost ($)	Total cost ($)
abamectin	Abba Ultra Miticide/Insecticide	6.31	24.96	31.27
acetamiprid	Assail 30 SG Insecticide	34.84	25.06	56.90
bifenthrin	Bifenture EC Agricultural Insecticide	8.18	25.29	33.48
buprofezin	Centaur WDG Insect Growth Regulator	20.96	25.00	45.96
carbaryl	Sevin Brand XLR Plus Carbaryl Insecticide	29.33	25.70	55.02
clothianidin	Belay Insecticide	14.21	25.00	39.21
esfenvalerate	Asana XL	7.12	24.95	32.08
imidacloprid*	Wrangler Insecticide	4.57	20.94	25.51
lambda-cyhalothrin	Warrior II	7.33	25.11	32.44
pyriproxyfen**	Seize 35 WP Insect Growth Regulator	59.22	25.00	84.22

*Target NGN

** Ant bait is excluded because ants are not targeted by NGNs. Esteem Ant Bait (PUR product number = 45394), the only bait used on almond during the study period, is omitted.

Table 10 shows the average acreage shares for each non-NGN alternative used on almond. In January through March, both clothianidin and imidacloprid are cancelled (largely consistent with current use patterns), while for the rest of the year only imidacloprid is cancelled. Averaged over the three-year period (2015–2017) when NGNs were available, clothianidin and imidacloprid were used on 2.0% of total almond acres treated with insecticides.

Table 10: Average Annual Acreage Shares of Alternative Insecticides with and without Target Nitroguanidine Substituted Neonicotinoids (NGNs): Almond, 2015–2017

Active ingredient	**Target NGNs available (%)**	**Target NGNs cancelled (%)**	
	Annual	**Jan to Mar**	**Apr to Nov**
abamectin	48.7	49.7	48.8
acetamiprid	0.8	0.8	0.8
bifenthrin	23.9	24.4	23.9
buprofezin	0.5	0.5	0.5
carbaryl	0.06	0.06	0.06
clothianidin*	-	-	1.8
esfenvalerate	10.8	11.1	10.9
lambda-cyhalothrin	12.0	12.3	12.1
pyriproxyfen**	1.3	1.3	1.3
Total	98.0	100	100

*Post-bloom use only

**Ant bait is excluded because ants are not targeted by NGNs

NOTE: Totals do not sum to 100 due to rounding

In order to evaluate economic impacts of cancellation and partial cancellation of these two NGNs, the use of alternative AIs is scaled up in proportion to their acreage shares, as discussed in the methods section. The main alternative insecticides for almond were abamectin and bifenthrin, together accounting for 72.5% of total almond acres treated with insecticides, or 78.7% of acres treated with non-NGN insecticides.

Table 11: Costs Per Acre for Target Nitroguanidine Substituted Neonicotinoids and the Composite Alternative: Almond

Active ingredient	Material cost ($)	Application cost ($)	Total cost ($)	Cost increase for switching (%)
----Jan to Mar----				
clothianidin	14.53	25.04	39.57	-15.5
imidacloprid	2.80	27.18	29.97	11.5
composite alternative	8.24	25.19	33.43	-
---Apr to Nov---				
imidacloprid	4.57	20.94	25.51	22.0
composite alternative	8.10	25.06	33.16	-

Table 11 shows the average per acre costs for clothianidin and imidacloprid in the pre-bloom/bloom period and imidacloprid only in the post-bloom period, and the cost of the composite alternative in each of these periods. For almond in the pre-bloom/bloom period, switching to the alternatives would lead to an 11.5% increase in cost on acres using imidacloprid and a 15.6% decrease in cost on acres using clothianidin. In the post-bloom period, switching to the alternative would lead to a 22.0% increase in cost on acres using imidacloprid.

Table 12. Change in Treatment Cost due to Cancellation of Target Nitroguanidine Substituted Neonicotinoids (NGNs): Almond, 2015–2017

Year	Cost with target NGNs ($)	Cost without target NGNs ($)	Change in cost ($)	Change in cost (%)	Change in material cost (%)	Change in application cost (%)
2015	442,829	471,805	28,977	6.5	-15.3	115.3
2016	248,068	274,131	26,064	10.5	104.2	-4.2
2017	69,832	79,327	9,495	13.6	27.3	72.7

Table 12 reports the projected changes in total cost due to the cancellation of clothianidin and imidacloprid in the pre-bloom/bloom period and imidacloprid in the post-bloom period ranging from a total statewide change in cost of $9,495 in 2017 to $28,977 in 2015. Depending on the year, the increase in treatment costs for acres treated with NGNs is 6.5% to 13.6%. The final two columns disaggregate the percent change in costs into the percent due to the change in material costs and the percent due to the change in application costs. The contribution of material and application costs varies from year to year, depending on the relative acreage of imidacloprid and clothianidin. The absolute value of the costs is small because very few almond acres are treated with NGNs. Across the three-year study period, NGNs were only applied to 2.0% of almond acres.

Conclusions

The anticipated change in costs to almond from the restrictions on NGNs is small, both as a dollar value and as a percentage increase. This is due to the off-setting effects of the change in treatment costs for some alternatives and the relatively small acreage treated with NGNs.

Cherry

California is the second largest producer of sweet cherry in the US, behind only Washington. There were 33,000 bearing acres of sweet cherry in 2017, which produced 97,800 tons worth over $330 million (CDFA, 2018a). Out of the 95,000 tons of utilized production, 86,600 tons (91.2%) were sold in the fresh market at an average price of $3,750 per ton. The remainder were processed at an average price of $717 per ton. By export value, cherry was the 18th most important agricultural product in California. $160 million of production was exported in 2017, nearly half the total value of California cherry production. California's exports accounted for 24.3% of total cherry U.S. export value. Cherry are grown throughout the Central Valley, with some orchards scattered in the foothills. Cherry production is concentrated in San Joaquin County, which produced over $185 million in cherry: 42.2% of state production, in 2017. The next most important cherry-producing counties were Kern (22.8% of production value), Fresno (10.6%), Kings (6.4%), and Stanislaus (6.1%). Cherry was also a top ten agricultural commodity by value in 2017 for Contra Costa ($6 million) and Santa Clara ($11 million) counties. Figure 4 maps the distribution of California's 2017 cherry production.

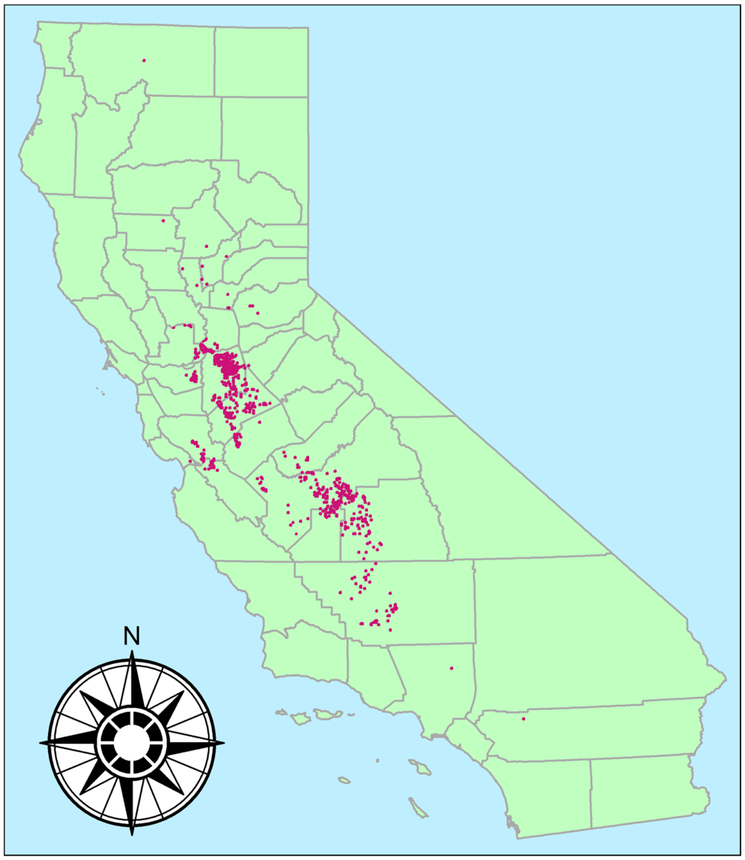

Figure 4. California cherry production: 2017

IPM Overview

Cherry in California is attacked by a variety of insects, diseases, and nematodes. All four NGNs are registered in cherry; however, only imidacloprid and thiamethoxam are regularly used and only imidacloprid and clothianidin are considered high risk. Imidacloprid and thiamethoxam are used against black cherry aphid (*Myzus cerasi*), cherry leafhopper (*Fieberiella florii*) and mountain leafhopper (*Colladonus montanus*). Clothianidin and dinotefuran are registered in cherry, but very little clothianidin is used and dinotefuran is not used at all.

Target Pests

Black cherry aphid (*Myzus cerasi*).

Black cherry aphid overwinter as eggs within the orchard and can have multiple generations in the spring, leading to high populations. Severe infestations can cause leaf curling, which can be more severe in young trees. In the summer, black cherry aphid numbers drop substantially in cherry as they migrate to mustard weeds. There are a number of effective alternative insecticides for black cherry aphid: acetamiprid, beta-cyfluthrin, chlorpyrifos[3], diazinon (delayed dormant treatment or in season), esfenvalerate, flupyradifuone, lambda-cyhalothrin, and thiamethoxam. Sulfoxaflor is not currently registered in cherry but could be in the future at which point it would be an alternative for controlling black cherry aphid. A suite of natural enemies may keep the aphids below damaging levels. Conservation of natural enemy habitat and limiting the use of disruptive insecticides may help maintain the natural enemy complex. Acetamiprid, beta-cyfluthrin, chlorpyrifos, esfenvalerate, and lambda-cyhalothrin are quite damaging to natural enemies of black cherry aphid, disrupting biological control. Diazinon is as effective but is a water contaminate of high concern in California.

Leafhoppers.

Cherry and mountain leafhoppers are vectors for X-disease, also known as cherry buckskin, that can result in tree death. Cherry leafhopper prefers to feed on cherry. Adults are dark brown, mimicking cherry buds, and are active mid-April to May, July, and September-October. Cherry leafhopper overwinter as eggs in the orchard or on nearby ornamental trees. Thiamethoxam is a viable alternative to imidacloprid. Additionally, cherry leafhopper can be effectively controlled with a diazinon or esfenvalerate as delayed dormant treatment or in-season applications. Fenpropathrin and lambda-cyhalothrin are effective in-season but disrupt natural enemies, as does esfenvalerate (Van Steenwyk et al., 1993; Van Steenwyk and Freeman, 1987). Acetamiprid is effective (Grant and Van Steenwyk 2000). Mountain leafhopper is also brown as an adult but has a distinctive yellow head on the upper thorax. It overwinters in vegetation or herbaceous crops near orchards. Cherry is not a preferred host of this leafhopper, however, it will feed on trees and thereby spread X-disease. It needs to be controlled in-season, which can be done with pyrethroids (beta-cyfluthrin, fenpropathrin, esfenvalerate, lambda-cyhalothrin), acetamiprid, or diazinon. Pyrethroids are disruptive to natural enemies and could cause mite outbreaks that will then need to be treated (Van Steenwyk and Freeman, 1987).

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[3] DPR has initiated the process leading to the ban of chlorpyrifos. On August 14, 2019, DPR sent notices to registrants to cancel chlorpyrifos product registrations (https://www.cdpr.ca.gov/docs/pressrls/2019/081419.htm). The economic analysis assumes it will not be available as an alternative.

Additionally, in-season application of pyrethroids, acetamiprid, and diazinon can disrupt control of black cherry aphid. As noted above, there are water quality concerns with diazinon.

Other Considerations: Resistance Management

In the absence of imidacloprid, pest populations may develop resistance to pyrethroids. A major pest in cherry is spotted winged drosophila (SWD). While imidacloprid are not directly used for SWD control, there is overlap in the alternatives for aphids and leafhoppers that is important to address. Pyrethroids are an important component of SWD management. Many of the alternatives to NGNs for black cherry aphid and leafhoppers are pyrethroids (beta-cyfluthrin, esfenvalerate, fenpropathrin, lambda-cyhalothrin, etc.), as noted above. Given the availability of imidacloprid for managing aphids and leafhoppers, growers and pest control adviser have moved away from using pyrethroids for these pests, even though they can be slightly more effective than the NGNs, in order to minimize the risk of developing pest populations that are resistant to pyrethroids. The greater the use, the more risk of resistance. There are three imidacloprid alternatives for leafhoppers in cherry that are not pyrethroids: thiamethoxam, acetamiprid, and diazinon. Black cherry aphids have several more alternatives as discussed above.

Target NGN Use: 2015-2017

Imidacloprid is the most heavily used NGN in cherry, followed by thiamethoxam. Clothianidin is rarely used. Figure 5 plots NGN use by month for 2015-2017. Only imidacloprid and clothianidin are considered high risk.

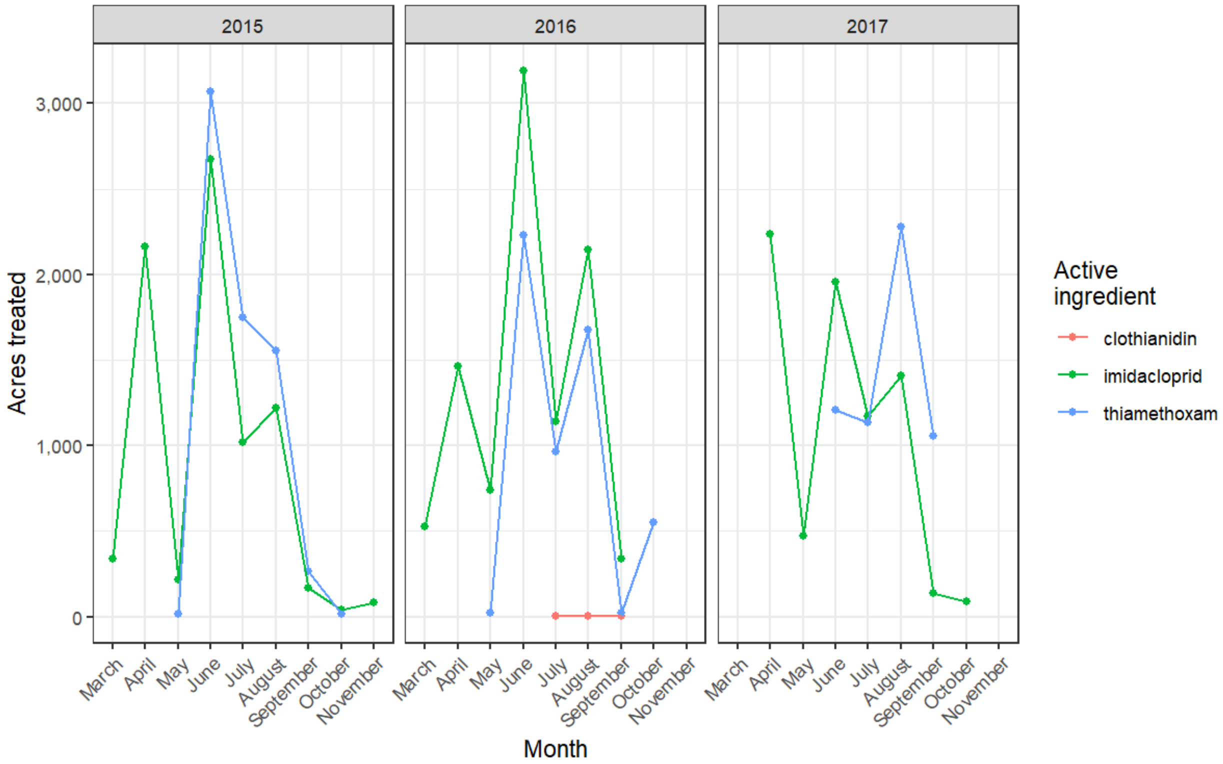

Figure 5: Monthly use of target nitroguanidine substituted neonicotinoids: cherry, 2015-2017

In March through May, imidacloprid and thiamethoxam are mainly applied against aphids. After May, they are mainly applied against leafhoppers.

Table 13 reports annual use of NGNs and alternative active ingredients for the 2015-2017 period based on pounds applied and acres treated. It also includes the average use rate of each AI per acre, calculated by dividing total pounds applied over the three-year period by the total number of acres treated. By acres treated, lambda-cyhalothrin was the most used AI, with over three times as many acres treated as the second most used AI, fenpropathrin. The two NGNs used extensively in cherry had the third and fourth most acres treated.

Table 13. Annual Use of Target Nitroguanidine Substituted Neonicotinoids and Alternative Active Ingredients: Cherry, 2015-2017

Active ingredient	**---------Pounds applied---------**				**--------------Acres treated--------------**				**Use rate (lbs/ac)**
	2015	2016	2017	Total	2015	2016	2017	Total	
acetamiprid	68	40	37	145	630	325	297	1,251	0.12
beta-cyfluthrin	13	3	1	18	591	148	81	821	0.02
clothianidin*	0	1	0	1	0	12	0	12	0.10
diazinon	1,439	1,453	594	3,485	1,067	855	425	2,347	1.49
esfenvalerate	141	114	137	392	2,602	2,259	2,273	7,133	0.05
fenpropathrin	3,901	3,374	4,624	11,899	12,332	10,544	14,435	37,310	0.32
imidacloprid*	850	1,069	909	2,828	7,921	9,549	7,478	24,948	0.11
lambda-cyhalothrin	1,499	1,497	1,553	4,549	37,596	36,811	39,318	113,725	0.04
thiamethoxam	532	432	468	1,432	6,672	5,471	5,679	17,823	0.08

*Target NGN

Economic Analysis

This section presents the estimated change in costs to cherry due to the cancellation of the two high risk NGNs: clothianidin and imidacloprid. This cost includes the change in pesticide material costs and application method costs. No yield decline is anticipated due to the use of alternatives. In the absence of any anticipated effect on yields, gross revenues will not change, so the change in treatment costs determines the effect on net returns. In addition to the caveats discussed in the methods section, the costs estimated below do not account for the potential effects of increased insect resistance to pyrethroids discussed above.

Table 14: Representative Products and Costs Per Acre: Cherry

Active ingredient	Representative product	Material cost ($)	Application cost ($)	Total cost ($)
acetamiprid	Assail 30 SG Insecticide	30.62	25.05	55.67
beta-cyfluthrin	Baythroid XL	9.63	25.00	34.63
clothianidin	Belay Insecticide	14.73	25.00	39.73
diazinon	Diazinon 50W	25.66	25.00	50.66
esfenvalerate	Asana XL	6.36	24.96	31.32
fenpropathrin	Danitol 2.4 EC Spray	28.03	25.00	53.03
imidacloprid	Admire Pro	10.24	23.27	33.51
lambda-cyhalothrin	Warrior II	8.18	25.02	33.21
thiamethoxam	Platinum 75SG	20.57	25.00	45.57

Table 14 presents representative products for each active ingredient used on cherry 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 application cost per acre is the average application cost based on application method across all applications of the AI to the crop. Most applications on cherry are ground spraying, so the variation in application cost is minimal. The total cost per acre, ranges from $31.21 to $55.67 per acre. Growers consider other factors in addition to price per acre when deciding which insecticides to use, as discussed above.

Table 15. Average Annual Acreage Shares of Alternative Insecticides with and without Target Nitroguanidine Substituted Neonicotinoids (NGNs): Cherry, 2015–2017

Active ingredient	Target NGNs available (%)	Target NGNs cancelled (%)
acetamiprid	0.6	0.7
beta-cyfluthrin	0.4	0.5
diazinon	1.1	1.3
esfenvalerate	3.5	4.0
fenpropathrin	18.2	20.7
lambda-cyhalothrin	55.4	63.0
thiamethoxam	8.7	9.9
Total	87.9	100

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

Table 15 shows the average acreage shares for each alternative AI used on cherry, with and without clothianidin and imidacloprid being available. Averaged over the three-year period 2015–2017 when the NGNs were available, the target NGNs were used on 12.1% of total cherry acres treated with insecticides and alternative AIs were used on 87.9% of cherry acreage treated with insecticides.

If the two target NGNs were cancelled, 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 lambda-cyhalothrin and fenpropathrin, together accounting for 73.6% of total cherry acres treated with insecticides, which is 83.7% of acres treated without the target NGNs.

Table 16: Costs Per Acre for Target Nitroguanidine Substituted Neonicotinoids and the Composite Alternative: Cherry

Active ingredient	Material cost ($)	Application cost ($)	Total cost ($)	Cost increase for switching to composite alternative (%)
clothianidin	14.73	25.00	39.73	-2.24
imidacloprid	10.24	23.27	33.51	15.91
composite alternative	13.83	25.01	38.84	-

Table 16 shows the per acre costs for the two target NGNs as well as the cost of the composite alternative, whose price we use as a representative pesticide cost if the NGNs were cancelled. For cherry, switching to the alternative would lead to an increase in both material cost and application cost for imidacloprid. Material cost to clothianidin users will decrease when switching to composite alternative while the application cost is essentially unchanged. Imidacloprid users will incur a total per acre cost increase of 15.9% while clothianidin users will incur a 2.2% cost decrease.

Table 17. Change in Treatment Costs due to Cancellation of Target Nitroguanidine Substituted Neonicotinoids (NGNs): Cherry, 2015–2017

Year	Cost with target NGNs ($)	Cost without target NGNs ($)	Change in cost ($)	Change in cost (%)	Change in material cost (%)	Change in application cost (%)
2015	265,390	307,652	42,263	35.0	67.2	32.8
2016	320,434	371,376	50,942	34.9	67.2	32.8
2017	250,560	290,461	39,901	35.0	67.2	32.8

Table 17 reports the calculated change in costs due to the cancellation of clothianidin and imidacloprid. The final two columns of Table 17 disaggregate the percent change in cost into the percent due to the change in material cost and the percent due to the change in application cost. The increase in total cost ranges from 34.9% in 2016 to an increase of 35.0% in 2015 and 2017. The absolute value of this cost increase ranges from $39,901 in 2017 to $50,942 in 2016.

Almost all of this cost increase is due to the increase in cost on acres treated with imidacloprid. Though clothianidin is a high risk NGN for cherry, it was only used on 12 acres in 2016 and not at all in 2015 and 2017.

Conclusions and Critical Uses

In the case of cherry, the total cost of managing target pests is calculated to increase by approximately one third, but the magnitude of the total change in net returns is likely to be small.

As in other crops, the impact on the development of resistance is a consideration 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. In cherry, an additional complication to this fundamental biological process is that resistance is a concern for a pest not managed with NGNs directly. Unlike the target pests considered here, spotted winged drosophila (SWD) can result in substantial yield losses, reducing gross revenues significantly (Walsh et al. 2011). Using NGNs for other pests allows growers to save other products for use against SWD.

Citrus

Citrus—specifically grapefruit, lemon, orange, mandarin, and their hybrids—are one of California's top ten most economically important crops. In 2017, California produced 3.9 million tons of citrus from 267,400 acres, generating $2.2 billion in gross receipts. California is the largest producer and exporter of lemon, orange, and mandarin, and the second largest producer of grapefruit, in the US. California accounted for 51% of national citrus acreage and 66% of national value (CDFA, 2018).[4] Export products related to citrus production had gross receipts of $979 million, ranking as California's sixth largest agricultural export commodity by value. California exported $677 million of orange (63.9% total U.S. exports), $219 million of lemon (91%), $49 million of mandarin (88.4%), and $34 million of grapefruit (29%).

Table 18. California Citrus Production Acreage and Value: 2016-2017 Crop Year

Citrus crop	**Acreage (bearing)**	**Production value ($1,000)**
Grapefruit, All	9,400	83,647
Lemon	47,000	717,746
Orange, All	152,000	888,331
Mandarin (and Hybrids)	59,000	532,038
Total Citrus Fruit	267,400	2,221,762

Source: CDFA (2018).

Note: The acreage values reported here from CDFA (2018) differ from the values reported in the 2018 California Citrus Acreage Report. As noted by USDA NASS in the latter report, the surveyed acreage values may differ due to data collection reasons, particularly because participation in acreage surveys is voluntary.

Table 18 reports acreage and production value for California citrus fruits in the 2016-2017 crop year. For grapefruit, 176,000 tons were produced on 9,400 bearing acres, for a per acre yield of 18.7 tons and gross revenues of $84 million. For lemon, 820,000 tons were produced on 47,000 bearing acres, for a per acre yield of 17.4 tons and gross revenues of $718 million. For orange, 1.9 million tons were produced on 152,000 bearing acres, for a per acre yield of 12.7 tons and gross revenues of $888 million. Just under 20% of California orange acreage is planted to Valencia, the majority are navel. For mandarin and mandarin hybrids (including tangelo, tangerine and tangor), 940,000 tons were produced on 59,000 bearing acres, for a per acre yield of 16.1 tons and gross revenues of $532 million.

There are four major citrus production regions in California: the San Joaquin Valley, Coastal, Inland Southern California, and the Desert (Figure 6). While most regions grow all cultivars of citrus, the environmental conditions in each region favor some cultivars over others. For example, the cool climate of the coast allows lemon to produce multiple crops, the desert heat

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[4] Bearing acreage for citrus fruit reported throughout this section are based on values from CDFA (2018). Note that these values differ slightly from those reported in the 2018 California Citrus Acreage Report from USDA NASS. See note to Table 18 for more information.

provides the best conditions for grapefruit, and the San Joaquin Valley's cold winters favor orange and mandarin.

Figure 6. California citrus production and growing regions: 2017

Since 2006, the acreage planted to mandarin has increased significantly in the San Joaquin Valley (by more than 50,000 acres) and the coastal areas of California, while orange plantings (primarily Valencia) have declined somewhat (Figure 7). Other regions and cultivars have remained relatively stable. The increased acreage in citrus classified as mandarin, including satsuma, clementine, mandarin and their hybrids, is due to the popularity of easy peeling fruit with consumers.

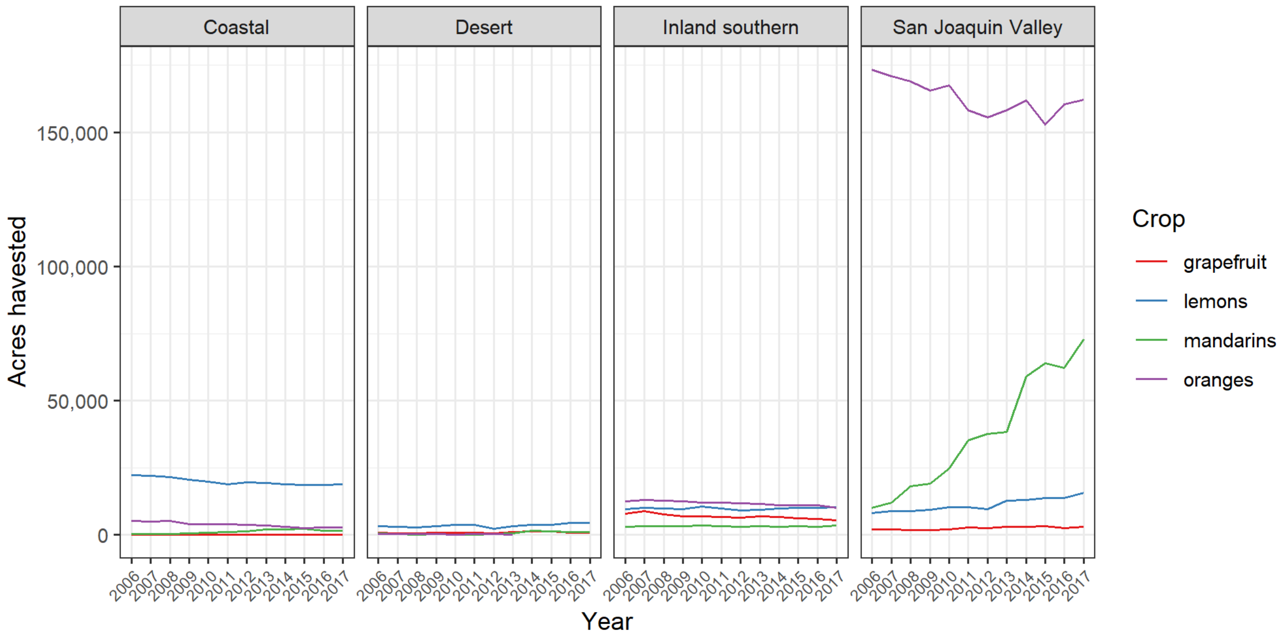

Figure 7. Acres planted to orange, mandarin, lemon and grapefruit by region, 2006-2017

Figure 8 and Figure 9 report exports by destination country and value for California orange and lemon, respectively. The top five export countries for orange are South Korea, Canada, Japan, Hong Kong and China. The top five export countries for lemon are Japan, Canada, South Korea, Australia and Hong Kong.

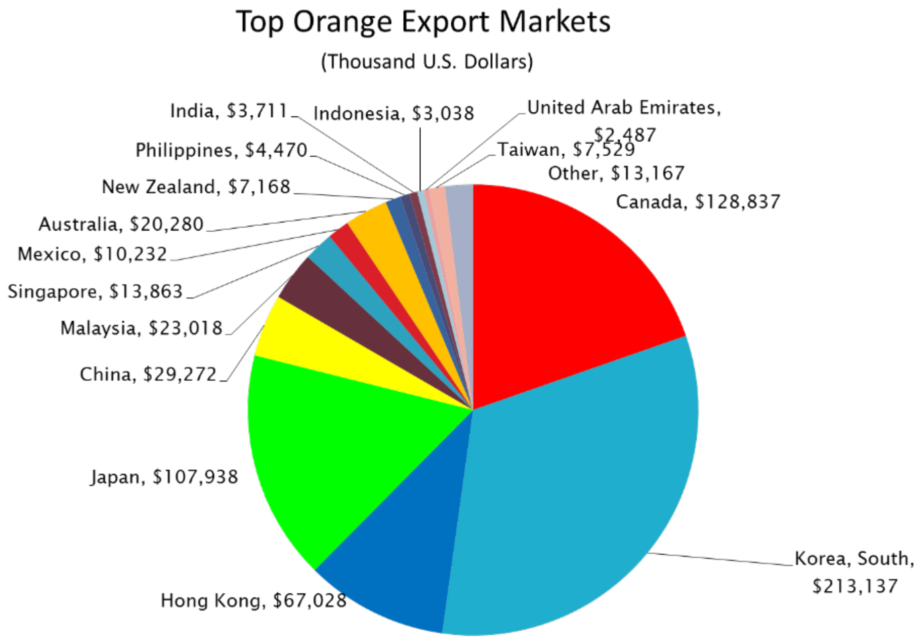

Figure 8. Top export markets: orange, 2017

Source: https://ccqc.org/

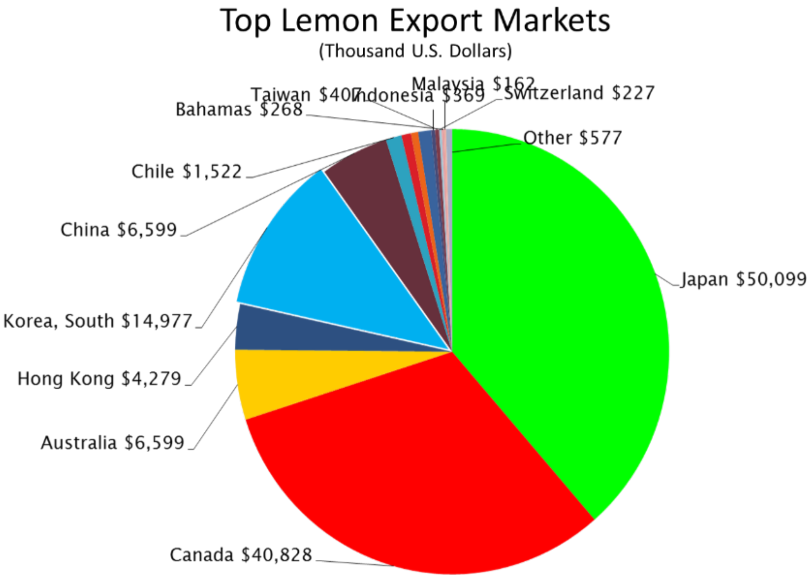

Figure 9. Top export markets: lemon, 2017

Source: https://ccqc.org/

Not all of the importing countries have fully established Maximum Residue Levels (MRLs) or the levels that are established are below the US tolerances established. If fruit is treated near harvest, growers will not use an insecticide that has a lower or unestablished MRL because they run the risk of the fruit being rejected if that level is exceeded. This is one of the driving forces behind choice of insecticides and influences which alternatives can be used. Growers targeting a specific export market will take its MRLs into account.

IPM Overview

NGNs are used in citrus to manage glassy-winged sharpshooter, citricola scale, citrus leafminer, export quarantine pests such as Fuller rose beetle, and invasive pests such as Asian citrus psyllid. They are also used to treat nursery citrus plants before shipping and citrus orchards prior to harvest in order to combat the geographic spread of insect pests. Two NGNs are registered in California citrus: imidacloprid and thiamethoxam. Thiamethoxam was determined to be low risk to bees and imidacloprid was determined to be high risk (Troiano et al. 2018). As such, only imidacloprid is considered as a potentially regulated AI in this analysis.

Within the four growing regions, the combination of cultivar and environment results in different pest complexes that require different management tactics. 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 infesting lemon and broad mite infesting all varieties of citrus. 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 in the southern region, where treatments were traditionally infrequent. It has also initiated eradicative treatments in other regions of the state. Asian citrus psyllid is the vector of huanglongbing (HLB), a devastating, incurable bacterial disease of citrus that has reduced Florida citrus production by 50% and is threatening the California citrus industry. Imidacloprid is used for multiple reasons for ACP control: 1) it is used as a systemic where eradication of the pest is occurring as it is the most long-lasting and effective control agent for nymphs that are tucked inside foliage and protected from foliar sprays, 2) it is used as a systemic by nurseries to provide long-term protection of nursery stock going to retail nurseries, and 3) as a foliar, it is used as part of the spray and move program to disinfest orchards of ACP prior to harvest so that ACP is not moved in bulk citrus. In addition to ACP, imidacloprid is used in citrus for glassy-winged sharpshooter, citricola scale, citrus leafminer, and the Fuller rose beetle.

Imidacloprid is unique as a systemic insecticide because it persists in the plant for three or more months at a level that controls key pests such as citrus leafminer, Asian citrus psyllid, and citricola scale. Its systemic activity is safer for natural enemies than foliar formulations of neonicotinoids or pyrethroids. The persistence reduces the number of other insecticides that need to be applied. It has well-established MRLs and a short pre-harvest interval making it convenient to use. It is relatively inexpensive.

Target Pests

Glassy-winged sharpshooter (*Homalodisca vitripennis*). Glassy-winged sharpshooter (GWSS) overwinters in citrus, emerges in spring, and can spread Pierce's Disease in neighboring grape vineyards. Federal funds are provided to reimburse citrus growers for pesticides applied to reduce glassy-winged sharpshooter in citrus in some regions of the state. An average of 6,000 acres of citrus per year were treated in Kern County (10% of county citrus acreage) between 2001 and 2016, generally during the months of March through July. There have been occasional treatments in Tulare County as well. In the early years of the program, treatments were applied in early spring to reduce the overwintering GWSS adults and again later in the season to control hatching GWSS nymphs (Castle et al. 2005). The treatments were highly effective for many years, however, some populations of GWSS have begun to develop resistance to imidacloprid (Andreason et al. 2018) and in response, the treatment program is replacing imidacloprid with alternative insecticides. Because of resistance problems in GWSS, the periodic appearance of ACP in Kern County, and data by Byrne and Morse (2012) showing that uptake of imidacloprid is best after bloom when there is root activity, growers who use imidacloprid for GWSS have recently changed the timing of application to summer (thereby avoiding impacts on bees). The alternative treatments for GWSS are other foliar neonicotinoids such as acetamiprid and thiamethoxam (an NGN considered low risk in citrus), beta cyfluthrin, fenpropathrin and flupyradifurone. The neonicotinoids, butenolides and pyrethroids are the most effective insecticides for controlling this pest (Grafton-Cardwell et al. 2003).

Citricola scale (*Coccus pseudomagnolarium).* Citricola scale is a serious citrus pest in the San Joaquin Valley. Heavy infestations reduce vigor, kill twigs, and reduce fruit set. Additionally, honeydew excreted from the scales causes sooty mold to grow on fruit causing fruit to be downgraded in the packinghouse, reducing revenues. Citricola scale is not controlled by natural enemies in the San Joaquin Valley because it has only one generation per year and there are long periods of time when it is in a stage unsuitable for parasitism. Thus, citricola scale is a driver of broad-spectrum pesticide use in San Joaquin Valley citrus, and imidacloprid is an effective and common treatment applied during July-September (Grafton-Cardwell and Reagan 2008). The alternatives to imidacloprid are foliar treatments of acetamiprid, thiamethoxam, buprofezin, and carbaryl. Narrow range oil is available for organic use but is not regularly used on its own in conventional groves. Buprofezin, carbaryl and narrow range oil are significantly less effective in controlling citricola scale compared to the neonicotinoids (Grafton-Cardwell and Scott 2011; Grafton-Cardwell and Reger 2019). Foliar formulations of neonicotinoids are most commonly used for this pest. For citricola scale, uses are primarily July-September, after citrus bloom has ended, avoiding effects on bees.

Citrus leafminer (*Phyllocnistis citrella*). Citrus leafminer attacks all citrus types, tunneling along the surface of new leaves and reducing their photosynthetic capability. Citrus leafminer is mainly a pest of young trees and causes damage by stunting growth. Imidacloprid is one of the most effective tools for reducing citrus leafminer populations because it is translocated to new tissues (the target of citrus leafminer oviposition and tunneling) over many months (Sétamou et al. 2010). The alternative AIs are systemic thiamethoxam and cyantraniliprole and foliar abamectin, chlorantraniliprole, cyantraniliprole, methoxyfenozide, acetamiprid, and diflubenzuron. Narrow range oil is available for organic use but is not regularly used in conventional groves. Imidacloprid can have a longer residual than the foliar treatments (Sétamou et al. 2010). Treatment timing for nonbearing trees would be any time the trees are producing new leaf flush from March-October.

Fuller rose beetle (*Naupactus godmani*). Fuller rose beetle does not cause economic damage in California citrus, however South Korea currently considers it a phytosanitary risk because it has not been found in that country. FRB prefers to deposit its eggs in cracks and crevices and the tight space under the calyx of navels is a preferred oviposition site. South Korea is a major export market for California citrus. In years past, if FRB eggs were found on fruit, the load was treated with methyl bromide at its destination. However, with the reduction in uses of methyl bromide worldwide, the expectation is that citrus growers in California will conduct preharvest treatments to eliminate FRB. Imidacloprid is one of several tools that can be used to reduce FRB larvae in the soil. There is currently a seven-point plan in place that requires growers wishing to export to South Korea to treat twice with FRB effective materials during the season, with the second application relatively close to harvest. Alternative active ingredients include foliar applied beta-cyfluthrin, carbaryl, cryolite, thiamethoxam, and cyantraniliprole and soil applied bifenthrin. MRLs are not established for cryolite and the MRL for carbaryl is significantly lower than the US tolerance. Bifenthrin is difficult to use because it is not registered for citrus fruit and so must growers be very careful when applying it to the ground to avoid contact with the fruit. Growers can apply a sticky product to the trunk of trees to help with this pest, but this is extremely labor intensive and hard to maintain. Imidacloprid is a key product for FRB control because it is also effective against citricola scale and one treatment will control both pests.

Asian Citrus Psyllid (*Diaphorina citri*). Asian citrus psyllid (ACP) is currently the most serious pest of citrus because it is the vector of *Candidatus* liberibacter asiaticus the bacterium thought to be responsible for huanglongbing (HLB) or citrus greening. There is currently no cure for HLB and so the primary method to prevent disease spread is psyllid control. The most important, critical use of imidacloprid, is to control ACP and so reduce the spread of HLB. There are quite a number of alternative insecticides that have efficacy against ACP; beta-cyfluthrin, fenpropathrin, dimethoate, carbaryl, cyantraniliprole, diflubenzuron, fenpyroximate, flupyradifurone spinetoram, spirotetramat, thiamethoxam, and zeta-cypermethrin. However, none of these insecticides have the residual life combined with the anti-feedant qualities of imidacloprid so necessary to prevent transmission of disease (Serikawa et al. 2012; Qureshi et al. 2014; Miranda et al. 2016; Langdon and Rogers 2017; Tofangsazi and Grafton-Cardwell 2018). It is difficult to reach young nymphs and eggs inside folded young leaves with foliar insecticides. Systemic imidacloprid can provide 3 months of protection, whereas other products last only 2-4 weeks. Other systemic neonicotinoids (dinotefuran and thiamethoxam) do not provide the same length of protection. Local eradication of ACP has been achieved through the use of systemic imidacloprid in combination with a foliar pyrethroid in both commercial and residential areas of the San Joaquin Valley. Either product alone would not have the same effect because the foliar provides knockdown and surface protection against re-infestation but may not reach the young stages that are protected by leaves. The systemic imidacloprid protects the new flush and reaches the youngest instars when they begin to feed. The nymphs are critical to control because they are the stage that acquires the bacteria and when they molt and fly away, they take the bacteria with them. The anti-feedant quality of the product blocks transmission of the bacterium by psyllid feeding and no other product has the same level of effect. Thus, imidacloprid is a critically needed tool for managing the spread of this devastating disease.

In addition to specific pests, imidacloprid is used for spraying orchards to disinfest them of ACP prior to the fruit being harvested and moved.[5] The alternatives for this spray and move program including cyfluthrin, beta cyfluthrin, fenpropathrin, zeta cypermethrin, and thiamethoxam. The difficulty is that there are seasonal limits for each of these insecticides, lemon are often sized picked gradually over time, and the treatments have to be applied within 14 days of harvest. Growers can run out of insecticides to apply if they harvest an orchard frequently. The alternative programs are to wash or mechanically disinfest fruit after harvest, but these methods can be damaging to the fruit. Systemic imidacloprid is also used by citrus nurseries as a protectant prior to shipping to prevent spread of psyllids and prevent establishment of psyllids in retail nurseries (Byrne et al. 2016, 2017), however, nurseries are not considered in this analysis.

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[5] http://phpps.cdfa.ca.gov/PE/InteriorExclusion/pdf/acpgrowerinformation.pdf

Target NGN Use: 2015-2017

A total of 54,937 pounds of imidacloprid was used on 122,144 acres of citrus during 2017. The region of greatest use was the San Joaquin Valley. The majority of applications were made to orange and mandarin in the San Joaquin Valley and lemon in Ventura, Riverside and Imperial counties.

Table 19: Annual Use of Target Nitroguanidine Substituted Neonicotinoids and Alternative Active Ingredients: Citrus, 2015-2017

Active ingredient (AI)	**-------Lbs of AI applied-------**				**------------Acres treated------------**				**Use rate (lbs/ac)**
	2015	2016	2017	Total	2015	2016	2017	Total	
(s)-cypermethrin	2,656	2,632	1,980	7,268	53,206	54,854	41,813	149,873	0.05
abamectin	3,393	5,253	4,506	13,152	151,574	161,911	167,378	480,864	0.03
acetamiprid	4,401	3,534	4,200	12,135	23,261	19,424	23,617	66,302	0.18
beta-cyfluthrin	2,835	3,762	3,912	10,509	75,784	97,475	106,095	279,354	0.04
bifenthrin	1,564	3,084	3,434	8,082	3,773	8,193	9,071	21,037	0.38
buprofezin	12,247	18,423	45,041	75,711	6,288	9,023	22,663	37,974	1.99
carbaryl	37,826	127,755	20,913	186,494	4,133	11,800	2,545	18,478	10.09
chlorantraniliprole	2,561	2,092	2,056	6,709	25,165	25,749	23,962	74,876	0.09
cyantraniliprole	3,649	3,313	2,392	9,354	27,586	21,444	19,557	68,588	0.14
cyfluthrin	1,902	1,392	1,115	4,409	34,490	25,814	18,930	79,234	0.06
diflubenzuron	5,847	5,239	8,355	19,441	26,711	28,677	46,029	101,416	0.19
dimethoate	6,392	4,457	6,834	17,683	6,810	5,185	7,928	19,923	0.89
fenpropathrin	20,433	17,420	15,043	52,896	57,741	51,604	42,333	151,678	0.35
flupyradifurone	34	557	1,025	1,616	200.75	3,369	6,435	10,004	0.16
imidacloprid	50,886	55,353	54,754	160,993	113,234	123,628	119,495	356,357	0.45
malathion	13,508	12,722	13,666	39,896	5,133	7,153	7,887	20,173	1.98
spinetoram	14,418	14,914	14,999	44,331	169,073	180,169	173,815	523,056	0.08
spinosad	2,067	2,130	2,590	6,787	19,232	19,544	22,850	61,625	0.11
spirotetramat	20,900	21,143	22,600	64,643	136,231	137,422	147,971	421,623	0.10
thiamethoxam	11,485	13,337	14,583	39,405	129,527	160,623	174,824	464,973	0.08
(s)-cypermethrin	2,656	2,632	1,980	7,268	53,206	54,854	41,813	149,873	0.05

Timing of imidacloprid applications. Examining the years 2010, 2013 and 2017, the timing of the use of imidacloprid has changed, shifting from an early season emphasis (March-June) to a summer emphasis (May to September) as shown in **Error! Reference source not found.**. In the early years imidacloprid was used primarily for GWSS control and to encourage vigorous spring growth. Over time, GWSS developed resistance to imidacloprid and efficacy declined for that pest over 20 years of use. Later, imidacloprid became increasingly used for citricola scale in the summer months. In 2012, Byrne and Morse demonstrated that significant uptake of imidacloprid into the tree does not occur until June when the roots become active. Additional studies showed that a higher level of uptake is needed for phloem-feeding ACP control versus xylem-feeding GWSS and the shift in concern to ACP control affected grower preference for the timing of use (Byrne and Toscano 2007, Sétamou et al. 2010). Notably, these later treatments fully protect bees from the effects of imidacloprid applied to citrus (Byrne et al. 2014a, b, 2017).

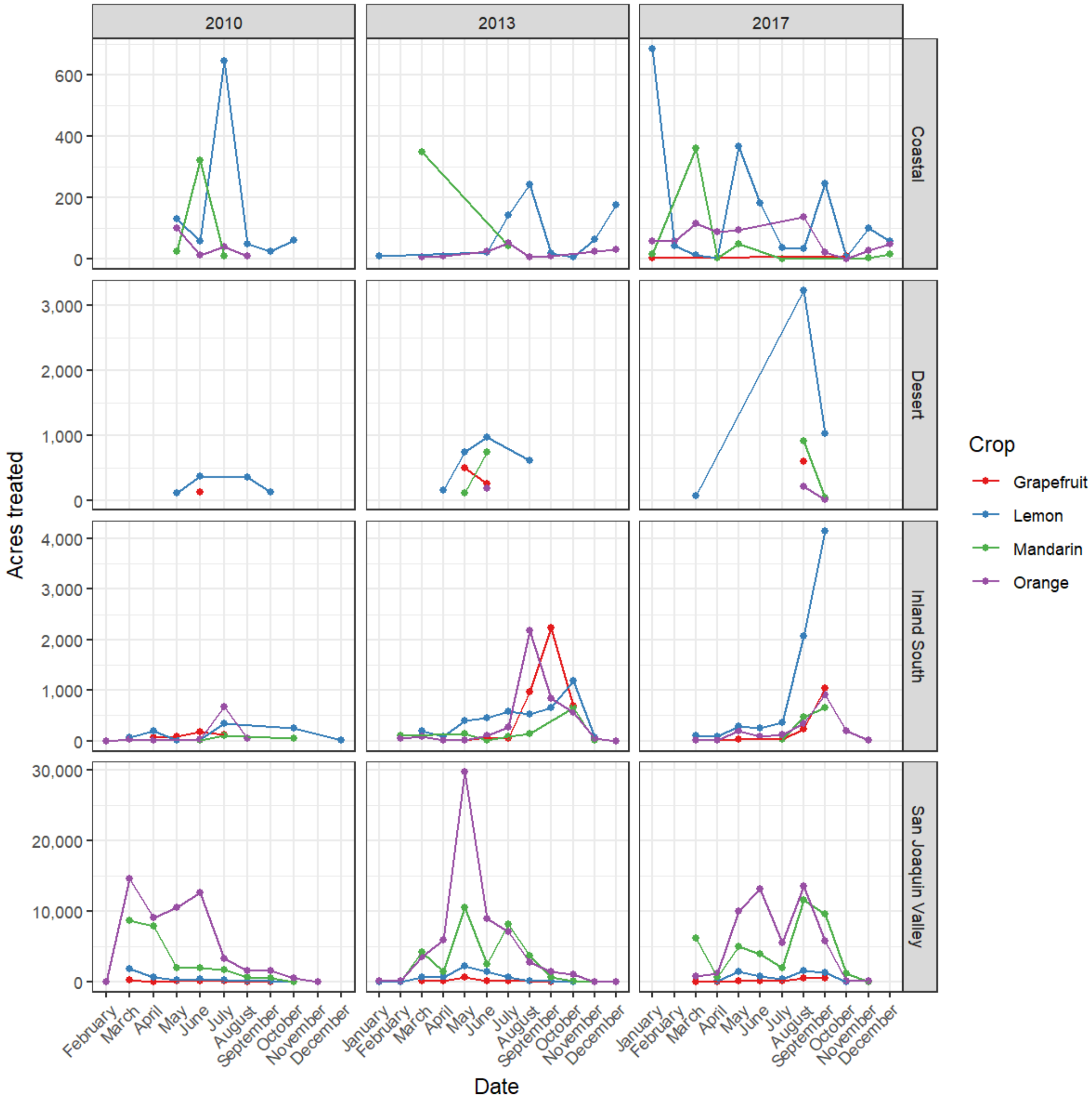

Figure 10. Imidacloprid use by month, region, and crop: acres treated, 2010, 2013 and 2017

San Joaquin Valley. The San Joaquin Valley (Stanislaus, Madera, Fresno, Tulare and Kern counties) is the largest growing region, planted with 81% of state citrus acreage. Within the San Joaquin Valley, 63.9% of citrus acreage is in orange and 28.7% is in mandarin. Imidacloprid was first introduced in California in 2001. Its use significantly increased during 2008-10, a few years after less-expensive, generic brands were introduced (Figure 11). Imidacloprid use since 2010 has fluctuated, ranging between 35,000-45,000 lbs per year on an average of 90,000-100,000 acres (Table 19). Most growers only treat once per year with the product because the systemic formulation is preferred over the foliar and there is a per season limit of 0.5 lb ai/acre, the maximum and typical single use rate when applied as a systemic to a mature citrus tree. A half rate (0.25 lb/acre) is used to control pests on trees less than 4 years old.

Early on, the majority of imidacloprid uses in the San Joaquin Valley were systemic applications for glassy-winged sharpshooter (GWSS) or citricola scale control, as well as for nematode suppression for improved citrus root health. Over time, GWSS has developed resistance to imidacloprid and its efficacy for managing this pest has declined. Citrus leafminer arrived in California in 2001 and spread throughout the state in the ensuing years and imidacloprid has been used extensively to protect nonbearing citrus (<5% of planted citrus) from leaf damage caused by citrus leafminer, citrus thrips and aphids.

Since 2016, imidacloprid use has increased in response to the periodic appearance of Asian citrus psyllid in the San Joaquin Valley. The suggested grower response to ACP detections in this region, where eradication efforts are underway, is a treatment with a foliar pyrethroid and systemic imidacloprid. These treatments are still low in number in this region, and so the increased use relative to use during 2010-2015 has changed only slightly. This treatment pattern will change significantly if ACP becomes more widely established in the San Joaquin Valley.

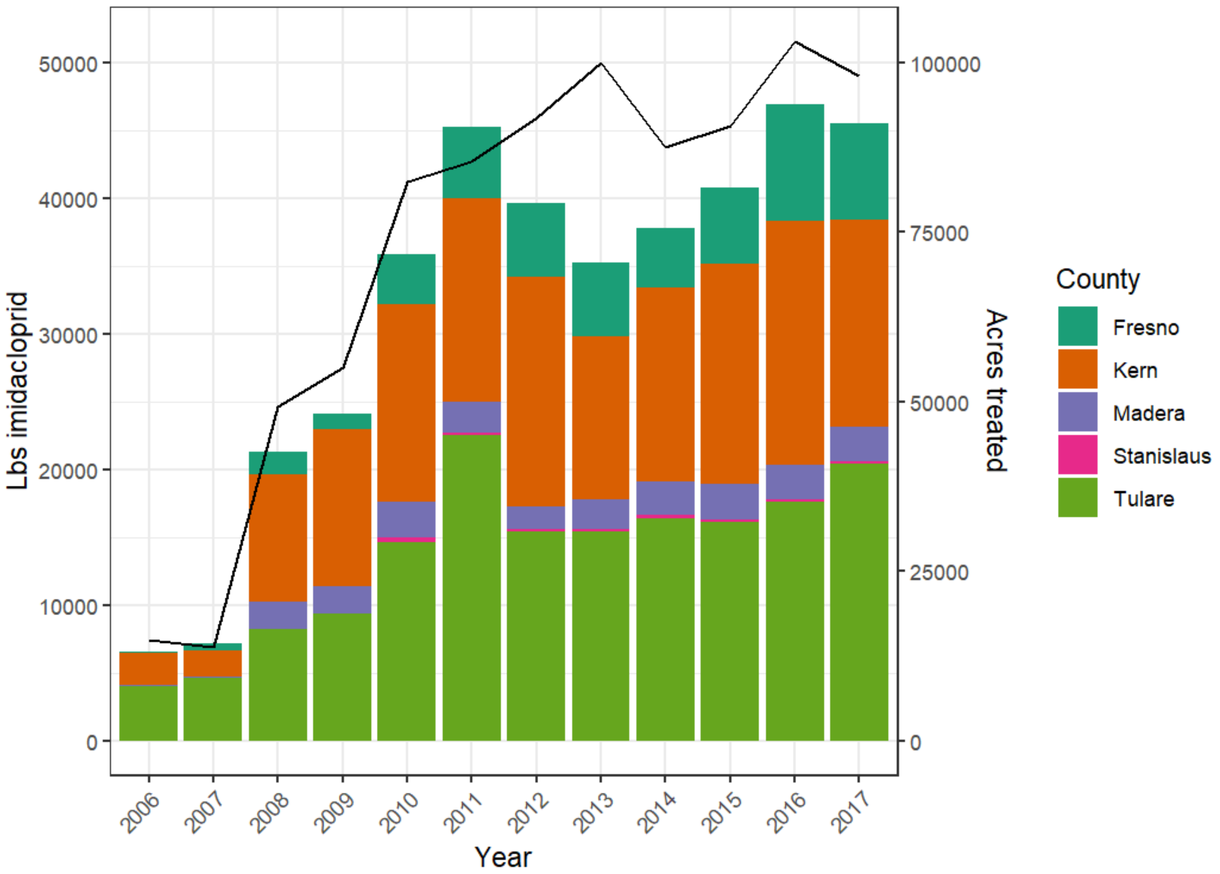

Figure 11: Pounds of imidacloprid used and acres treated in the San Joaquin Valley region

Coastal region. In the Coastal region (Ventura, Santa Barbara, San Luis Obispo and Monterey), the heavy soils and steep hillsides do not allow effective use of systemic imidacloprid in many areas. In 2006, federal funds were provided to growers to treat for GWSS with imidacloprid, and 6,000 lbs of imidacloprid were applied on 12,000 acres of citrus (Figure 12). Since that time, imidacloprid use has been applied to less than 2,000 acres and most uses of imidacloprid have been as foliar treatments in response to ACP eradication efforts (2012-2016) and preharvest treatments to move bulk citrus. There is no seasonal pattern in the use of imidacloprid. This is because bulk citrus treatments are applied to the orchard within 14 days of harvest and lemon harvest can occur at nearly any time of year.

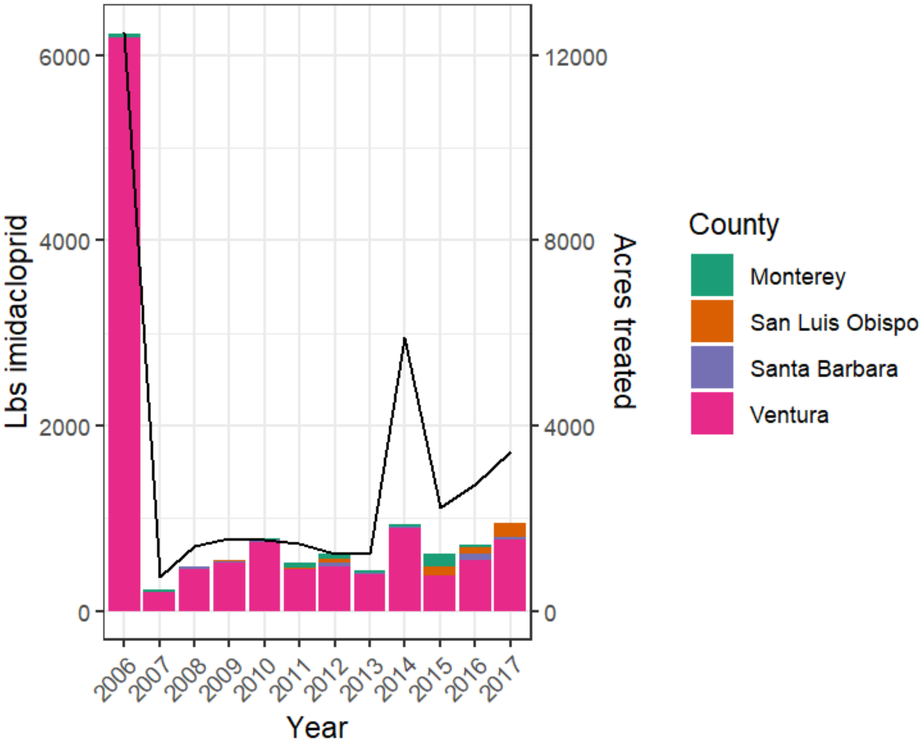

Figure 12: Imidacloprid use on citrus in the Coastal region by county: pounds applied and acres treated, 2006-2017

Desert region. In the Desert region (Imperial County and the Coachella Valley in Riverside County), uses of imidacloprid are almost exclusively for either citrus leafminer on young trees or part of the areawide program to reduce Asian citrus psyllid since 2012, increasing uses from 500 lbs ai/year to 3000 lbs ai/year (Figure 13). The Imperial and the Coachella Pest Control Districts coordinate the growers to treat during August and September (Figure 13) with systemic imidacloprid and a winter (December-January) treatment of a pyrethroid. Asian citrus psyllid densities have dropped to nearly undetectable levels in commercial citrus because of this program. In contrast, psyllids can still be found in untreated residential areas. The combination of very effective insecticides and the high heat of these valleys that hardens foliage and limits egg laying by the psyllids is key to keeping HLB out of this region. There are alternatives to imidacloprid, principally systemic thiamethoxam; however, they are not as persistent or effective as imidacloprid.

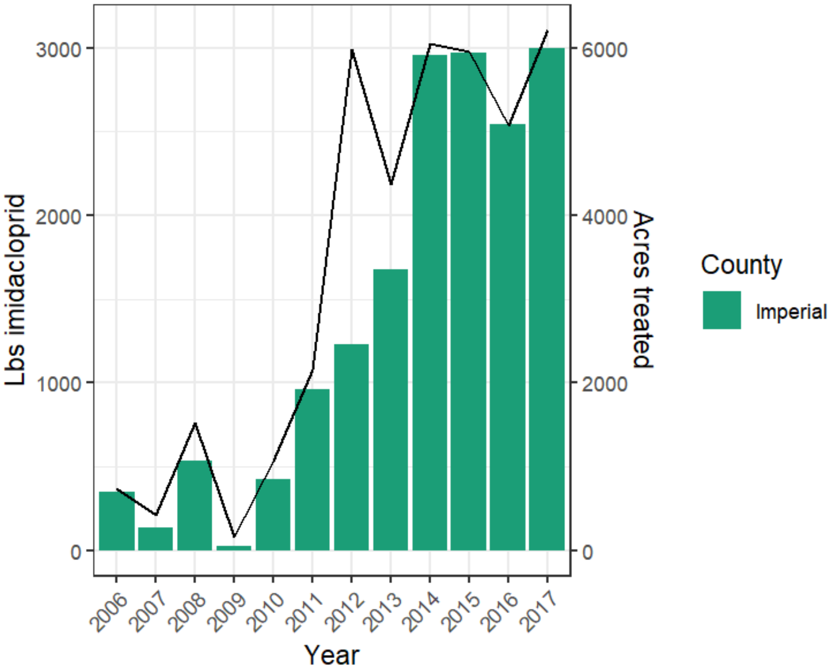

Figure 13: Imidacloprid use in the Desert region: pounds applied and acres treated, 2006-2017

Inland southern California. In the Inland southern California region (San Diego, central Riverside, San Bernardino), uses of imidacloprid were very limited until the Asian citrus psyllid appeared and established and treatments increased from <1000 lbs ai/year to >5000 lbs ai/year (Figure 14). Imidacloprid treatments are applied primarily during July-September for areawide management of Asian citrus psyllid.

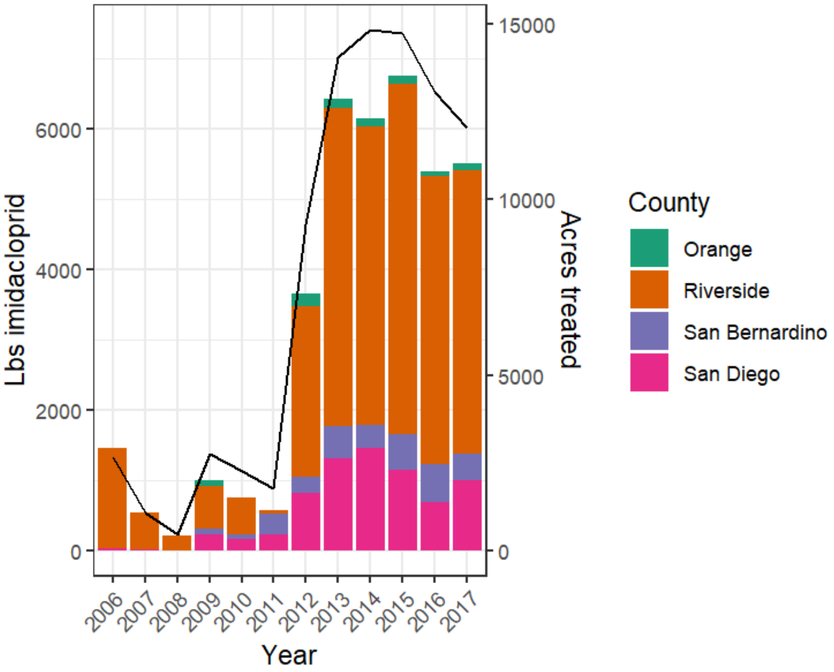

Figure 14: Imidacloprid use in the Inland Southern California region by county: pounds applied and acres treated, 2006-2017

Economic Analysis

This section presents the estimated change in net returns for citrus fruits arising from the cancellation of imidacloprid. The change in net returns is determined by changes in material costs and application costs of replacing imidacloprid because there are no anticipated yield (and associated gross revenue) effects.

Table 20: Representative Product Cost per Acre: Citrus

Active ingredient	**Representative product**	**Material cost ($)**	**Application cost ($)**	**Total cost ($)**
(s)-cypermethrin	Mustang	4.78	25.25	30.03
abamectin	Agri-Mek SC Miticide/Insecticide	17.01	25.02	42.02
acetamiprid	Assail 70WP Insecticide	64.34	24.96	89.30
beta-cyfluthrin	Baythroid XL	16.40	25.05	41.45
bifenthrin	Brigade WSB Insecticide/Miticide	96.74	25.00	121.74
buprofezin	Centaur WDG Insect Growth Regulator	74.05	25.00	99.05
carbaryl	Sevin Brand XLR Plus Carbaryl Insecticide	150.93	25.00	175.93
chlorantraniliprole	Altacor	43.47	24.92	68.39
cyantraniliprole	Exirel	99.58	24.94	124.52
cyfluthrin	Tombstone Helios Insecticide	7.61	25.07	32.68
diflubenzuron	Micromite 80WGS	57.97	25.01	82.99
dimethoate	Drexel Dimethoate 4EC	10.54	24.94	35.48
fenpropathrin	Danitol 2.4 EC Spray	30.65	25.32	55.98
flupyradifurone	Sivanto 200 SL	44.98	25.02	70.00
Imidacloprid*	Admire Pro	27.42	11.92	39.34
malathion	Malathion 8 Aquamul	12.08	25.00	37.08
spinetoram	Delegate WG	57.39	25.03	82.43
spinosad	Success	32.88	24.99	57.87
spirotetramat	Movento	87.18	24.98	112.16
thiamethoxam**	Actara	21.70	24.39	46.08

*Target NGN

**NGN under consideration for cancellation in other crops; low risk in citrus

This section presents the estimated change in net returns for citrus fruits arising from the cancellation of imidacloprid. The change in net returns is determined by changes in material costs and application costs of replacing imidacloprid because there are no anticipated yield (and associated gross revenue) effects.

Table 20 reports the representative products for each active ingredient used on citrus from 2015 to 2017 and the average cost per acre. The average use rate is computed by dividing total pounds applied over the three-year period by the total acres treated. The pesticide material cost is obtained by multiplying the average use rate by the price per pound of active ingredient, which is calculated based on the product formulation and product price. Application costs are calculated based on the different application methods mentioned previously. Including material and application costs, the cost per acre varies significantly for the different AIs, ranging from \$30.03 for (s)-cypermethrin to \$175.93 for carbaryl. Growers consider a wide variety of factors beyond cost per acre in determining which AI to use, as discussed above.

Table 21: Average Annual Acreage Shares of Alternative Insecticides with and without Target Active Nitroguanidine Substituted Neonicotinoids (NGNs): Citrus, 2015–2017

Active ingredient	Acreage share with target NGNs available (%)	Acreage share without target NGNs available (%)
(s)-cypermethrin	4.4	4.9
abamectin	14.1	15.8
acetamiprid	1.9	2.2
beta-cyfluthrin	8.2	9.2
bifenthrin	0.6	0.7
buprofezin	1.1	1.2
carbaryl	0.5	0.6
chlorantraniliprole	2.2	2.5
cyantraniliprole	2.0	2.2
cyfluthrin	2.3	2.6
diflubenzuron	3.0	3.3
dimethoate	0.6	0.7
fenpropathrin	4.5	5.0
flupyradifurone	0.3	0.3
malathion	0.6	0.7
spinetoram	15.4	17.1
spinosad	1.8	2.0
spirotetramat	12.4	13.8
thiamethoxam	13.6	15.2
Total	89.5	100

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

Table 21 provides the acreage shares for the alternatives used on citrus from 2015 to 2017. The second column reports the acreage share treated with each alternative active ingredient when imidacloprid is available. On average, 10.5% of citrus acreage was treated with imidacloprid each year. The third column reports rescaled acreage shares if imidacloprid were unavailable. The four most applied alternative AIs are spinetoram, abamectin, thiamethoxam (also under consideration for cancellation in other crops) and spirotetramat, which together are projected to have an acreage share of 61.9% of treated acreage when imidacloprid is not available. Note total acreage of citrus treated with insecticides may not correspond to total citrus acreage because some orchards may receive multiple insecticide applications.

Table 22: Costs Per Acre for Target Nitroguanidine Substituted Neonicotinoids and the Composite Alternative

Active ingredient	Material cost ($)	Application cost ($)	Total cost ($)	Cost increase of switching to composite alternative (%)
imidacloprid	27.42	11.91	39.33	68.70
composite alternative	41.42	24.94	66.37	-

Table 22 reports the average per acre costs for imidacloprid as well as the cost of the composite alternative. For citrus, switching to the alternative would lead to an increase in both material cost and application cost. Total cost per acre would rise by 68.7% on acreage that had been treated with imidacloprid. On average, the cost per acre increases by $27.04.

Table 23. Change in Treatment Costs due to Cancellation of Target Nitroguanidine Substituted Neonicotinoids (NGNs): Citrus, 2015–2017

Year	Cost with target active ingredients ($)	Cost without target active ingredients ($)	Change in cost ($)	Change in cost (%)	Change in material cost (%)	Change in application cost (%)
2015	4,453,763	7,514,774	3,061,010	68.7	51.8	48.2
2016	4,862,578	8,204,561	3,341,983	68.7	51.8	48.2
2017	4,700,045	7,930,322	3,230,277	68.7	51.8	48.2

Table 23 summarizes the annual change in total pesticide costs owing to cancellation of imidacloprid for each of the three base years. Depending on the acres treated with imidacloprid, the total increase in costs would have been $3.06 million to $3.34 million. Across, all years, changes in material cost (51.8%) and application cost (48.2%) contribute almost evenly to the overall increase.

Conclusions

There is a substantial percentage cost increase on acreage that must be treated with alternatives if imidacloprid is cancelled in citrus. However, the increase is small in absolute value on a per acre basis. Important considerations regarding the use of imidacloprid in citrus are outside the analytical approach used here. These factors indicate that costs to the citrus industry could potentially be much larger.

Citrus is vulnerable to endemic and invasive pest species, and imidacloprid is especially useful because it is broad spectrum, effective, and relatively compatible with current pest management strategies in most citrus regions. It is especially important in vector-pathogen situations such as with the Asian citrus psyllid because it reaches the young instars in the new foliage, it has a long residual and it has anti-feedant qualities that help prevent disease transmission. These properties make it especially useful in CDFA's control efforts in both commercial and home citrus. It is one of only two tools available for the residential treatments (beta-cyfluthrin and imidacloprid). It is used heavily in the HLB quarantine areas where treatments of residential and commercial citrus are mandatory. Growers have other insecticide choices for ACP, but it is by far the most effective and cost effective control agent. Without imidacloprid, it is likely that HLB will spread at a much faster rate in the state, putting into jeopardy the $2 billion/year citrus industry.

Cotton

The vast majority of cotton in California is grown in the San Joaquin Valley, although there is some grown in the southeast region (low desert, Palo Verde and Imperial Valleys) and in the Sacramento Valley. Two species of cotton are produced in California: Acala/Upland (*Gossypium hirsutum*) and Pima (*G. barbadense*). Pima is a premium, extra-long staple cotton with longer fibers than upland cotton, and it commands a higher price.

Cotton generated over $475 million in gross receipts in 2017, a 40% increase from 2016. California is the third largest cotton producer by value in the US, accounting for 7.0% of gross national receipts. California exported $377 million in cotton: 8.2% of total US export value in 2017 (CDFA, 2018A). Roughly three in every four bales of cotton produced in California were exported. Although cotton was only the 18th most valuable agricultural commodity in the state, it was the 11th most important agricultural commodity for export.

Cotton 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. Of the 304,000 acres planted to cotton in 2017, 216,000 acres (71.1%) were planted to American-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. Pima cotton was the second most important agricultural commodity in Kings County. Growing regions are defined in Table 4.

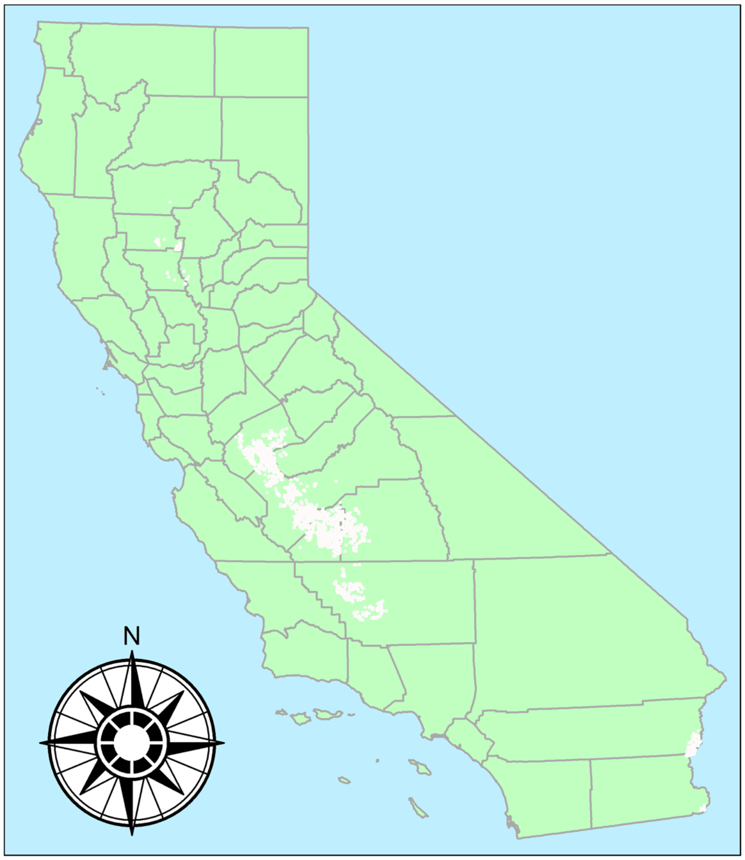

Figure 15. California cotton production: 2017

IPM Overview

In cotton production, a flower bud is called a square and the fruit is called a boll. Cotton lint is the fiber inside the boll. When the bolls dry and mature, they split open, exposing the lint. Pima cotton has a longer growing season and is more susceptible to damage than upland cotton by pests late in the season.

Cotton grown in California faces damage by a number of insect and mite pests, many of which can reach population levels that require treatment with pesticides to prevent economic damage. These pests can reduce yields directly by causing damage to squares and bolls and also indirectly via stand loss, leaf feeding, or feeding on the vascular system, which reduces the plant's productivity. Aphids and whiteflies can also cause substantial losses in marketable yield and economic returns via effects on lint quality by contaminating exposed cotton lint with sugars from the honeydew they excrete (Godfrey et al. 2000). Lint covered in honeydew is not marketable.

Lygus, aphids, whiteflies, and mites are the key pests in cotton requiring management. Other potential pests include thrips, which can be early-season pests that damage seedlings, although they are typically only a problem under cool, spring conditions. Various caterpillar species can be intermittent pests (through both leaf and square feeding and boll feeding), although one of the most important caterpillar pests historically, pink bollworm, has been eliminated through an intensive area-wide management program. Stink bugs can also be pests by attacking buds, flowers, and bolls. This includes native stink bugs as well as the invasive (in California) brown stink bug.

Cotton is used to make fabrics and quality is thus very important, both for individual growers and for entire regions. Minimizing contamination of exposed lint by honeydew from aphids or whiteflies, or so-called "sticky cotton," is a key concern for cotton growers and ginners in California. Sticky cotton causes problems in roller gins, necessitating special handling. If sticky cotton makes it to the textile mill, processing efficiency and product quality is diminished, and shutdown of the mill is a possibility. The issue can have region-wide and long-lasting consequences because a reputation of sticky cotton from a given region can negatively impact sales and prices for multiple years, and textile mills can blacklist growing regions over sticky cotton. California has thus far maintained a reputation for producing clean, high-quality cotton.

Cotton has a long history of using the integrated pest management (IPM) approach for insects, starting in the 1950s. Cotton was one of the first crops University of California IPM chose to promote in the 1970s. Pest managers in cotton currently use IPM methods at both the field and landscape levels (e.g., growers coordinating lygus management in safflower to reduce pressure in cotton), although the extent and level of adoption of IPM practices can be variable, depending on individual growers and growing regions. California cotton production presents a unique IPM challenge because late-season infestations of both cotton aphid and whitefly can occur simultaneously, something not typically seen in other states, e.g., Arizona, which generally faces whiteflies but not aphids, or Texas, which faces aphids, but not whiteflies. Part of the challenge for California is that the three to four-week period immediately before harvest is the most important for managing these pests because this is the time at which the lint is in danger of being contaminated, but this is a time window when insecticides do not work as well and pre-harvest intervals can limit options.

Lygus, cotton aphid, silverleaf whitefly, and spider mites are considered the key pests in California cotton. Management of pests is interconnected, and with multiple pests often present throughout the season, growers may have to address more than one pest simultaneously. In addition, damage done to the natural enemy community by insecticide applications for one pest may create problems with a different pest that had been controlled by natural enemies or that could have been controlled by natural enemies later in the season. Use of broad-spectrum organophosphate, pyrethroid, and carbamate materials can contribute to outbreaks of spider mites, aphids, whiteflies, and caterpillar pests.

All four NGNs evaluated in this study are registered and used in cotton, although the frequency of use varies by active ingredient, owing to differences in efficacy and label restrictions. NGNs are used to target sucking insect pests, so they are relevant for the primary pests of lygus, cotton aphid, and silverleaf whitefly. Of the four active ingredients, imidacloprid is the only one available under a number of different trade names and as a component of premixes. It is also the most likely to be tank-mixed with other insecticides. Across the state, imidacloprid is applied to substantially more acres compared to the other NGNs.

How insecticides (including NGNs) are applied varies and is affected by how the cotton crop is grown. Recently, some cotton growers have started to shift away from furrow irrigation towards drip irrigation (and in their crop rotation as a whole). The share of cotton acreage using drip irrigation varies by region due to differences in water availability. For the state as a whole it is currently estimated by UCCE experts to be around 20% of acreage. Unlike furrow irrigation, drip irrigation allows chemigation, e.g., application of insecticides through the drip line.

In addition, drip irrigation can influence how foliar insecticides are applied, although it is not the sole factor affecting this choice. Foliar applications by air are common, especially for fields using furrow irrigation owing to logistical constraints associated with ground applications. Aerial applications make it more difficult to achieve good coverage within a large cotton canopy and on the undersides of leaves where whiteflies and aphids reside. With drip irrigation, ground applications, which improve coverage and insecticide efficacy (especially mid- to late-season), are more feasible, although ground applications with full plant canopy can be challenging.

Target Pests

Lygus bug (*Lygus hesperus).* Lygus is a perennial problem and usually the most important arthropod pest in the main cotton growing region in California, the San Joaquin Valley, and in other regions as well. Lygus uses over 100 plant species as hosts, including many crop species, and is a highly mobile pest as an adult.

In cotton, lygus injury is primarily from feeding on squares, which causes plants to respond to damage with abscission of the squares. Lygus can also damage young bolls and affect quality. Plants are most susceptible to damage to small squares in the early season, but lygus can cause damage from early square formation (May) through early open boll stages (August). Lygus is a key pest because of the damage it causes and because insecticides targeting lygus can knock out natural enemy communities that are critical for controlling other pest species over the course of the growing season. Since lygus is often targeted for management early on, this sets the stage for economically significant infestations of other pests over the course of the season, especially if broad-spectrum foliar sprays are used. The decision to treat for lygus is based on a combination of lygus densities, whether or not reproduction is occurring (presence of nymphs), and crop characteristics, particularly square retention and how far off square retention is from what is considered normal for a given plant stage.

Lygus infestations can also delay fruit and boll set, an important determinant of yield potential and harvest timing. If many squares are lost, plants may put more resources into vegetative growth, producing tall plants with few bolls. Damage and the accompanying loss of fruiting positions and bolls can extend the season. Extending the season is problematic from an agronomic standpoint, although it is possible with cotton as compared to other crops. Extended seasons and later harvests may necessitate additional irrigation, which increases costs and may not be possible depending on water availability. An extended season also can complicate defoliation because cooler weather requires higher rates of defoliants or multiple applications. Ineffective defoliation leads to leaf trash in the harvested cotton, which reduces quality. Extended seasons also prevent completion of groundwork before winter rains. An extended season also extends the period during which open bolls are susceptible to late-season aphid and whitefly issues.

Insecticides applied in cotton fields are the primary means of lygus management, but several other tactics are also employed. First, agronomic practices to produce a vigorous cotton plant, such as proper weed management, fertilization, and irrigation, can help minimize effects on yield by ensuring retention of squares is sufficient to achieve high yields. Second, management of lygus populations at the regional level has had some success. This has involved managing lygus in safflower, a preferred host, with a well-timed, region-wide insecticide application before they migrate into cotton. Host plant resistance (conventional breeding or transgenic) is not currently available.

NGNs are not the primary insecticides used for lygus but are still commonly used since they are softer on natural enemies than many alternative AIs. Lygus management is a balance between reducing lygus populations and averting secondary outbreaks of spider mites, aphids, and whiteflies. Since 2007, flonicamid has been the standard for lygus management in cotton, typically one to three applications, with other insecticides rotated in to varying degrees. It is a selective material that also controls cotton aphid and does not overly harm natural enemy populations. Sometimes a pyrethroid will be added to flonicamid for targeting lygus.

Imidacloprid is sometimes used to manage early-season (low-level) lygus populations, often in conjunction with early-season cotton aphids, although lygus are typically the pest of primary concern. Some of these applications are preventative. Imidacloprid typically suppresses lygus vs. controlling them, although it appears that some resistance is present. Imidacloprid will often be tank mixed with another material to improve efficacy and residual and/or control both adults and nymphs, e.g., bifenthrin or other pyrethroids, or dimethoate, or novaluron. A relatively common imidacloprid pre-mix is imidacloprid plus beta-cyfluthrin.

Clothianidin is also used to target lygus, although its use is restricted to early season. The additional issue with clothianidin is that there are rotational crop restrictions on the product label for multiple crops from immediately to 12 months after use. In practice, this means that clothianidin cannot be used on cotton when any of the crops on the plant-back restrictions list and are rotation for that field.

A number of other active ingredients are used for managing lygus. Pyrethroids (lambda-cyhalothrin, beta-cyfluthrin, bifenthrin, (s)-cypermethrin) can be used to manage lygus. Pyrethroids were relied on for lygus control in the 1990s and into the early 2000s but use of pyrethroids alone has declined owing to resistance problems. Today, they still provide good control and residual in some areas, though they are ineffective in other regions. Since pyrethroids do not conserve natural enemies, their use leads to outbreaks of aphids, spider mites, or whiteflies. Oxamyl is another broad-spectrum material that is used to target lygus, more often in the later part of the season, but it also does not conserve natural enemies leading to outbreaks of other pests. Dimethoate is occasionally used to target lygus, but it is broad spectrum. Acetamiprid (sometimes mixed with a pyrethroid) is sometimes used for lygus, but generally later in the season and often also targeting aphids or whiteflies. Indoxacarb can be used for lygus management, although it only provides suppression and is more of a backup material. In 2017 and 2018, another very effective and selective material, sulfoxaflor, has been used for lygus management. Though it was only available under a Section 18 emergency exemption in 2017 and 2018, the registration process is underway in California.

Cotton aphid (*Aphis gossypii*). Cotton aphid can be a nearly season-long pest in some areas and extremely important to manage, although management mid- to late-season is most critical. Aphids cancel plant nutrients, stunting plants and competing with developing plant square or bolls for resources. Infestations on seedling cotton and pre-reproductive cotton generally do not warrant treatment as plants can compensate for any injury and natural enemies often effectively reduce aphid populations. During the reproductive phases of squaring and boll-filling, aphid feeding cancels resources otherwise available to developing squares or bolls, which reduces yield. After bolls have opened and until harvest, aphids can contaminate exposed lint with honeydew. As previously discussed, sticky cotton and lint contamination is a severe problem, necessitating low action thresholds during the late-season. The amount of stickiness caused in lint is not easily quantifiable. The problem of sticky cotton can decrease lint prices over entire production regions or cause issues selling cotton from an entire region.

NGNs play a large role in current aphid management practices. Early-season aphids are often managed with imidacloprid, often in conjunction with lygus management. An early season application will depress aphid and lygus populations and prevent them from building. In the South East region, imidacloprid is sometimes used early as a preplant chemigated insecticide for aphid and fleahopper management. Imidacloprid is used around first bloom or post-bloom to manage aphids. Thiamethoxam is used from mid- to late-season for aphids. Clothianidin is used more for lygus than aphids, but it will incidentally manage aphid populations when used. There are non-NGN materials for aphid management. Flonicamid is effective on aphids and applications that target lygus during the reproductive phase of cotton will also manage aphids. Flonicamid can be used in the absence of lygus to target aphids. However, the reliance on flonicamid earlier in the season makes it less useful later in the season, owing to resistance issues.

Acetamiprid is frequently used for aphid (and whitefly) management throughout the season. Flupyradifurone is another alternative material with good activity against aphids, although its use has likely been hampered by price and lower efficacy with aerial applications later in the season. Additionally, it has a one-year plant-back restriction for safflower, which precludes its use in some areas. Naled sometimes will be used for mid/late season aphids.

There are alternative management practices that can help control aphids. Planting and harvesting as early as possible and avoiding late season irrigation can help; however, these practices are somewhat weather dependent and are not typically driven by aphid management. High rates of nitrogen fertilizer can lead to higher aphid and whitefly populations. Managing fertilizer can help manage aphids but can run counter to agronomic decisions aimed to create high yields. Natural enemies can control aphid populations earlier in the year, thus preventing outbreaks mid- to late-season. Conservation of natural enemies, i.e., avoiding the use of broad spectrum insecticides, is therefore important for avoiding aphid problems. Some upland cultivars are less susceptible to aphids (smooth-leaved varieties typically have fewer aphids than hairy-leaved ones), but this information is not always available to growers and cultivar choice is made based on agronomic considerations. In addition, much of the acreage has shifted to Pima, where less information is available.

Silverleaf whitefly (*Bemesia tabaci* biotype B). Silverleaf whitefly causes problems similar to cotton aphid. Both adults and nymphs are sucking pests, damaging plants by removing nutrients and reducing yields. They also generate honeydew and can contaminating lint later in the season. This pest has become more of an issue in recent years, showing up earlier and going through more generations in cotton. Populations tend to be highest near urban areas and the southern/eastern portions of the San Joaquin Valley. Fields near alternative hosts (such as melons) are also particularly at risk of late-season movement of whiteflies as alternative hosts decline. High rates of nitrogen fertilizer are conducive to whitefly population growth.

Similar to cotton aphids, insecticides are heavily relied upon for silverleaf whitefly management. Some cultivars are less susceptible, but variety choice is not driven by whitefly management and information on resistance to whiteflies is generally not available (see aphid section). At the landscape level, avoiding planting cotton by or downwind of known hosts (like melons) can help reduce whitefly pressure. Natural enemies can help regulate whitefly populations and generalist predators are key sources of mortality of whiteflies in cotton fields.

Though NGNs play a role in whitefly management, primarily for managing moderate whitefly pressure, insect growth regulators (IGRs) are the primary management tool. NGNs are mainly used when adult whitefly populations are moderate to high and/or there is greater pressure from immigrating adult whiteflies. Acetamiprid is an alternative to the NGNs to manage moderate to high whitefly populations.

The IGRs - buprofezin, pyriproxyfen, and spiromesifen - are good alternatives for low to moderate whitefly populations. They are ideally used to selectively target whiteflies and avoid broad-spectrum materials. IGRs are best suited for strategic use earlier in the season when whitefly populations are low and population growth can be disrupted. These compounds are very selective and help conserve natural enemies.

Owing to their selectivity, IGRs are not effective against cotton aphids. This is an important distinction because concurrent infestations of aphids and whiteflies can occur, especially mid- to late-season. One option that controls both pests is flupyradifurone. It is a newer material that is used for mid- to late-season infestations of whiteflies similarly to how it is used for aphids and with the same caveats. NGNs, acetamiprid, and flupyradifurone may be used if there is high pressure from immigrating adults earlier in the season, and then followed by IGRs after movement from overwintering sites has subsided.

To avoid harvesting sticky cotton, mid-season management of whiteflies is critical since late-season populations are difficult to control. Late season management often shifts to broad-spectrum materials to reduce populations of immigrating adults. Immigration events can be extremely rapid. Broad spectrum insecticide use is best avoided until late in the season because of the potential for inducing outbreaks of spider mites or aphids. The NGNs do not play a large role in managing late season aphids, and as such, this particular pest management issue is not part of this analysis.

Stink bugs. A variety of stink bugs attack cotton: Consperse stink bug (*Euschistus conspersus*), Say stink bug (*Chlorochroa sayi*), western brown stink bug (*Euschistus impictiventris*), and brown stink bug (*Euschistus servus*)**.** Generally, stink bugs are not abundant enough in cotton to warrant management. However, the brown stink bug is a new pest in California cotton, so far only in the southeast region, and there is the possibility that its damage could create boll rots. If there is a significant feeding and early weather development, then there is a possibility for damage.

Primary tools for managing stink bugs are broad spectrum, including acephate, (s)-cypermethrin, bifenthrin, or a pre-mix or tank mix of pyrethroids. Of the NGNs, clothianidin and dinotefuran are the most active on stink bugs and are sometimes combined with a pyrethroid (lambda-cyhalothrin, etc.) to improve efficacy. Dinotefuran is more applicable for cotton because of clothianidin label restriction.

Target NGN Use: 2015-2017

Statewide for 2015-2017, imidacloprid was the most-applied NGN for cotton by a substantial margin, followed by clothianidin, thiamethoxam, and then dinotefuran (Table 24). Among the alternatives to the NGNs, only flonicamid and acetamiprid were applied to more acres than imidacloprid: 1,024,959 and 499,964 acres, respectively. Flonicamid is used as part of a program for managing cotton aphid. It is primarily used for lygus but applications for lygus also control aphids. However, due to resistance considerations it cannot be used throughout the entire season. Acetamiprid can be used as part of a program for managing cotton aphid and silver leaf whitefly.

Table 24: Annual Use of Target Nitroguanidine Substituted Neonicotinoids 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	
(s)-cypermethrin	1,217	2,815	1,735	5,767	26,604	57,527	36,026	120,156	0.05
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	0.1
buprofezin	18,285	14,568	15,475	48,328	38,649	44,392	44,165	127,207	0.38
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
dinotefuran	592	1,019	1,232	2,843	5,554	9,130	12,285	26,969	0.11
flonicamid	23,404	27,106	39,702	90,212	262,422	304,963	457,574	1,024,959	0.09
flupyradifurone	5,651	8,051	10,242	23,943	32,387	48,801	64,065	145,254	0.16
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	0.1
lambda-cyhalothrin	1,794	1,627	3,449	6,870	48,217	44,166	97,469	189,852	0.04
naled	56,237	80,883	86,502	223,622	46,685	67,751	74,518	188,954	1.18
oxamyl	5,446	1,103	36,533	43,081	5,664	1,146	38,844	45,654	0.94
pyriproxyfen	2,080	1,411	1,155	4,645	31,228	21,461	17,493	70,183	0.07
spiromesifen	1,785	1,705	8,386	11,876	7,723	7,287	33,498	48,507	0.24
sulfoxaflor	NA	NA	10,745	10,745	NA	NA	155,256	155,256	0.07
thiamethoxam	1,782	1,485	3,084	6,352	28,677	23,798	51,734	104,209	0.06

The vast majority of cotton acres treated with NGNs are in the San Joaquin Valley, which is also where the majority of cotton is produced. All four NGNs under evaluation are used to some degree in the San Joaquin Valley at various points during cotton production. In the San Joaquin Valley, imidacloprid was the primary NGN applied to cotton, followed by clothianidin, thiamethoxam, and dinotefuran. In the Sacramento Valley, almost all the applications of NGNs in recent years were of imidacloprid. There is a similar pattern in the southeast region.

Use of imidacloprid is highest in June, followed by July (Figure 16). Clothianidin is the second most-used NGN in cotton on a treated acreage basis from 2015-2017, followed by thiamethoxam. Use of clothianidin drops off precipitously after June because the label restricts applications to the early season.

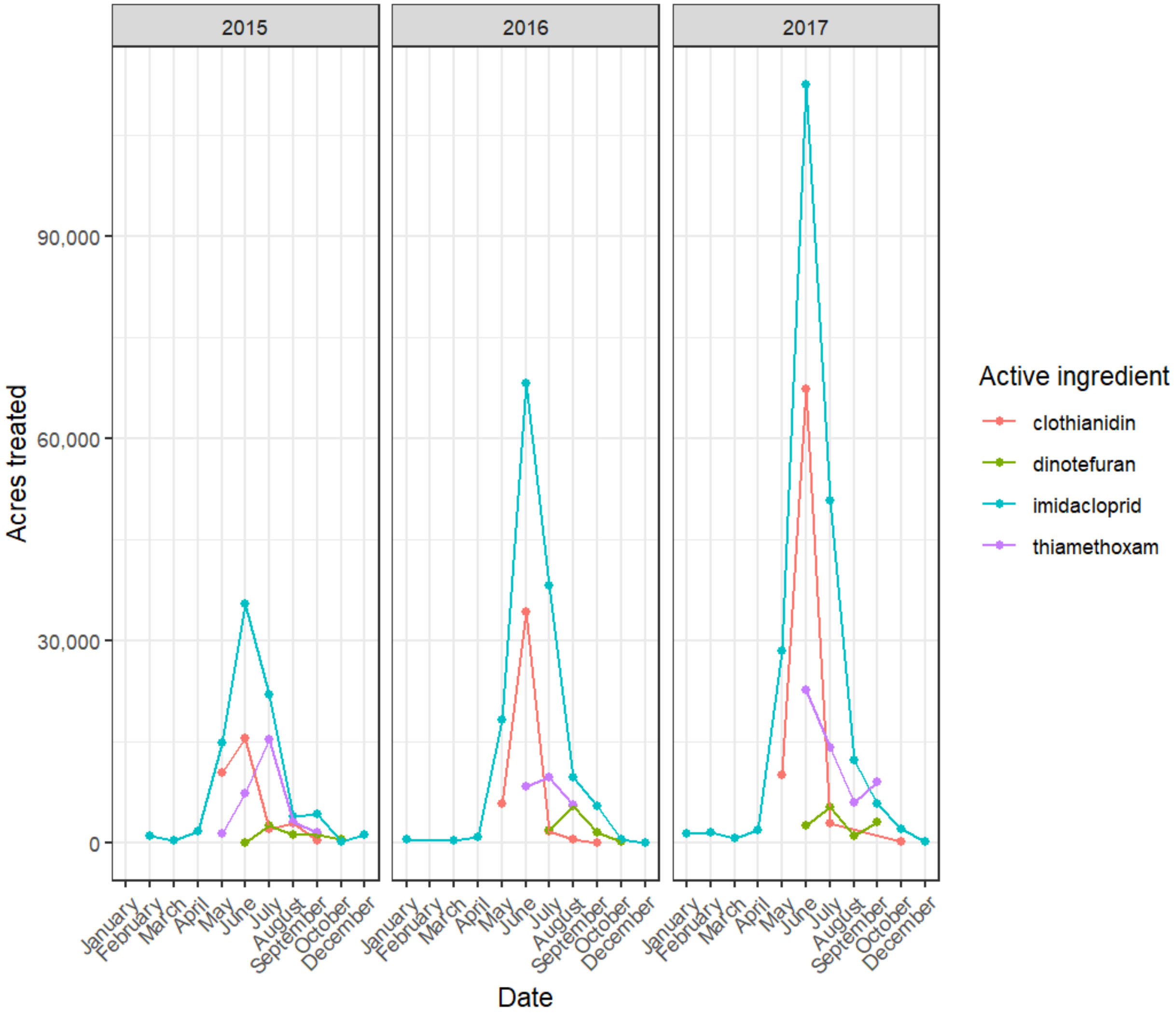

Figure 16. Monthly use of target nitroguanidine substituted neonicotinoids: Cotton, 2015-2017

Other considerations. Secondary pest infestations are an important consideration. Because of the interconnected nature of IPM of the key pests in cotton (lygus, cotton aphid, silverleaf whitefly, and spider mites), "secondary" pest outbreaks are a key concern. Pest managers have to account for how applications targeting one pest will affect populations of other pests and natural enemies. Effects can be immediate as is the case with spider mites, which reproduce very quickly. Additionally, there can be longer term effects such as late season outbreaks due to the cumulative effects of a sparse natural enemy community. NGNs play an important role in this regard because they are typically softer on natural enemies than the organophosphates, carbamates, or pyrethroids alternatives. Some NGNs can also be applied systemically through drip irrigation which could promote conservation of natural enemy communities, although there has not been much research on this practice in California cotton to date.

Resistance management is also a significant concern for IPM of cotton pests. All of the pests that are the primary targets of NGNs have repeatedly displayed an ability to become resistant to the insecticides relied upon to control them. Some of the materials currently used to manage these pests (such as lygus), are no longer as effective as they used to be. Resistance management relies on a combination of availability of multiple modes of action to use in rotation and education about how to use these materials. Overreliance on a key material throughout the season is a sure way to generate resistance. For instance, flonicamid is currently an extremely effective and selective material for lygus and aphids, but if multiple modes of action are not used for lygus management and repeated applications of flonicamid are used instead, there is a strong possibility insecticide resistance will develop.

Economic Analysis

This section presents the estimated change in net revenues to cotton due to cancellation of the four NGNs. This change includes the change in pesticide material costs and changes in application costs when an alternative treatment requires a different application method. No yield impacts are anticipated as a result of cancellations, due to the use of alternatives, so gross revenues will not change.

Table 25: Representative Products and Costs Per Acre: Cotton

Active ingredient	Representative product	Material cost ($)	Application cost ($)	Total cost ($)
(s)-cypermethrin	Mustang	3.76	19.83	23.59
acephate	Acephate 97UP Insecticide	14.09	21.08	35.17
acetamiprid	Assail 70WP Insecticide	30.21	18.82	49.03
beta-cyfluthrin	Baythroid XL	10.90	19.99	30.90
bifenthrin	Bifenture EC Agricultural Insecticide	4.89	19.00	23.90
buprofezin	Courier	36.75	18.46	55.21
clothianidin	Belay Insecticide	13.61	22.62	36.23
dimethoate	Dimethoate 400	6.60	19.99	26.59
dinotefuran	Venom Insecticide	22.28	18.30	40.58
flonicamid	Carbine 50WG Insecticide	16.70	20.45	37.15
flupyradifurone	Sivanto Prime	45.93	20.39	66.32
imidacloprid	Wrangler Insecticide	2.77	20.04	22.81
indoxacarb	Dupont Steward EC Insecticide	27.94	20.81	48.74
lambda-cyhalothrin	Warrior II	7.40	19.67	27.07
naled	Dibrom 8 Emulsive	9.55	18.43	27.97
oxamyl	Dupont Vydate C-LV Insecticide/Nematicide	15.88	18.11	33.98
pyriproxyfen	Knack Insect Growth Regulator	0.71	19.70	20.41
spiromesifen	Oberon 2SC Insecticide/Miticide	49.21	20.14	69.35
sulfoxaflor	Transform	19.90	19.22	39.11
thiamethoxam	Centric 40WG	13.09	19.76	32.86

Table 25 presents representative products for each active ingredient used on cotton in 2015–2017 and their 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 application cost per acre is the average application cost based on application method across all applications of the AI to the crop. The costs of each application method are presented in the methods section (Table 5). The total cost per acre is the sum of the material and application cost per acre. There is substantial variation in the total cost per acre of AIs, which ranges from $20.41 to $69.35.

Table 26: Average Annual Acreage Shares of Alternative Insecticides with and without Target Nitroguanidine Substituted Neonicotinoids (NGNs): Cotton, 2015–2017

Active ingredient	Target NGNs available (%)	Target NGNs cancelled (%)
(s)-cypermethrin	2.56	3.03
acephate	2.40	2.85
acetamiprid	10.65	12.61
beta-cyfluthrin	2.39	2.82
bifenthrin	7.95	9.41
buprofezin	2.71	3.21
dimethoate	5.32	6.30
flonicamid	21.83	25.85
flupyradifurone	3.09	3.66
indoxacarb	4.07	4.81
lambda-cyhalothrin	4.04	4.79
naled	4.02	4.77
oxamyl	0.97	1.15
pyriproxyfen	1.49	1.77
spiromesifen	1.03	1.22
sulfoxaflor	9.92	11.75
total	60.5	100

Table 26 shows the average acreage shares for each non-NGN alternative used on cotton, with and without NGNs being available. Averaged over the three-year period 2015–17 when NGNs were available, NGNs were used on 39.5% of total cotton acres treated with NGNs and alternative AIs.

If NGNs were cancelled, the use of alternative AIs is scaled up in proportion to their acreage shares, as discussed in the methods section. The main alternative insecticides for cotton were flonicamid and acetamiprid, together accounting for 32.5% of total cotton acres treated with insecticides, or 38.5% of acres treated with non-NGN alternative AIs.

Table 27: Costs Per Acre for Target Nitroguanidine Substituted Neonicotinoids and the Composite Alternative: Cotton

Active ingredient	Material cost ($)	Application cost ($)	Total cost ($)	Cost increase for switching to composite alternative (%)
clothianidin	13.61	22.62	36.23	3.98
dinotefuran	22.28	18.30	40.58	-7.16
imidacloprid	2.77	20.04	22.81	65.15
thiamethoxam	13.09	19.76	32.86	14.67
composite alternative	17.98	19.70	37.67	-

Table 27 shows the average costs per acre for the four target NGNs as well as the cost of the composite alternative, whose price we use as a representative pesticide cost that would be paid by growers if NGNs were cancelled. For cotton, switching to the composite alternative would lead to an increase in material costs for all acres using NGNs except dinotefuran. Application costs would increase for all acres using NGNs except dinotefuran. Overall, dinotefuran users would reduce their costs by about 7% when switching to the alternative. Clothianidin users would incur the lowest cost increase (4%) and imidacloprid users would incur the largest cost increase (65%).

Table 28. Change in Treatment Costs due to Cancellation of Nitroguanidine Substituted Neonicotinoids (NGNs): Cotton, 2015–2017

Year	Cost with target NGNs ($)	Cost without target NGNs ($)	Change in total cost ($)	Change in total cost (%)	Change in material cost (%)	Change in application cost (%)
2015	4,248,275	5,680,628	1,432,353	33.7	108.1	-8.1
2016	5,937,779	8,199,690	2,261,912	38.1	107.2	-7.2
2017	10,081,123	13,645,341	3,564,218	35.4	108.4	-8.4

Table 28 reports the anticipated changes in total cost due to the cancellation of NGNs. Insecticide costs for management of the target pests in cotton are estimated to increase by approximately by one third. The percent change in costs ranges from 33.7% in 2015 to 38.1% in 2016. In all years, the increase in material costs is greater than the increase in total costs. The reduction in application costs associated with the use of some alternatives partially offsets the increase in material costs.

The magnitude of these changes is driven by the large treated cotton acreage and the large material cost differences between imidacloprid, the most widely used NGN on cotton, and alternatives that account for a large share of non-NGN treated acreage. In 2017, for example, total treated cotton acreage was 2,061,131 and the share of treated acreage that was treated with one of the four NGNs was 12.7%. One example of the change in relative costs was flonicamid, which had a cost per acre of $37.15, and increased its share of total acres treated by 4.02%, or 82,857 acres. Compared to the cost per acre of imidacloprid ($22.81) or clothianidin ($36.23), which accounted for the bulk of acres treated with an NGN, costs would increase by roughly two thirds for imidacloprid and would be similar for clothianidin. For the 76,132 acres that are modeled as switching from applying imidacloprid to flonicamid, the total increase in costs is $807,021.

Conclusions and Critical Uses

A substantial cost increase per treatment is anticipated if all four NGNs are cancelled in cotton. In addition, secondary pest infestations and faster development of resistance to other active ingredient in cotton pests are important factors influencing future costs that are not addressed here.

Grape

Grape is was California's largest crop by value of production in 2017 and ranked behind only milk and cream for all agricultural commodities. 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 is by far the largest grape-producing state, and accounted for 82.9% of national bearing acreage, 84.4% of national production, and 89.6% of national production value in 2017 (NASS 2018). Export products related to grape production exceeded $2.5 billion, which was 12.2% of California's total agricultural export value, second only to almond.

There are three categories of grape produced in California: wine, raisin, and table. By bearing acreage, wine grape accounted for 67.6% in 2017, raisin grape 19.0%, and table grape the remaining 13.4% (CDFA 2018a). Production per acre tends to be higher for table and raisin grape than wine grape; as a result, wine grape accounted for 61.9% of production tonnage, while raisin and table grape account for 19.6 and 18.5% of production tonnage. Table and wine grape had the highest average value per unit in 2017 at $1,330 per ton and $927 per ton, respectively, compared to only $380 per ton for raisin grape. In terms of total production value, wine grape accounted for 64.2%, table grape 27.5%, and raisin grape 8.3%. Wine grape accounted for 76.5% of non-bearing acreage in 2017, table grape 19.6%, and raisin grape only 3.9%. Note there are many varieties of within the main variety categories of wine, raisin, and table grape. 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 2018b). 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%). Data available on pesticide use differentiate only between wine and other grape types, not between raisin and table grape (or varieties within a category).

Grapes are used in a wide variety of products. In 2017, 4.2 million tons of grape—or 64.6% of total production—were crushed for wine, concentrate, juice, vinegar or beverage brandy (CDFA 2018b, c). By variety, 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. That not all table grapes are sold fresh to market or raisin grapes are dried indicates that the distinction between varieties can be ambiguous. For example, 94,268 tons of raisin grapes and 131,884 tons of table grapes were crushed in 2017 (CDFA 2018c).

Grape production of all types occurs throughout the state of California. Figure 17 maps raisin and table grape production, and Figure 18 maps wine grape production. Table grape production is concentrated in Kern ($1,549 million), Tulare ($761 million), and Fresno ($378 million) counties, and is a top ten production value crop in five counties (the previous three plus Riverside and Madera) (CDFA 2018a). Raisin grape production is concentrated in Fresno ($270 million), Kern ($112 million), and Madera ($109 million) and is 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). The former two counties were driven by high value production.

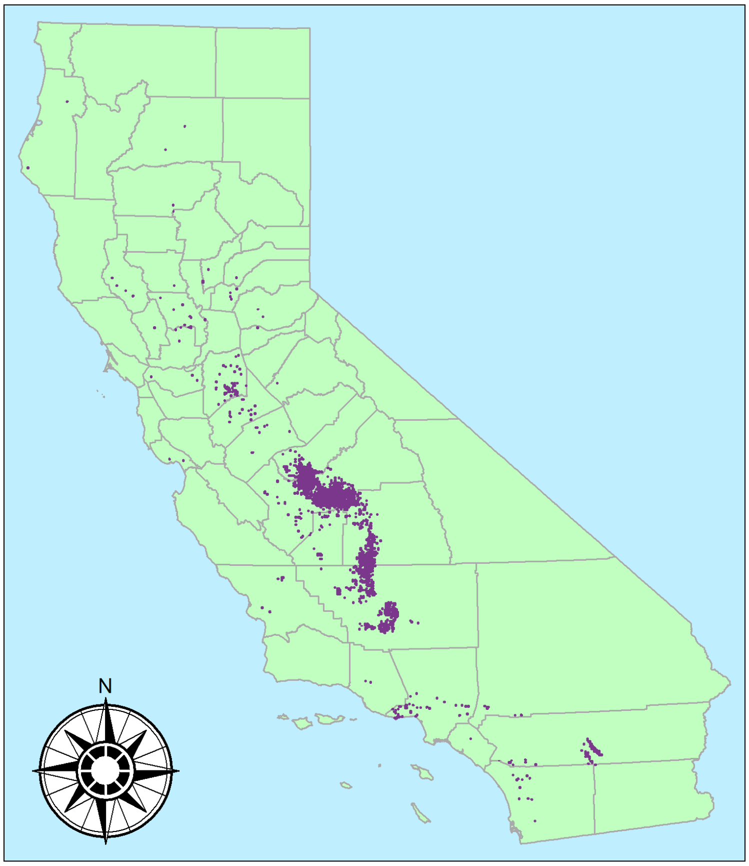

Figure 17. California raisin and table grape production: 2017

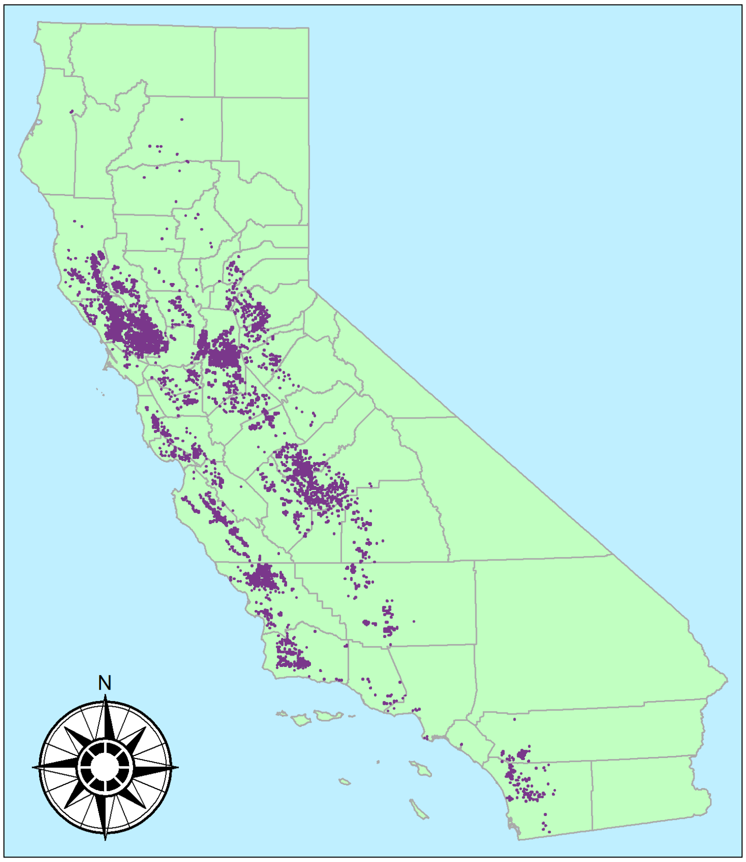

Figure 18. California wine grape production: 2017

IPM Overview

Grape growers use NGN products against leafhoppers (western grape, variegated, Virginia creeper), mealybugs (grape, obscure, long tail, pink hibiscus and vine) and grape phylloxera. Vine mealybug is a problem in all grape growing areas but can be especially bad in warmer areas, such as the southern San Joaquin Valley. Raisin grape and table grape are more concentrated in the warmer growing areas than wine grape, and, as such, tend to have more problems with vine mealybug. As detailed below in the target pest section, there are alternatives for leafhoppers and mealybugs but phylloxera management does not have good neonicotinoid alternatives. All four NGNs – clothianidin, dinotefuran, imidacloprid, and thiamethoxam – are classified as high risk in grape.

Target Pests

Leafhoppers. The leafhopper complex that attacks grape includes western grape leafhopper (*Erythroneura elegantula*), variegated leafhopper (*Erythroneura variabilis*), and Virginia creeper leafhopper (*Erythronuera ziczac*). The three species have somewhat different ranges in California, but the damage they cause to grape is very similar. Grape leafhopper is found in the Sacramento, San Joaquin, and North Coast valleys as well as the warmer areas of the central coast. Variegated leafhopper is a pest mostly in the Central Valley and southern California but can go as far north as the San Joaquin Valley and Napa. Virginia creeper leafhopper is found in the Sacramento Valley, the North Coast wine region, and the northern Sierra foothills.

Leafhopper nymphs and adults feed on the contents of plant cells in grape leaves, which causes light yellow spots. Large populations can lead to defoliation, but even moderate populations reduce the photosynthetic efficacy of the plants. Additionally, leafhopper frass can cause sooty mold on the fruit, a concern for table grape.

In addition to the NGNs, leafhoppers can be controlled with acetamiprid, beta-cyfluthrin, bifenthrin, *burkholderia*, fenpropathrin, flupyradifurone, lambda-cyhalothrin, pyrethrin, and sulfoxaflor. Flupyradifurone, burkholderia, *chromobacterium subtsugae* strain A, and pyrethrin were all equally effective for Virginia creeper and grape leafhopper in one efficacy study (Van Steenwyk et al. 2018a). There are also natural enemies that attack the leafhoppers and provide control in some areas and situations. The parasitoids *Anagrus erythroneurae* and *Anagrus daanei* are particularly important for western grape and Virginia leafhopper. The cultural practice of removing basal leaves during berry set and two weeks after is also helpful. Limiting overly vigorous growth can suppress populations. These cultural controls can supplement biological control and often eliminate the need for treatment.

Mealybugs. Grape (*Pseudococcus maritimus*), obscure (*Pseudococcus viburni*), long tail (*Pseudococcus longispinus*), pink hibiscus (*Maconellicoccus hirsutus*), and vine (*Planococcus ficus*) mealybugs all attack grape in California. Mealybugs feed by using their sucking mouthparts to pierce the plant tissue and extract sap from the phloem, reducing plant vigor. They excrete honeydew, which can cause the growth of sooty mold on the fruit. Different grape varietals are differentially susceptible to mealybug damage from mold. All five mealybugs can transmit diseases.

The vine mealybug is more difficult to control than the *Pseudococcus* spp. mealybugs, i.e., grape, obscure, long tail, and hibiscus mealybugs. Vine mealybug is a more difficult to control because unlike the *Pseudococcus* mealybugs, which only produce two generations per year, the vine mealybug can produce multiple generations per year. Thus, vine mealybug can develop very high and damaging populations late in the season as the grapes are maturing. Adding to the problem, vine mealybugs may hide in the grape bunches, making them harder to kill with contact insecticide. This is especially an issue in warmer regions as the warm temperature allows for even more generations of vine mealybug.

Alternatives to the NGNs for mealybug control are spirotetramat, acetamiprid, flupyradifurone, sulfoxaflor, fenpropathrin, and beta-cyfluthrin. Chlorpyrifos was an alternative, but chlorpyrifos products are in the process of being cancelled by DPR. Sulfoxaflor is not currently registered in grape but may be in the near future.

For vine mealybug, growers use a series of treatments that include imidacloprid. Haviland et al. (2011) found that a combination of spirotetramat and buprofezin was the only treatment to significantly reduce vine mealybug damage and Van Steenwyk et al. (2016c) found that sequential use of spirotetramat and flupyradifurone was effective. The NGNs are a part of that program but could be replaced with acetamiprid or extra applications of spirotetramat. However, heavier use of spirotetramat could lead to resistance; growers are already encouraged to rotate it with other active ingredients to prevent this. As spirotetramat is the primary effective active ingredient besides imidacloprid, it would be difficult to rotate it in order to manage resistance without incurring yield loss. Additionally, growers have access to mating disruption products. Use of mating disruption has been increasing, especially with the 2016 registration of a product with a user-friendly formulation. Mating disruption decreases the need for chemical controls. Mealybugs are attacked by a variety of natural enemies, but they do not regularly produce sufficient control (Daane et al. 2012; Walton et al. 2012). The most useful one, *Anagyrus pseudococci*, can be released into 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 in pest control.

Grape phylloxera (*Daktulosphaira vitifoliae*). Grape phylloxera is a small insect, somewhat like an aphid, that feeds on the roots of grape causing vines to be stunted or even die. It is more of a problem in regions with cooler, clay heavy soil such as Napa, Sonoma, Lake, Mendocino, Monterey, Sacramento, and Yolo counties.

Resistant root stock is the best way to control phylloxera. However, NGNs are currently a crucial part of control phylloxera on non-resistant varieties. On the east coast of the USA , grape phylloxera can be effectively treated with soil drenches of imidacloprid, fenpropathrin, clothianidin, spirotetramat, and pyriproxyfen (Johnson et al. 2009). Spirotetramat is the only alternative for the type of phylloxera in California (Van Steenwyk et al. 2009). As discussed earlier, more intensive use of spirotetramat is problematic due to the potential effect on the development of resistance. Although not considered in this analysis, the continued development of phylloxera-resistant grape root stock would benefit California growers.

Target NGN Use: 2015-2017

The timing of applications and total acres treated did not vary much across years for raisin/table grape (Figure 19). Over the three-year period, total applications of NGNs, most notably imidacloprid and thiamethoxam, increased in wine grape. The pattern of use over the course of the year remained fairly comparable. The increasing use in wine grape is due to greater vine mealybug pressure, lower price, and ease of use of the NGNs. Applications early in the year are done through chemigation. Applications starting around August are mostly for leafhopper and are applied with air-blast speed sprayers.

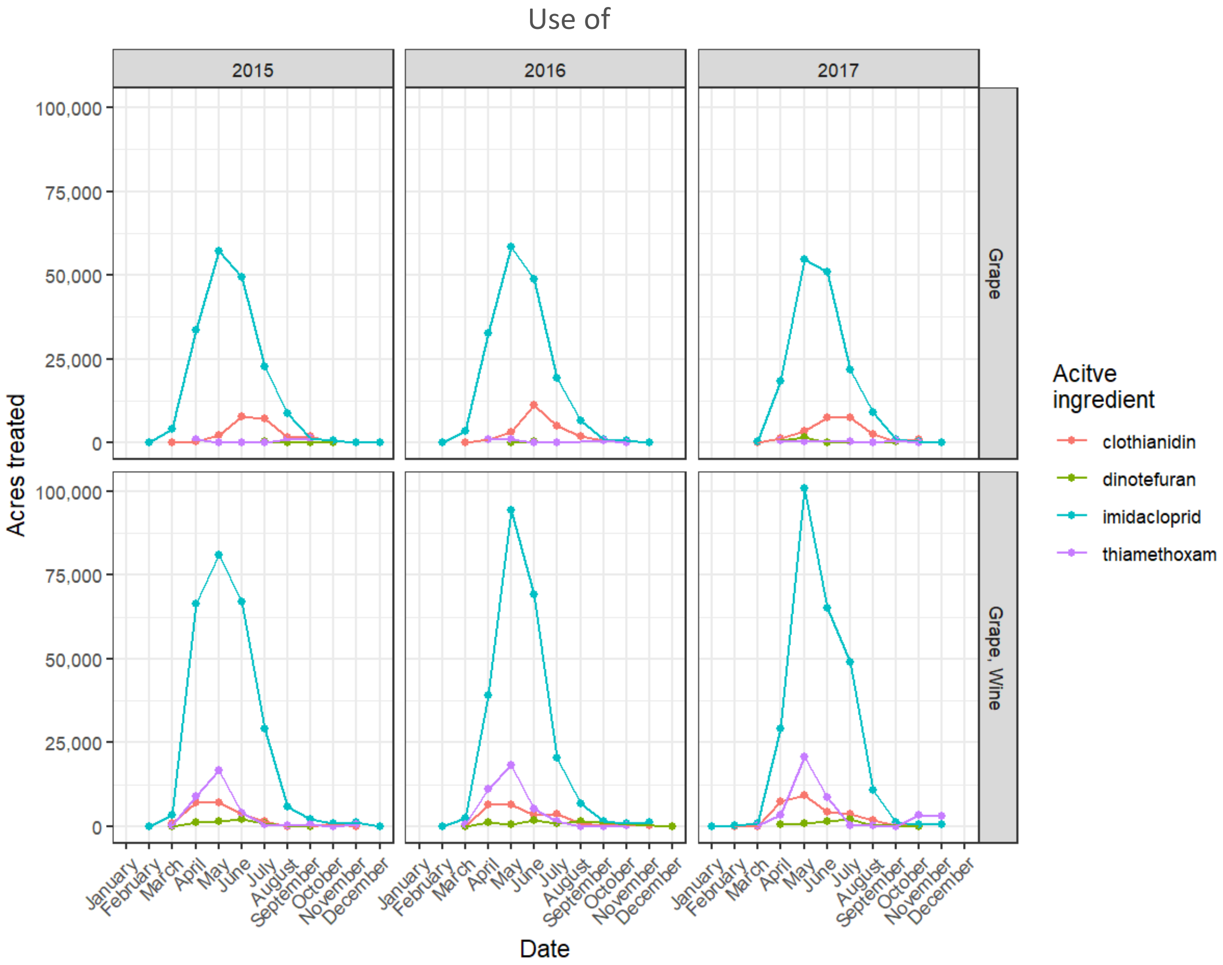

Figure 19. Monthly use of target nitroguanidine substituted neonicotinoid use: raisin and table grape and wine grape, 2015-2017.

Table 29 reports the annual and total use of target and alternative active ingredients over the 2015-2017 period, measured as acres treated and as total pounds of active ingredient for raisin/table grape. Table 30 reports the same information for wine grape. Over 1 million acres in total were treated with NGNs over the three-year period. Cancellation of the NGNs would have a significant impact on use patterns. Spirotetramat, a major alternative to NGNs, was applied to just under a million acres. Given the potential development of resistance owing to increased use of spirotetramat, restriction in NGN use could have substantial indirect effects on use patterns.

Table 29: Annual Use of Nitroguanidine Substituted Neonicotinoids and Alternative Active Ingredients: Raisin and Table Grape, 2015-2017

Active ingredient	**-----------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
beta-cyfluthrin	628	664	879	2,171	24,317	25,472	33,238	83,028	0.03
bifenthrin	235	119	45	398	2,335	1,369	604	4,307	0.09
buprofezin	36,856	33,043	36,505	106,405	68,237	60,098	67,447	195,782	0.54
burkholderia sp	3,217	5,352	10,663	19,232	314	1,069	2,981	4,364	4.41
clothianidin	2,240	2,268	2,349	6,858	21,153	23,171	23,704	68,027	0.10
dinotefuran	62	39	748	849	399	308	3,896	4,602	0.18
fenpropathrin	9,475	9,489	6,055	25,019	35,662	32,046	21,182	88,890	0.28
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
lambda-cyhalothrin	--	--	4	4	--	--	90	90	0.04
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
thiamethoxam	447	345	207	998	3,767	2,863	2,469	9,099	0.11

* Target active ingredients (NGNs)

Table 30: Annual Use of Nitroguanidine Substituted Neonicotinoids and Alternative Active Ingredients: Wine Grape, 2015-2017

Active ingredient	**------------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
beta-cyfluthrin	41	141	94	277	1,487	4,890	3,339	9,716	0.03
bifenthrin	21	30	17	69	185	320	352	856	0.08
buprofezin	13,157	17,965	16,838	47,960	20,264	27,633	22,579	70,475	0.68
burkholderia sp	242	2,096	4,256	6,594	27	307	670	1,003	6.58
clothianidin	3,226	3,146	3,944	10,315	21,689	21,868	28,428	71,985	0.14
dinotefuran	818	795	1,075	2,687	5,988	6,532	5,887	18,408	0.15
fenpropathrin	1,254	627	376	2,258	4,711	2,703	1,558	8,973	0.25
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
lambda-cyhalothrin	NA	0	NA	0	NA	8	NA	8	0.03
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
thiamethoxam	2,833	3,165	4,707	10,705	32,066	37,444	40,273	109,783	0.10

* Target active ingredients (NGNs)

Economic Analysis

This section presents the estimated change in costs to grape production owing to the potential cancellation of the four NGNs. This cost includes the change in pesticide material costs and changes in application costs when an alternative treatment requires a different application method. We report costs separately for raisin/table grape and wine grape because of differences in pest management. No reduction in yield or quality is anticipated due to the use of alternatives, so gross revenues will not change as a result of cancellation.

Table 31 presents representative products for each active ingredient used on raisin and table grape (sub-divided by category) in 2015–2017 and their costs per acre. Table 32 presents the same information for wine grape. The material cost per acre is the product of the average use rate (lbs/acre) over this period and the price per pound. The application cost per acre is the acre-weighted average application cost based on application method across all applications of the AI to the crop. The costs of each application method are presented in the methods section. The total treatment cost acre is the sum of the material and application cost per acre.

Table 31: Representative Products and Costs Per Acre: Raisin and Table Grape

Active ingredient	Representative product	Material cost ($)	Application cost ($)	Total cost ($)
acetamiprid	Assail 30 SG Insecticide	23.77	25.00	48.77
beta-cyfluthrin	Baythroid XL	11.40	25.02	36.42
bifenthrin	Brigade WSB Insecticide/Miticide	23.29	25.02	48.30
buprofezin	Applaud 70 DF Insect Growth Regulator	34.94	25.00	59.94
burkholderia	Venerate	67.17	25.00	92.17
clothianidin	Belay Insecticide	14.68	24.62	39.29
dinotefuran	Venom Insecticide	38.97	19.28	58.25
fenpropathrin	Danitol 2.4 EC Spray	24.74	25.00	49.74
flupyradifurone	Sivanto 200 SL	49.43	25.04	74.47
imidacloprid	Admire Pro	15.24	18.20	33.44
lambda-cyhalothrin	Warrior II	8.38	25.00	33.38
lavandulyl senecioate	Checkmate VMB-F	47.30	24.99	72.29
spirotetramat	Movento	63.08	25.00	88.07
thiamethoxam	Platinum 75 SG	16.82	18.90	35.72

Table 32. Representative Products and Costs Per Acre: Wine Grape

Active ingredient	Representative product	Material Cost ($)	Application cost ($)	Total cost ($)
acetamiprid	Assail 30sg Insecticide	19.90	24.65	44.55
beta-cyfluthrin	Baythroid XL	12.42	25.00	37.42
bifenthrin	Brigade WSB Insecticide/Miticide	20.16	25.28	45.44
buprofezin	Applaud 70 DF Insect Growth Regulator	43.75	25.02	68.76
burkholderia	Venerate	100.23	23.95	124.18
clothianidin	Belay Insecticide	20.87	15.99	36.85
dinotefuran	Venom Insecticide	30.85	16.48	47.33
fenpropathrin	Danitol 2.4 EC Spray	22.12	25.03	47.15
flupyradifurone	Sivanto 200 SL	42.62	23.44	66.06
imidacloprid	Admire Pro	19.03	15.76	34.79
lambda-cyhalothrin	Warrior II	6.29	25.00	31.29
lavandulyl senecioate	Checkmate VMB-F	42.38	24.77	67.14
spirotetramat	Movento	64.05	24.47	88.52
thiamethoxam	Platinum 75 SG	14.95	10.50	25.45

Differences in the cost per acre for representative products between the two categories of grape are due to different average use rates and application methods over the period. The NGNs have lower average application costs because they are frequently applied with chemigation. There is substantial variation in the total cost per acre of AIs, ranging from $33.38 to $92.17 for table and raisin grape, and from $25.45 to $124.18 per acre for wine grape. For table and raisin grape, *burkholderia* sp strain a396 had the highest cost. This AI is primarily used in organic production but is potentially a viable alternative in conventional vineyards. As its share of acres with and without the NGNs being available is less than 0.5%, the high cost has a very small effect on the overall changes in material and total treatment costs.

Table 33: Average Annual Acreage Shares of Alternative Insecticides with and without Target Nitroguanidine Substituted Neonicotinoids (NGNs): Raisin and Table Grape, 2015–2017

Active ingredient	**Target NGNs available (%)**	**Target NGNs cancelled (%)**
acetamiprid	2.85	4.71
beta-cyfluthrin	5.58	9.22
bifenthrin	0.29	0.48
buprofezin	13.16	21.74
burkholderia	0.29	0.48
fenpropathrin	5.97	9.87
flupyradifurone	0.29	0.48
lambda-cyhalothrin	0.02	0.03
lavandulyl senecioate	2.72	4.49
spirotetramat	29.35	48.50
Total	60.5	100

Table 34. Average Annual Acreage Shares of Alternative Insecticides with and without Target Nitroguanidine Substituted Neonicotinoids (NGNs): Wine Grape, 2015–2017

Active ingredient	**Target NGNs available (%)**	**Target NGNs cancelled (%)**
acetamiprid	2.94	6.64
beta-cyfluthrin	0.57	1.28
bifenthrin	0.05	0.11
buprofezin	4.12	9.30
burkholderia	0.06	0.13
fenpropathrin	0.52	1.18
flupyradifurone	0.43	0.97
lambda-cyhalothrin	0.00	0.00
lavandulyl senecioate	3.09	6.96
spirotetramat	32.54	73.41
Total	44.3	100

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

Table 33 shows the average acreage shares for each non-NGN alternative used on raisin and table grape with and without NGNs being available, and Table 34 presents the same information for wine grape. Averaged over the three-year period 2015–17 when NGNs were available, NGNs were used on 39.5% of total table/raisin grape acres treated with insecticides and on 55.7% of total wine grape acres treated with insecticides.

To represent the situation if NGNs were cancelled, the use of alternative AIs is scaled up in proportion to their acreage shares, as discussed in the methods section. The main alternative insecticides for table/raisin grape were buprofezin and spirotetramat, together accounting for 42.5% of total table/raisin grape acres treated with insecticides, or 70.2% of acres treated with non-NGN insecticides. Spirotetramat is the main alternative insecticide for wine grape, accounting for 73.41% of acres treated with a non-NGN insecticide.

Table 35: Costs Per Acre for Target Nitroguanidine Substituted Neonicotinoids and Composite Alternative: Raisin and Table Grape

Active ingredient	Material cost ($)	Application cost ($)	Total cost ($)	Cost increase for switching to composite alternative (%)
clothianidin	14.68	24.62	39.29	79.69
dinotefuran	38.97	19.28	58.25	21.20
imidacloprid	15.24	18.20	33.58	110.24
thiamethoxam	16.82	18.90	35.72	97.65
composite alternative	45.60	25.00	70.60	-

Table 36. Costs Per Acre for Target Nitroguanidine Substituted Neonicotinoids and Composite Alternative: Wine Grape

Active ingredient	Material cost ($)	Application cost ($)	Total cost ($)	Cost increase for switching to composite alternative (%)
clothianidin	20.87	15.99	36.85	119.57
dinotefuran	30.85	16.48	47.33	70.95
imidacloprid	19.03	15.76	34.79	132.57
thiamethoxam	14.95	10.50	25.45	217.92
composite alternative	56.32	24.56	80.91	-

Table 35 and Table 36 report the average per acre costs for the four target NGNs as well as the cost of the composite alternative, used as a representative pesticide cost per acre if NGNs were cancelled. For both categories of grape, switching to the alternative would lead to an increase in total cost per acre, owing to increases in both material and application costs. For raisin/table grape, dinotefuran users would incur the lowest cost increase (21.2%) and imidacloprid users would incur the largest cost increase (110.2%) (Table 35). For wine grape, dinotefuran users would incur the lowest cost increase (71.0%) and thiamethoxam users would incur the largest cost increase (217.9%) (Table 36).

Table 37. Change in Treatment Costs due to Cancellation of Nitroguanidine Substituted Neonicotinoids (NGNs): Raisin and Table Grape, 2015–2017

Year	Cost with target NGNs($)	Cost without target NGNs ($)	Change in cost ($)	Change in cost (%)	Change in material cost (%)	Change in application cost (%)
2015	6,937,805	14,346,659	7,408,854	106.8	83.2	16.8
2016	6,745,552	13,924,944	7,179,392	106.4	83.4	16.6
2017	6,499,036	13,211,839	6,712,803	103.3	83.4	16.6

Table 38. Change in Treatment Costs due to Cancellation of Nitroguanidine Substituted Neonicotinoids: Wine Grape, 2015–2017

Year	Cost with target active ingredients ($)	Cost without target active ingredients ($)	Change in cost ($)	Change in cost (%)	Change in material cost (%)	Change in application cost (%)
2015	10,845,912	25,641,088	14,795,176	136.4	80.1	19.9
2016	10,281,423	24,428,377	14,146,954	137.6	79.9	20.1
2017	11,353,566	26,970,543	15,616,977	137.6	79.9	20.1

Table 37 (raisin and table grape) and Table 38 (wine grape) report the anticipated changes in cost due to the cancellation of NGNs. Total treatment costs for both categories of grape are approximately double. For table and raisin grape, the percent change in costs ranges from 103.3% in 2017 to 106.8% in 2015, depending on the NGN (Table 37). For wine grape, the percent change in costs ranges from 136.4% in 2015 to 137.6% in 2016 and 2017 (Table 38). The final two columns of the tables disaggregate the percent change in costs into the percent due to the change in material costs and the percent due to the change in application costs. For both categories of grape, around 80% of the cost increase is due to switching to more expensive insecticides, and around 20% of the cost increase is due to switching to more expensive application methods.

The magnitude of these changes is driven by the large treated grape acreage, the large percentage of acres that are treated with NGNs currently, and the large price differences between the NGNs and alternatives that account for a large share of non-NGN treated acreage. In 2017, for example, total treated raisin and table grape acreage was 511,127 and the share of treated acreage that was treated with any of the four NGNs was 36.6%. For example, spirotetramat, which had a cost per acre of $88.07, increased its share of total acres treated by 19.1%, or 97,625 acres. Compared to the cost per acre of imidacloprid ($33.58) or clothianidin ($39.29), which accounted for the bulk of acres treated with an NGN, costs are over twice as high. For the 76,132 acres that are modeled as switching from applying imidacloprid to spirotetramat, the total increase in costs is $4,148,433.

In addition to the change in materials costs per acre, there are some changes in application costs per acre due to moving to alternatives. Specifically, an air blast application costs approximately $25 per acre more than chemigation. Thus, for acreage previously receiving an NGN application using chemigation, alternatives that must be applied with air blast incur an additional cost. In 2017, for wine grape, for example, the total increase in application costs would be $3,132,872.

Conclusions and Critical Uses

There is a substantial cost increase anticipated if all four NGNs are cancelled in grape. The availability of efficacious alternatives varies by target pest. While there are alternatives that could replace the NGNs in the control program for vine mealybug, they are often more expensive. For phylloxera, spirotetramat is the only available alternative in the short run. In the long run, resistant cultivars are a desirable option. However, developing such cultivars is a costly and lengthy process, and planting them on a significant portion of current grape acreage would further extend the timeline.

Pistachio

California accounts for more than 99% of U.S. pistachio production and is the world's largest producer and exporter – globally accounting for 42.4% of production and 57.2% of export value (USDA FAS 2018). In 2017, there were approximately 250,000 acres of bearing pistachio orchards. Although adverse growing conditions in 2017 resulted in a 33% decrease in production value from 2016, gross receipts still exceeded $1 billion and pistachio was the state's ninth largest agricultural commodity by production value (CDFA 2018a).

Over $1.5 billion worth of pistachio are exported in 2017, making pistachio California's third most important export agricultural commodity by value. The quantity exported was equivalent to 78% of production (UCAIC 2018). By value of production, pistachio is the largest agricultural export commodity to China/Hong Kong and the fourth largest export to the European Union.

The three largest producing counties in California were Kern ($556 million), Fresno ($517 million) and Tulare ($342 million), which combined accounted for 80.6% of state production. Pistachio fell within the top ten agricultural commodities in five counties (Fresno, Kings, Kern, Madera, and Tulare) and within the top four agricultural commodities in three counties (Kern, Fresno, and Madera). Figure 20 depicts the geographic distribution of California's pistachio acreage.

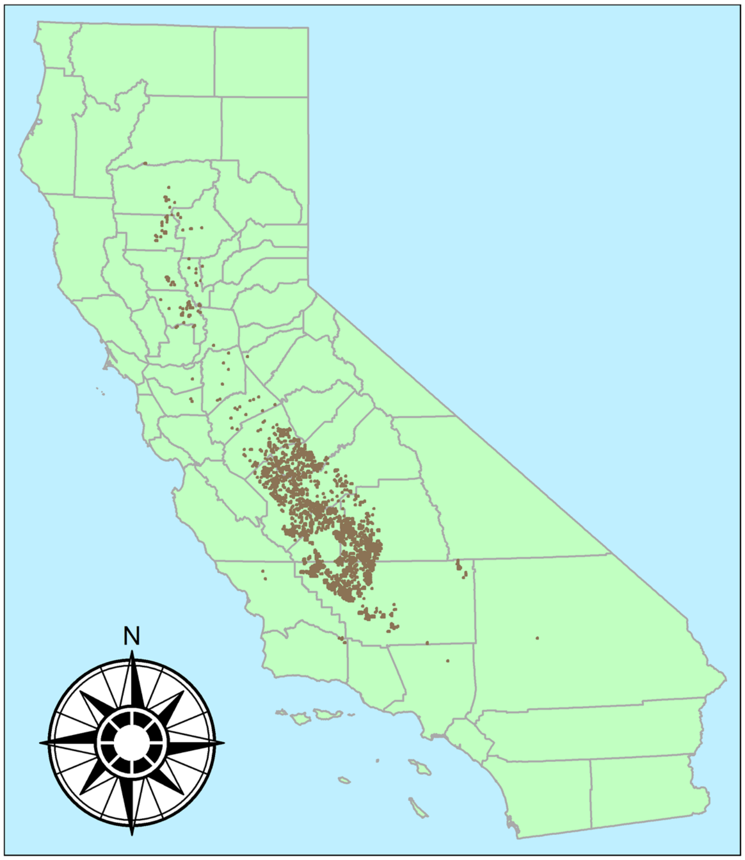

Figure 20. California pistachio production: 2017

IPM Overview

Imidacloprid is the only NGN used in pistachio. Imidacloprid is largely used for control of mealybug and scale, the most common of which is Gill's mealybug (Pseudococcidae: *Ferrisia gilli*). Some growers also use this AI for control of true bugs, but mealybug is the dominant target.

Target Pests

Gill's mealybug (*Ferrisia gilli*). Like many mealybugs, Gill's mealybugs are often covered by a white waxy substance that they excrete. They feed by piercing the outer layers of plant tissues with their mouthparts and extracting sap from phloem tissues, thus reducing plant vigor. They excrete honeydew, which can cause the growth of sooty mold, thereby reducing photosynthesis and nut quality and increasing nut staining. Mealybug damage can also cause nuts to shrivel on the tree; this is bad for marketability of the pistachio nuts and for the management of navel orangeworm, which overwinters in dried nuts. In California, Gill's mealybug has three generations a year and overwinters as small nymphs. In spring when pistachio trees are going through bud break, nymphs feed on the new buds.

Given the cryptic nature of mealybugs, imidacloprid is a useful chemistry because of its systemic activity. Pyriproxyfen, buprofezin, and spirotetramat are effective alternatives. Pyriproxyfen and buprofezin are contact products, and to be effective, applications must be well-timed relative to a systemic product. Spirotetramat is systemic and use has been increasing over the past ten years. Acetamiprid is also systemic and could be used in place of imidacloprid. There are generalist natural enemies that attack Gill's mealybug, but they are not often found in pistachio, possibly owing to the use of broad spectrum insecticides for control of true bugs. Keeping equipment clean helps prevent spreading mealybugs between orchards.

Other Considerations: Resistance Management

As is true for other pests and other commodities, one consequence of eliminating use of the NGNs is that there will be fewer AIs in fewer classes of action for resistance management.

Target NGN Use: 2015-2017

Imidacloprid use in pistachio has increased from 2015 to 2017 (Table 39), as has pistachio acreage, increasing from 233,000 in 2015 to 250,000 in 2017. Acres treated as a fraction of acres planted increased by roughly 3% over that period. Imidacloprid is used on substantially more acres than any of the alternatives and is currently the standard for controlling Gill's mealybug. Peak use occurs in May as growers manage Gill's mealybug (Figure 21).

Table 39: Annual Use of Target Nitroguanidine Substituted Neonicotinoids and Alternative Active Ingredients: Pistachio, 2015-2017

Active ingredient	**--------Pounds applied---------**				**------------Acres treated------------**				**Use rate (lbs/ac)**
	2015	2016	2017	Total	2015	2016	2017	Total	
acetamiprid	750	1,552	1,446	3,748	5,094	10,107	9,299	24,500	0.15
buprofezin	45,163	34,997	56,727	136,887	26,497	21,879	34,213	82,589	1.66
imidacloprid*	18,848	17,300	21,366	57,514	99,610	102,884	115,312	317,807	0.18
pyriproxyfen**	19	10	220	249	217	86.7	2,481	2,785	0.09
spirotetramat	3,385	4,164	4,555	12,104	26,286	34,690	36,575	97,551	0.12

*Target NGN
**Excludes bait products

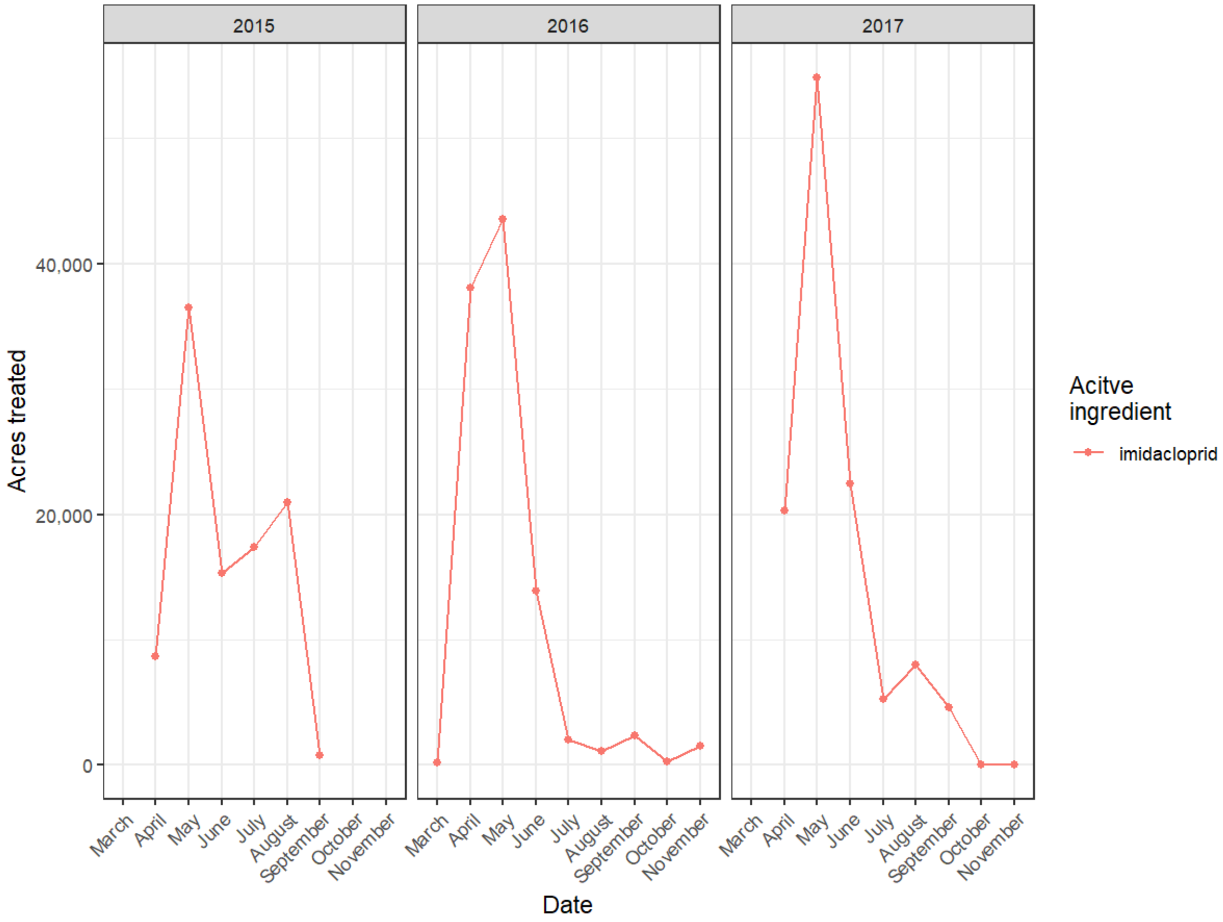

Figure 21. Monthly use of target nitroguanidine substituted neonicotinoids: pistachio, 2015-2017

Economic Analysis

This section presents the estimated change in net revenues for pistachio owing to the cancellation of imidacloprid, the only NGN used on pistachio. This includes the change in both pesticide material and application costs when an alternative treatment requires a different application method. No yield or quality reduction is anticipated due to the use of alternatives. In the absence of any anticipated effect on yields, gross revenues will not change, so the impact on net returns is determined by the impact on costs.

Table 14Table 40 presents representative products for each active ingredient used on pistachio in 2015–17 and their cost 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 application cost varies based on the different application method mentioned previously. There is substantial variation in the cost per acre of AIs, ranging from $31.06 per acre to $131.31 per acre.

Table 40: Representative Products and Costs Per Acre: Pistachio

Active ingredient	Representative product	Material cost ($)	Application cost ($)	Total cost ($)
acetamiprid	Assail 30sg Insecticide	53.77	23.37	77.14
buprofezin	Applaud 70 Df Insect Growth Regulator	106.55	24.76	131.31
imidacloprid	Admire Pro	10.97	20.09	31.06
pyriproxyfen*	Seize 35 Wp Insect Growth Regulator	45.15	25.00	70.15
spirotetramat	Movento	70.55	24.93	95.48

*Excludes bait products

Table 41 shows the average acreage shares for each non-NGN alternative AI used on pistachio, with and without imidacloprid being available. Averaged over the three-year period 2015–17 when imidacloprid is available, it was used on 60.5% of total pistachio acres treated with insecticides, and alternative AIs were used on 39.5% of pistachio acreage treated with insecticides.

If imidacloprid was cancelled, the uses of alternative AIs are scaled up in proportion to their acreage shares, as discussed in the methods section. The two most common alternative AIs were spirotetramat and buprofezin, together accounting for 86.8% of the acres treated without NGNs.

Table 41: Average Annual Acreage Shares of Alternative Insecticides with and without Target Nitroguanidine Substituted Neonicotinoids (NGNs): 2015–2017

Active ingredient	Target NGNs available (%)	Target NGNs cancelled (%)
acetamiprid	4.7	11.8
buprofezin	15.7	39.8
pyriproxyfen*	0.5	1.3
spirotetramat	18.6	47.0
total	39.5	100

*Excludes bait products

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

Table 42 reports the average per acre costs for imidacloprid as well as the cost of the composite alternative, whose price we use as a representative pesticide cost if imidacloprid were cancelled. For pistachio, switching to the alternative would lead to an increase in both material cost and application cost. Total cost per acre would rise by 245.3%.

Table 42: Costs Per Acre for Target Nitroguanidine Substituted Neonicotinoids and the Composite Alternative: Pistachio

Active ingredient	Material cost ($)	Application cost ($)	Total cost ($)	Cost increase for switching to composite alternative (%)
imidacloprid	10.97	20.09	31.06	245.3
composite alternative	82.56	24.68	107.24	-

Table 43 reports the estimated change in materials cost due to the cancellation of imidacloprid. For pistachio, total insecticide costs increase dramatically from just over $3 million per year, to more than $10 million per year, a percentage increase of 245.2%. The percent change in costs is constant because only one NGN is used on pistachio, so there is no change in the ratio of NGN use between years. The change in total cost is almost entirely due to increase in material cost. The material cost for imidacloprid is $11 per acre which is lowest among all insecticides used in pistachio. Two major alternatives, spirotetramat and buprofezin have material cost of $70.55 and $106.55 per acre respectively.

Table 43. Change in Treatment Total Costs due to Cancellation of Nitroguanidine Substituted Neonicotinoids (NGNs): Pistachio, 2015–2017

Year	Cost with target NGNs ($)	Cost without target NGNs ($)	Change in cost ($)	Change in cost (%)	Change in material cost (%)	Change in application cost (%)
2015	3,094,133	10,682,409	7,588,276	245.2	94	6
2016	3,195,828	11,033,509	7,837,681	245.2	94	6
2017	3,581,865	12,366,289	8,784,424	245.2	94	6

The magnitude of these changes is driven by the large treated pistachio acreage, the large share of treated acres that are treated with imidacloprid currently, and the large price differences between imidacloprid and its most-used alternatives. In 2017, for example, total treated pistachio acreage was 197,881 and the share of the treated acreage treated with imidacloprid was 58.3%. One example of the change in relative costs was spirotetramat, which had a cost per acre of $95.48, and increased its share of total acres treated by 28.4%, or 56,198 acres. Compared to the cost per acre of imidacloprid ($31.06), costs are over three times higher. For the acres that are modeled as switching from applying imidacloprid to spirotetramat, the total increase in costs is $3,620,275, over a quarter of the total increase in costs.

Conclusions and Critical Uses

Imidacloprid is the major pesticide used for controlling Gill’s mealybug in pistachio. It also has the lowest cost per acre ($31.06/ac), including application costs. The cost of the alternative bundle is $107.24 per acre, including application costs. Pistachio, therefore, has a large increase in pesticide costs under a cancellation of NGNs because many acres would need to switch to the alternative bundle, and the alternative bundle is much more expensive than the NGN treatment.

Strawberry

California is the largest strawberry producer in the U.S. accounting for 89% of national production. There were 38,200 harvested acres in 2017, which produced 1,461,200 tons worth over $3.1 billion (CDFA, 2018a). Strawberries are mainly sold in the fresh market, which has a higher price per unit than the processed market. A small portion of production went into the processing market. In 2017, strawberries sold in the fresh market were worth over $2.9 billion with an average price of $2,460 per ton. The remainder were processed at an average price of $464 per ton. By export value, strawberry was the 10th most important agricultural product in California. $415 million of production was exported in 2017. California's exports accounted for 87.9% of national strawberry exports by value. The three largest strawberry producing counties, Monterey ($677 million), Ventura ($587 million), and Santa Barbara ($358 million), accounted for 78.6% of state production in 2017. The next most important strawberry-producing counties were San Luis Obispo (10% of production value) and Santa Cruz (9.2%). Strawberry was also the second agricultural commodity by value in 2017 for Orange County ($19 million produced). Figure 22 maps the distribution of California strawberry production.[6]

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[6] Although strawberry nursery production occurs in multiple counties, only Siskiyou County reports pesticide applications and acreage productions to the state. Some of the acreage in the figure may be nursery production rather than commercial fruit production.

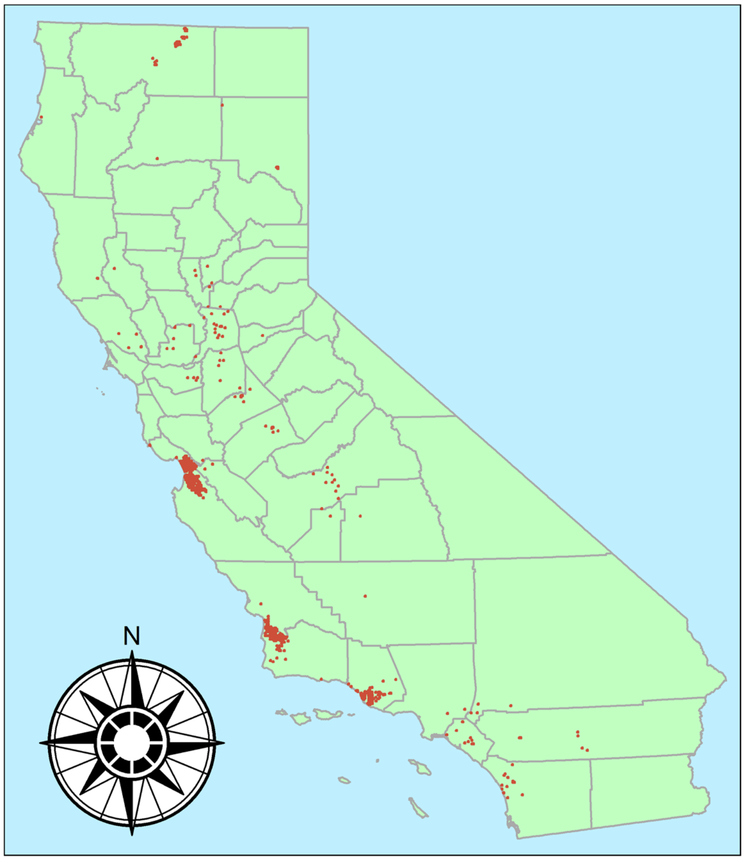

Figure 22. California strawberry production, 2017

Strawberry Production Systems

Strawberry production occurs in four designated 'districts'; moving northward on the California coast the four districts are the Orange-San Diego-Coachella district, Oxnard, Santa Maria, and Salinas-Watsonville. Production in these districts for calendar year 2018 are presented in Table 44. Until recently, the percentage of total California production was much greater in the Oxnard district, and more similar to that of Santa Maria, and Salinas-Watsonville. (Production has been shifting to Mexico, which has lower costs.) Of these 'districts', production practices in the Orange-San Diego-Coachella and Oxnard districts are most similar to one another, as are those in the Santa Maria and Salinas-Watsonville districts.

Table 44: US Strawberry Acreage and Yield: 2018

District	Percent of production	Total production (1,000 flats)
Orange-San Diego-Coachella	0.0	9
Oxnard	5.7	11,222
Santa Maria	35.6	70,047
Salinas-Watsonville	58.7	115,491

The most important difference in production practices in these regions can best be characterized by use of two distinctly different seasonal planting systems. In the "summer planting" system that is characteristic of the Orange-San Diego-Coachella and Oxnard districts, the annual strawberry crop is planted during summer for fruit harvest in fall through spring. In the Santa Maria and Salinas-Watsonville districts "fall planting" system, the annual strawberry crop is planted from late September to mid-November, depending on location, for fruit harvest beginning in the spring and continuing through early fall. Table 45 presents typical planting periods, flowering periods, and harvest periods for California's production areas.

Table 45: Flowering and Harvest Periods by Production Region: Strawberry

District	Planting Period	Flowering Period	Harvest Period
Orange-San Diego-Coachella	mid Sept-mid Oct (Fall planting)	Nov-Apr (Fall planting)	Dec-Apr (Fall planting)
Oxnard	mid-July-Sept (Summer Planting)	Oct-May (Summer Planting)	Oct-early June (Summer Planting)
Santa Maria	mid Oct-mid Nov	Feb-Nov	mid Feb-Nov
Salinas-Watsonville	mid Oct-mid Nov	Late Feb-Nov	mid-March-Nov

Strawberry is a perennial plant, but in California commercial production it is typically managed as an annual crop, although a small percentage of the acreage is kept for a second year of harvesting. Strawberries are harvested in California every month of the year, with peak statewide production occurring in late spring. This year-round production can be attributed to the use of cultivars that have broad environmental adaptation, the use of innovative production systems that maximize yield, fruit quality, harvest efficiency, and the use of pest and pathogen-free soil environments.

Strawberry cultivars are classified into two general groups: "short-day" and "day-neutral." Transplants of certified stock are used for both groups. Short-day cultivars form flower buds when exposed to daily light periods (photoperiods) of 14 hours or less. They grow vegetatively during the short days of fall and produce fruit early in the spring. In California growing areas with mild winters, short-day cultivars continue forming flower buds throughout the winter. The transplant stock comes from high-elevation nurseries where temperatures are low enough to provide adequate chilling (Darrow 1966). Day-neutral cultivars, also called "ever-bearing," form flower buds throughout the year, irrespective of photoperiod, as long as temperatures are favorable and therefore produce ripe berries in summer into the fall after production has tapered off and ended for short-day cultivars. In California, short-day cultivars are more typically planted in the Orange-San Diego-Coachella and Oxnard districts while both short-day and day-neutral cultivars are grown in the Santa Maria and Salinas-Watsonville districts. When production is tapering off and ends in the southern districts, production increases in the more northernly districts allowing year-around production in the state.

California strawberries are primarily grown for the fresh market, although there is a substantial market for “processing” strawberries that are picked for freezing or juice. Because the price for the processing market is very low relative to the fresh market, few if any California growers produce strawberry primarily for processing, but rather sell for this purpose when there is no market for fresh berries from a particular region such as late spring berries from southern California and the Oxnard district when other growing regions are in full production or when there are substantial cull (but acceptable for processing) berries present. These cull fruit often are the result of insect feeding or contamination that results from the presence of large numbers of insects. Because of the low value of processing berries and because appearance is not crucial, they are rarely treated with insecticides except to prevent the presence of insects in harvested and processed fruit.

IPM Overview

Two NGNs are registered for and applied to control sucking insect pests in California strawberry: imidacloprid and thiamethoxam. Both were designated as high risk (Troiano et al. 2018). Insect pests associated with NGN labels for California strawberry include aphids, leafhoppers, lygus bugs, root weevils and grubs, and whiteflies. The importance of these insects may vary by region and year. Strawberry regions are defined in Table 46.

Table 46: Strawberry Growing Regions

Region	**Counties**
Southern California	Orange, San Diego, Riverside, San Bernardino
Oxnard	Ventura
Santa Maria	Santa Barbara, San Luis Obispo
Central Coast	Monterey, Santa Cruz, Santa Clara, San Benito

Target Pests

Aphids. Several aphids affect strawberry. The most important of these occur early in the fruiting season and can become problematic in all production districts. These include the green peach aphid (*Myzus persicae*), the strawberry aphid (*Chaetosiphon fragaefolii*), and the melon aphid (*Aphis gossypii*). The most common type of damage associated with aphid feeding is contamination of the fruit with the honeydew that they produce and the associated growth of sooty mold fungi on the honeydew. In addition, when aphids molt, their caste skins stick to the fruit. Fruit contamination with honeydew, sooty mold and insect skins renders the fruit unmarketable for the fresh market, greatly reducing the value of the fruit. Aphids can also transmit viruses that significantly reduce fruit yield, among them strawberry mottle virus, strawberry crinkle virus, and strawberry mild yellow edge virus.

The seriousness of viruses transmitted by aphids varies by production system. Aphid transmitted viruses are not a serious problem in annual production plantings when the strawberry transplants are certified as virus-free, but they can become a problem in strawberry plants that are grown for more than one year. Aphids present the biggest risk for nurseries, which are not included in this analysis. Aphid control to prevent transmission of viruses is a major concern for California strawberry nursery production because the nurseries undergo a state certification process before their transplants can be sold, and all nurseries routinely treat for aphids to meet certification standards.

Early season aphids in production fields can be controlled with imidacloprid applied by chemigation before the initiation of harvest, and this application is useful to prevent virus infection when there is a source of virus nearby. In the absence of virus, they are more commonly controlled when their populations begin to build after harvest begins. Foliar applications of thiamethoxam are a common and effective control for aphids during the harvest season. Acetamiprid is a direct alternative to a foliar thiamethoxam spray. Other alternatives include foliar applications of flonicamid, naled, and the pyrethroids bifenthrin and fenpropathrin. In general, foliar applications of these alternative insecticides can be substituted for thiamethoxam on a spray for spray basis. Flupyradifurone, a butenolide insecticide that recently received a Section 2(ee) registration for lygus bug control in strawberry, could also prove an alternative to the NGNs. However, only two applications a year can be made, and growers would likely target lygus with those sprays because they are considered to be more serious pest problems and are more difficult to control with currently registered insecticides.

Lygus bug (*Lygus hesperus).* Lygus bug is considered the most important insect pest of fresh market strawberry production. Adults and nymphs damage fruit by feeding on developing fruit results in distortion of the fruit that is referred to as “catfacing.” These damaged fruit cannot be marketed as fresh fruit. If untreated, damage will commonly exceed 35% in a typical strawberry field. Lygus is present at damaging levels every year in all growing districts except southern California.

The primary insecticides used for lygus bug control for the last 25 years include bifenthrin, fenpropathrin, and malathion, but high levels of resistance to these chemicals are found in lygus populations (Zalom 2009), particularly in Watsonville/Salinas, Santa Maria and Oxnard. In most production districts naled and acetamiprid are also used for lygus control but are only considered moderately effective. Novaluron is fairly effective for control of lygus nymphs early season and flonicamid is fairly effective at reducing lygus feeding but does not kill the insects very quickly. The efficacy of both of these chemicals is reduced when lygus populations become greater as the harvest season progresses. The NGN thiamethoxam is also used for lygus control in California strawberry. As a stand-alone product, its efficacy is modest and similar to that of acetamiprid or naled. However, it is most useful when applied in a tank mix with another insecticide such as naled, novaluron, or a pyrethroid to enhance their efficacy (Joseph and Bolda 2016). Thiamethoxam is applied at least once each season to about 25% of California strawberry fields, mostly in a tank mix with another product. A newer AI, flupyradifurone, is effective against lygus (Joseph and Bolda 2016) and is considered an alternative. However, flupyradifurone can only be applied twice during a season so additional sprays for lygus control are still necessary.

Strawberry growers have incorporated use of vacuum machines from time to time when the local lygus bug populations become resistant to the primary insecticides used for their control.

In these cases, weekly or twice-weekly vacuuming is usually used in combination with whatever insecticides are available for their control to reduce the total amount of catfacing. Vacuums have been shown to reduce the number of lygus adults by 75% and nymphs by about 9 to 50% each time a field is vacuumed (Pickel et al. 1994).

In 2019, sulfoxaflor, a sulfoximine insecticide, a new chemical has become available for use by California strawberry growers specifically for lygus control under a Section 18 registration. There are no field observations at this time with regard to its efficacy in commercial applications. Previous field trials on strawberry in the Central Coast production area by UC Cooperative Extension personnel indicate the expected efficacy of sulfoxaflor to be somewhat better than thiamethoxam used with a tank mix partner, but similar to that of novaluron and flonicamid (Zalom 2012; Joseph and Bolda 2016). Sulfoxaflor applications are restricted at this time to a maximum of 28,000 acres and may not be used before 7 pm or after 3 am. As this exemption was only granted in 2018, there are no data available to use in this analysis. This means that though sulfoxaflor will be an alternative, it cannot be evaluated in this report.

Root weevils and grubs. Several species of root beetles are associated with strawberry in other US growing areas. Those species that are reported to occur in California include the black vine weevil (*Otiorhynchus sulcatus), the* cribrate weevil (*Otiorhynchus cribricollis),* Fuller rose weevil (*Pantomorus cervinus), and two species of scarab beetles (Hoplia dispar and H. callipyge).* These are only an occasional problem, primarily in nonfumigated fields following another host crop such as alfalfa, or in second-year strawberry fields. Adults feed on foliage, but the damage is insignificant. The larvae (grubs) of all of the species feed on roots and crowns for one to two years (in the case of Hoplia beetles) and can kill the plants. Unless the current California production system, which largely includes annual plantings and preplant soil fumigation, changes dramatically, they are not likely to become a significant problem (Bolda et al. 2008).

Soil fumigation with methyl bromide, 1,3-dicloropropene, chloropicrin, metam sodium and metam potassium for control of soil pathogens effectively eliminates any root beetles that might be present before transplanting, but root beetles could invade and be present in strawberry fields that have been planted for two or more years. This practice is rare in the primary strawberry production districts, but it occasionally occurs in small u-pick farms. In cases where root weevils are present, both imidacloprid or thiamethoxam applied by chemigation provide effective control. Diazinon applied by chemigation is also effective in controlling these beetles. Owing to the very limited acreage and scope of this pest problem in strawberry, diazinon was not included in the alternatives to NGNs in this report.

Whiteflies. The most important whitefly pest of California strawberry is the greenhouse whitefly (*Trialeurodes vaporariorum*) which occurs in all growing regions. Other whiteflies present in strawberry fields include the iris whitefly (*Aleyrodes spiroeoides*) and the strawberry whitefly (*Trialeurodes packardi*). Whiteflies reduce yield directly through their feeding on leaf tissue that stunts plant growth and reduces fruit quality (Bi and Toscano 2007). They can also have an economic impact indirectly by producing sticky honeydew on the fruit surface that provides a substrate for the growth of sooty mold fungi which renders the fruit unsuitable for the fresh market. Greenhouse whiteflies can transmit plant viruses including strawberry pallidoses associated virus and beet pseudo yellows virus that can result in rapid plant decline when they are present in tandem or with other plant viruses. Serious greenhouse whitefly outbreaks, often accompanied by virus transmission to strawberry, have occurred on several occasions in the last decade in the Oxnard, Santa Maria, and Salinas-Watsonville districts, resulting in significant crop losses for growers.

Prevention of whitefly establishment in new strawberry fields is essential when greenhouse whiteflies are present, especially during periods when an outbreak is occurring, to prevent virus transmission and to reduce the number of treatments that might need to be applied for control during the harvest season. Studies have shown that imidacloprid applied by chemigation at or shortly after transplanting is the most effective approach for controlling greenhouse whiteflies (BI et al. 2007; McKee et al. 2007). Applications with the insect growth regulator pyriproxyfen or other alternative chemicals such as spiromesifen (Bi et al. 2007), a tank mix of malathion and fenpropathrin, or the NGN thiamethoxam applied after whitefly populations begin to build during the harvest season are far less effective in preventing whitefly populations from building to damaging levels, and one or more of these chemicals will need to be applied more than once during the harvest season to control a greenhouse whitefly outbreak, with the estimated number of applications generally ranging from two to four.

Target NGN Use: 2015-2017

Imidacloprid is virtually always applied to the soil by chemigation, which is relatively simple for growers because all California strawberry cultivation uses drip irrigation. Owing to a 14 day preharvest interval (soil-applied) and a continual harvest once fruit are being produced, imidacloprid cannot be applied by chemigation, for all practical purposes, once harvest is initiated. Therefore, imidacloprid is only applied once preharvest. This practice is used on about 30% of California strawberry acreage in a given year but varies somewhat in number of acres treated and distribution between districts depending on pest outbreaks (particularly of whiteflies) that might have occurred the previous season. This variability is apparent in Figure 23, which plots use of imidacloprid and thiamethoxam by month and year. In each district, imidacloprid use peaks during planting.

In theory, imidacloprid can also be used as a foliar application, but this rarely occurs during the harvest season because of its 7-day pre-harvest interval when applied as a foliar spray because strawberry fruit are typically harvested on a more frequent schedule. Growers often harvest at 3-day intervals. In addition, label restrictions exclude the foliar use of imidacloprid once the plants begin to bloom. As Figure 23 shows, imidacloprid use is essentially nil outside of planting season for three of the four production districts. The Santa Maria district is the only exception, with some summertime use.[7]

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[7] There are at least two possible reasons for this summertime use. First, whitefly outbreaks have been occurring more recently in the Santa Maria district than in the other districts, and during an outbreak, growers may apply imidacloprid even at the expense of losing a couple harvests. Other districts may have had summertime use when

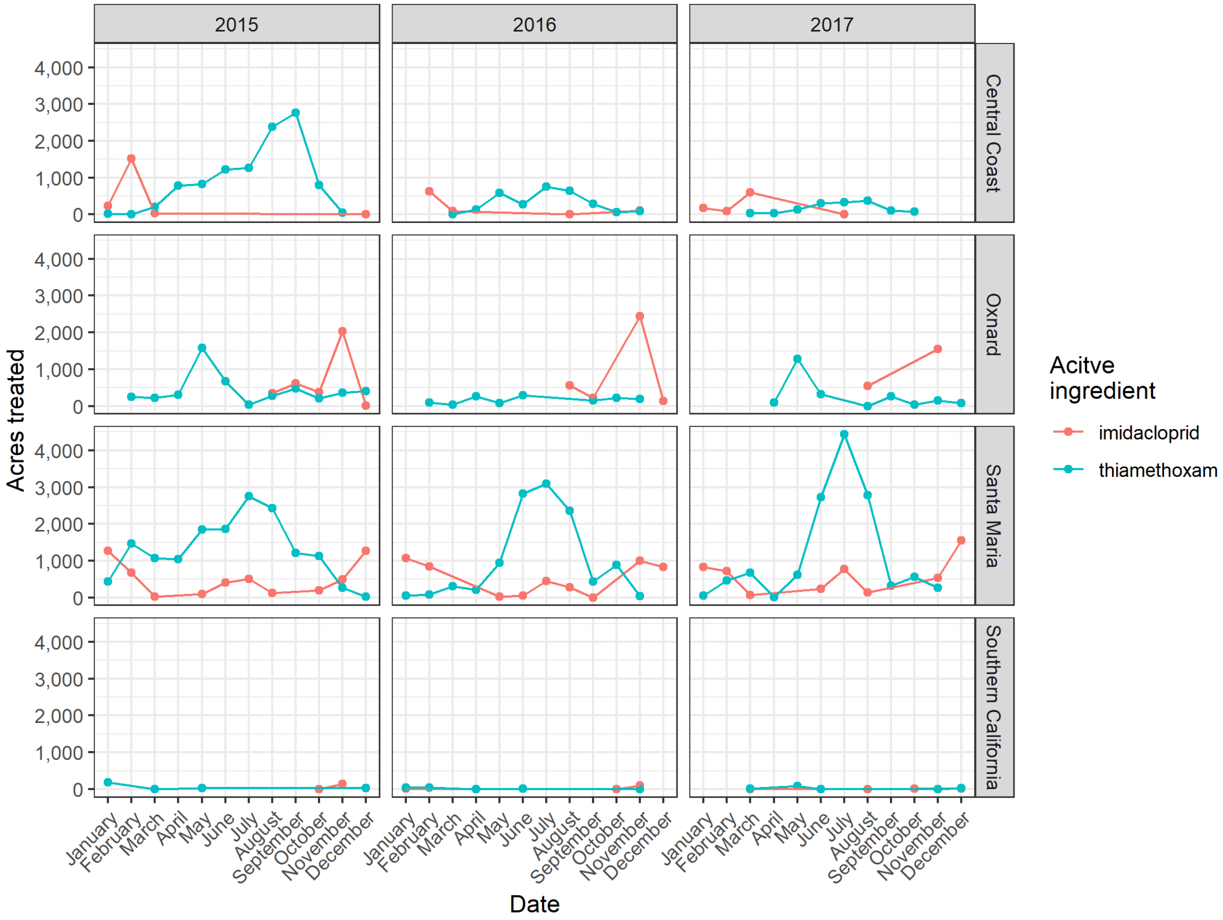

Figure 23: Monthly use of taret nitroguanidine substituted neonicotinoids: strawberry, 2015-2017

Thiamethoxam can be applied both as a soil treatment by chemigation or as a foliar spray. In California strawberry it is mostly applied via foliar spray, in part because of a 50 day preharvest interval for the chemigated product but also because of differences in efficacy of soil-applied neonicotinoids depending on soil texture. Thiamethoxam is most effective when used on heavy soils, while imidacloprid is very effective in light soils but ineffective in heavy soils. Strawberries are typically planted on lighter soils in the coastal areas where most California strawberries are grown. Thiamethoxam use varied considerably for each region over the 2015-2017 period (Figure 23).

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there were active outbreaks in those locations. Second, if a grower has a second-year field he may treat it in the summertime before pulling it out so that adult whiteflies don't emigrate to nearby first-year fields.

Table 47: Annual Use of Nitroguanidine Substituted Neonicotinoids and Alternative Active Ingredients: Strawberry Imidacloprid, 2015-2017

Active ingredient (AI)	**Lbs of AI applied**				**Acres treated**				**Use rate (lbs/ ac)**
	2015	2016	2017	Total	2015	2016	2017	Total	
fenpropathrin in mix w/malathion	1,134	1,011	643	2,788	4,261	3,532	2,420	10,212	0.27
imidacloprid*	5,146	4,486	4,290	13,922	11,419	10,151	10,199	31,769	0.44
malathion in mix w/ fenpropathrin	9,013	7,243	4,017	20,273	4,261	3,569	2,340	10,180	2.00
pyriproxyfen	147	81	123	351	2,241	1,212	1,840	5,292	0.07
spiromesifen	3,383	2,775	2,036	8,193	13,894	11,276	8,252	33,422	0.25

*Target NGN

Table 47 reports pounds applied, acres treated, and the average use rate for imidacloprid and alternative active ingredients applied to strawberry. Imidacloprid and spiromesifen each accounted for over a third of acres treated in the 2015-2017 period. The label for the only fenpropathrin products registered for use in strawberry to control whitefly requires application in a mix that also includes malathion. Across years, acres treated were the highest in 2015 for all active ingredients, consistent with the decline in total strawberry acreage over this period.

Table 48: Annual Use of Nitroguanidine Substituted Neonicotinoids and Alternative Active Ingredients: Strawberry Thiamethoxam, 2015-2017

Active ingredient (AI)	**Lbs of AI applied**				**Acres treated**				**Use rate (lbs/ ac)**
	2015	2016	2017	Total	2015	2016	2017	Total	
acetamiprid	5,687	4,254	4,409	14,349	45,591	33,701	34,741	114,033	0.13
bifenthrin	6,982	5,324	5,865	18,171	66,493	51,179	55,377	173,049	0.11
fenpropathrin	8,300	5,809	5,157	19,266	29,493	20,391	18,073	67,957	0.28
flonicamid	6,030	4,869	4,845	15,743	69,203	56,178	55,486	180,867	0.09
flupyradifurone	1,554	3,072	3,665	8,291	8,688	17,090	20,122	45,900	0.18
malathion	71,873	51,526	53,845	177,245	36,193	26,177	27,141	89,510	1.98
naled	19,586	12,651	12,817	45,054	20,070	12,796	12,774	45,640	0.99
novaluron	6,242	5,635	5,435	17,312	81,935	74,865	72,756	229,556	0.08
thiamethoxam*	1,883	966	1,028	3,878	30,918	15,535	16,682	63,134	0.06

*Target NGN

Table 48 reports pounds applied, acres treated, and the average use rate for thiamethoxam and alternative active ingredients applied to strawberry. Novaluron was applied to the most acres in the 2015-2017 period, 3.6 times as many acres as thiamethoxam. Across years, acres treated were the highest in 2015 for all active ingredients, consistent with the decline in total strawberry acreage over this period.

Other Considerations

Secondary pest outbreaks and the development of resistance to specific active ingredients are other factors that would be influenced if imidacloprid and thiamethoxam were no longer available for use on strawberry.

Secondary pest outbreaks. Imidacloprid applications during or after transplanting, but before initiation of harvest, are important to prevent virus transmission to strawberry by greenhouse whitefly (strawberry pallidoses associated virus, beet pseudo yellows virus) in all California production districts. Imidacloprid application is also important for aphid control to prevent virus transmission (strawberry mottle virus, strawberry crinkle virus, strawberry mild yellow edge virus) in cases where infected second year plantings are present and in strawberry nursery production where certified virus-free plants are grown because of the extended protection provided following application. Since alternative insecticides do not have the residual efficacy of imidacloprid applied to the soil by chemigation, multiple applications of alternative chemicals would have to be made to assure an adequate level of control to prevent virus transmission. Virtually all of the alternative chemicals would be applied to foliage and many are more disruptive of natural biological control than is imidacloprid, the result being outbreaks of other insects and spider mites that would also require insecticide sprays for their control.

Resistance management. Repeated applications of insecticides with similar modes of action creates selection pressure on resident insect populations that could lead to control failures. Many examples of control failures due to whiteflies and aphids have been documented in agricultural production systems worldwide, so a case can be made for maintaining imidacloprid and thiamethoxam uses as tools since relatively few alternative chemicals are registered on strawberry. In addition, lygus bugs are an annual problem as well as a very damaging insect that is very difficult to kill effectively with any insecticide, so multiple insecticide applications must be made each year in every production district for their control. The synergistic action of thiamethoxam with other chemicals such as novaluron and pyrethroids when applied in a tank mix (combination spray) are especially valuable in achieving greater levels of lygus control than individual sprays of these or other alternative chemicals, thereby reducing the total number of times individual sprays need to be applied.

Resistance management is done, in part, by rotating the use of products with different modes of action to reduce selection pressure on pests. For strawberry growers, it is important to maintain a variety of registered products since so few products actually become registered owing to the low number of acres produced nationally relative to other crops, i.e., limited market for registrants. In addition, the short preharvest interval necessary to make a chemical compatible with the frequent (often twice a week) picking schedule of fresh market berries, and the relatively great contribution of strawberry fruit to the US EPA ‘risk cup” calculation for a product since the fruit are consumed fresh shortly after harvest. The risk cup contribution means that registrants may choose not to register an effective chemical on strawberry because it might preclude its use on a crop with far greater acreage but where less residue may be present at harvest. As a result, maintaining an effective chemical class such as NGNs plays a more critical role in resistance management in strawberry production than in other crops since they may not be quickly replaced by a similarly effective product representing a different chemical class for a specific use, and therefore loss of a given chemical class can have an even greater impact.

Economic Analysis

This section presents the expected change in costs for strawberry production owing to the cancellation of imidacloprid and thiamethoxam. This cost includes the change in pesticide material costs and application method costs. In the absence of any anticipated effect on yields, gross revenues will not change. In addition to the caveats discussed in the methods section, the costs estimated below do not account for the potential effects of increased insect resistance to pyrethroids or for costs associated with managing secondary pest outbreaks.

Table 49 and Table 50 present representative products for each active ingredient used on strawberry 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 application cost per acre is the average application cost based on application method across all applications of the AI to the crop. Growers consider other factors in addition to price per acre when deciding which insecticides to use, as discussed above.

Table 49 presents representative products and their cost per acre for imidacloprid and its alternatives based on usage on strawberry usage from 2015-2017. In the case of imidacloprid, managing whiteflies using alternatives requires more than one application, generally ranging from two to four. The number of applications needed would likely vary as not all areas have whitefly infestations every year. The economic analysis assumes that three applications of the alternatives are required. Thus, all costs per acre are for *three applications* of the respective alternative, while the costs per acre for imidacloprid are for one application. Total costs per acre range from $73.98 to $236.25 per acre for three applications ($24.66 to $73.86 per acre for one application). Additionally, fenpropathrin must be applied with malathion to treat whiteflies in strawberry. Accordingly, when these AIs are applied in the composite alternative for imidacloprid, they will be applied together in a tank mix using a boom sprayer (cost: $25 per acre). Therefore, application costs per acre are split across these two AIs ($37.50 for three applications is $12.50 per application).[8]

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[8] In order to manage resistance, growers would tend to use multiple alternatives within a season rather than using the same one three times. These costs are used to compute the cost per acre of the composite alternative, which reflects use patterns across active ingredients and hence is consistent with the use of more than one specific alternative during the season.

Table 49: Representative Products and Costs per Acre: Strawberry (Imidacloprid)

Active ingredient	Representative product	Material Cost per acre($)	App Cost per acre($)	Total Cost per acre($)
fenpropathrin*	Danitol 2.4 EC Spray	71.98	37.50	109.48
imidacloprid	Admire Pro	26.56	5.62	32.18
malathion*	Malathion 8 Aquamul	36.48	37.50	73.98
pyriproxyfen	Esteem 0.86 EC Insect Growth Regulator	161.8	74.44	236.25
spiromesifen	Oberon 2 SC Insecticide/Miticide	147.82	73.77	221.59

* Danitol, the only product registered in strawberry, label requires a tank mix application that includes malathion when used to treat whitefly. Application costs are divided between the two.

Table 50 presents representative products and their cost per acre for thiamethoxam and its alternatives based on usage on strawberry usage from 2015-2017. Total cost per acre ranges from $32.93 to $75.19. For comparison to when they are applied in a tank mix in the composite alternative for imidacloprid, note that fenpropathrin and malathion application costs are $24.83 and $24.91 per acre, respectively, when applied to replace thiamethoxam as shown in Table 50.

Table 50: Representative Products and Costs per Acre: Strawberry (Thiamethoxam)

Active ingredient	Representative product	Material Cost per acre($)	App Cost per acre($)	Total Cost per acre($)
acetamiprid	Assail 70 WP Insecticide	44.23	24.80	69.03
bifenthrin	Brigade WSB Insecticide/Miticide	26.44	24.69	51.13
fenpropathrin	Danitol 2.4 EC Spray	25.08	24.83	49.92
flonicamid	Beleaf 50 SG Insecticide	33.25	24.92	58.17
flupyradifurone	Sivanto 200 SL	50.34	24.85	75.19
malathion	Malathion 8 Aquamul	12.08	24.91	36.99
naled	Dibrom 8 Emulsive	7.96	24.97	32.93
novaluron	Rimon 0.83 EC Insecticide	23.68	24.88	48.56
thiamethoxam	Actara	15.72	24.90	40.63

Table 51 and Table 52 show the average acreage shares for each alternative AI used on strawberry, with and without imidacloprid and thiamethoxam being available, respectively. Averaged over the three-year period 2015-2017 when the NGNs were available, the target NGNs were used on 35.0% and 6.4% of total strawberry acres treated with insecticides, respectively, and alternative AIs were used on 65.0% and 93.6% of strawberry acreage treated with insecticides. Total acres treated with insecticides does not correspond to total acres of strawberry grown since some growers may have used multiple AIs on the same field.

If the target NGNs were unavailable, 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 for imidacloprid—spiromesifen, fenpropathrin, and malathion—together accounted for 59.2% of strawberry acres treated, which is 91.0% of acres treated without imidacloprid. The three most common alternative AIs for thiamethoxam—novaluron, flonicamid, and bifenthrin—together accounted for 59.0% of strawberry acres treated, which is 63.0% of acres treated without thiamethoxam.

Table 51: Average Annual Acreage Shares of Alternative Insecticides with and without Target Nitroguanidine Substituted Neonicotinoids (NGNs): Strawberry (Imidacloprid), 2015–2017

Active ingredient	Acreage share with target active ingredients available (%)	Acreage share without target active ingredients available (%)
fenpropathrin	11.2	17.2
malathion	11.2	17.2
pyriproxyfen	5.8	9.0
spiromesifen	36.8	56.5
Total	65.0	99.9

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

Table 52: Average Annual Acreage Shares of Alternative Insecticides with and without Target Nitroguanidine Substituted Neonicotinoids (NGNs): Strawberry (Thiamethoxam), 2015–2017

Active ingredient	Acreage share with target active ingredients available (%)	Acreage share without target active ingredients available (%)
acetamiprid	11.5	12.3
bifenthrin	17.5	18.7
fenpropathrin	5.8	6.2
flonicamid	18.3	19.5
flupyradifurone	4.6	5.0
malathion	8.0	8.6
naled	4.6	4.9
novaluron	23.2	24.8
Total	93.6	100.0

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

Table 53 and Table 54 report the average per acre costs for the target NGNs, imidacloprid and thiamethoxam, as well as the cost of their respective composite alternatives, whose price we use as a representative pesticide cost if the NGNs were deregistered. For imidacloprid on strawberry, three applications of the composite alternative are required. The material and application cost per acre are higher for the composite alternative, so three applications result in a substantial cost increase per acre, from $32.18 to $178.11 (Table 53). The composite alternative for thiamethoxam is $0.05 less expensive to apply, but its material costs are $12.51 per acre more expensive (Table 54). Overall, imidacloprid users will incur a total per acre cost increase of 453.5% while thiamethoxam users will incur an increased cost of 30.6%.

Table 53: Cost per Acre for Target Nitroguanidine Substituted Neonicotinoids and the Composite Alternative: Strawberry, Imidacloprid

Active ingredient	Material cost ($)	Application Cost ($)	Total cost ($)	Cost increase for switching to composite alternative, three applications (%)
imidacloprid	26.56	5.62	32.18	453.5
composite alternative (one application)	38.93	20.44	59.37	-
composite alternative (three applications)	116.79	61.32	178.11	-

Table 54: Average Cost per Acre for Target Nitroguanidine Substituted Neonicotinoids and the Composite Alternative: Strawberry, Thiamethoxam

Active ingredient	Material cost ($)	Application cost ($)	Total cost ($)	Cost increase for switching to composite alternative (%)
thiamethoxam	15.72	24.90	40.63	30.6
composite alternative	28.23	24.85	53.07	-

Table 55 reports the expected change in costs owing to the removal of imidacloprid and thiamethoxam. For strawberry production, the percentage increase in total costs ranges from 126.4% in 2015 to an increase of 174.9% in 2016. The absolute value of this cost increase ranges from $2.05M in 2015 to $1.70M in 2017. The majority of this cost increase is due to replacing a single application of imidacloprid with three applications of the composite alternative. The percentage and absolute value cost increase in strawberry is large, so it is useful to compare these costs to gross revenues. At 760 cwt per acre and an average value of $63.80 per cwt, 2016 statewide average revenues were $48,488 per acre.[9] On a per acre basis, the cost of three applications of the composite alternative to replace one application of imidacloprid is $178.11 per acre, less than one-half of one percent of average gross revenues. The $53.07 per acre cost of the alternative to thiamethoxam is roughly one-tenth of a percent of average gross revenues.

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[9] Revenues include fresh and processed sales. Acreage and yield are not reported separately for fresh market and processing strawberry (CDFA, 2017). Often both fresh and processing strawberry are harvested from a planted acre.

Table 55. Change in Treatment Costs due to Cancellation of Target Nitroguanidine Substituted Neonicotinoids (NGNs): Strawberry, 2015–2017

Year	Cost with target active ingredients ($)	Cost without target active ingredients ($)	Change in cost ($)	Change in cost (%)	Share of change due to material costs (%)	Share of change due to application costs (%)
2015	1,623,527	3,674,935	2,051,408	126.4	60	40
2016	957,786	2,632,637	1,674,851	174.9	61.7	38.3
2017	1,005,933	2,702,065	1,696,132	168.6	61.5	38.5

Greenhouse whitefly and imidacloprid: gross revenue and net return losses. Replacing a preventative application of a systemic pesticide with one or more foliar treatments when an infestation occurs is a significant change in an integrated pest management program. For strawberry, there is the possibility that alternatives to imidacloprid may not provide adequate control of whitefly to avoid yield loss. While acreage that was not treated preventatively with imidacloprid at planting may not require treatment to control whiteflies (and their virus transmission) during the growing season if whiteflies do not invade a given field, when a severe enough outbreak of whiteflies does occur even three treatments of alternatives may not be sufficient to control it.

Zalom, Thompson and Glik (2004) report strawberry yield for a number of treatments with and without imidacloprid for a 2002-2003 trial conducted near Watsonville, CA. All products were applied once at their top label rates. Imidacloprid applied at planting resulted in the highest yield: 3,143.9 g/plant (Zalom et al. 2004). On average, treatments that did not include imidacloprid had yields that were 16.3% lower than imidacloprid applied at planting.[10] Spiromesifen was not included in that study. Later research indicates that spiromesifen is slightly more effective than pyriproxyfen against nymphs but only moderately effective against adults. This yield loss serves as an upper bound on the percentage yield loss if imidacloprid was cancelled because the alternative treatments were only applied once in the field trial, while control would tend to require 2-4 treatments and 3 treatments are used here to estimate the increase in costs due to the cancellation.

The price of strawberries may increase in response to a reduction in yield and the corresponding total quantity produced. The percentage change in price in response to a 1% change in quantity is referred to as the price flexibility of demand. Its inverse is referred to as the own-price elasticity of demand. If the price of strawberries do not change at all when the quantity produced changes, then the demand curve is referred to as perfectly elastic. If the price of strawberries increases by less than 1% when the quantity of strawberries produced increases by 1%, then demand is elastic. If buyers consider other fruits to be perfect substitutes

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[10] Treatments included in this calculation were pyriproxyfen, malathion, and malathion + fenpropathrin. Spiromesifen was not included in the trial.

for strawberries or if producers in other regions can increase sales, then a decrease in the quantity of California strawberries produced will not affect the price. In this case, assuming that all acres treated with imidacloprid would sustain a 16.3% yield decreases, gross revenues would decline 16.3% as well. In 2017, gross revenue losses would be $13,228.67 per acre, and total gross revenue losses on the 10,199 acres treated with imidacloprid would be $134,919,166.[11] Combining these losses with the cost increases calculated earlier, total net returns on acreage that was treated with imidacloprid in 2017 would decrease by $136,615,298.

If instead a change in the quantity of California strawberries produced was associated with a change in price, then a decrease in production would result in an increase in price. (Carter et al. 2004) estimated an own-price elasticity for strawberry of -1.54, which corresponds to a price flexibility of 0.649. Though the price of strawberries increases when quantity decreases, reducing losses, it does so less than proportionately.

In 2017, assuming that an acre was treated with imidacloprid was treated no more than once and that the remainder of the 38,200 harvested acres reported by CDFA (2018) were unaffected, then the total quantity of California strawberries produced would decline by 4.4%, and the price would increase by 2.8%. Gross revenues per acre would decline by 13.9% on these 10,199 acres. (Gross revenues per acre would increase by 2.8% on the remaining acreage.) Total gross revenue losses would be $115,340,972. Combining these losses with the cost increases calculated earlier, total net returns would decrease by $117,037,104. Table 56 reports annual losses in gross revenues and net returns for 2015-2017 for perfectly elastic demand and a demand elasticity of -1.54.

Table 56. Gross Revenue and Net Return Losses by Demand Elasticity and Year: 16.3% Yield Decrease on Acreage Affected by Cancelation of Imidacloprid

	--------Perfectly elastic demand---------		**--------Demand elasticity = -1.54--------**	
Year	**Decrease in gross revenues ($)**	**Decrease in net returns ($)**	**Decrease in gross revenues ($)**	**Decrease in net returns ($)**
2015	86,193,355	87,889,487	72,984,914	74,681,046
2016	133,747,432	135,422,283	114,411,582	116,086,433
2017	134,919,166	136,615,298	115,340,972	117,037,104

Conclusions and Critical Uses

Cancellation of imidacloprid and thiamethoxam in strawberry would result in a $1.7 million to $2.1 million increase in insecticide costs. Although imidacloprid is not nearly as widely used as thiamethoxam for strawberry, it is the main driver of the cost increase because one application would likely be replaced by three applications of more expensive alternatives. In percentage and absolute values these increases are large, but on a per acre basis they amount to less than

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[11] This gross revenue loss per acre estimate is also an appropriate estimate for losses incurred due to a localized outbreak. If the impacted acreage is a sufficiently small share of total acreage, the reduction in quantity produced will be too small to affect the price.

one-half of one percent of gross revenues for imidacloprid users and less than one-tenth of one percent of gross revenues for thiamethoxam users.

Net revenue losses increase substantially if yields decrease owing to the cancellation of imidacloprid. Using a yield loss estimate based on a single application of alternatives, annual net revenue losses ranged from $73.0 million (2015, imperfectly elastic demand) to $136.62 million (2017, perfectly elastic demand).

Tomato

Tomato was California's eighth largest commodity by value of production in 2017, with gross revenues of $1.1 billion (CDFA 2018a). Exports were $686 million (UCAIC 2018). Tomatoes in California are grown for two markets: fresh and processed. California is the largest producer of processing tomato and the second largest producer of fresh tomato in the U.S., behind only Florida. There were 33,700 acres of fresh tomato and 258,000 acres of processing tomato in 2016, which produced 531,000 and 12,647,000 tons worth $298 million and $1,032 million, respectively (CDFA 2017).

Fresh tomato production is concentrated in Fresno County ($72 million, 28.6% of California production) and Merced County ($67 million, 26.6%) in 2016. Other top fresh tomato producing counties include San Diego (17.0%), Kern (8.4%), and Santa Clara (6.1%). $41 million (13.8%) of fresh tomato were exported in 2016, which made fresh tomato the thirty-fifth largest agricultural product ranked by export value. Figure 24 displays the geographic distribution of California's fresh tomato production.

Processing tomato production is also concentrated in Fresno County, which produced $322 million (34.8%) in 2016. The next largest processing tomato producing counties were Yolo (12.5%), Kings (12.3%), San Joaquin (9.3%), and Merced (8.7%). Processing tomato were the seventh most important agricultural export for California, with a value of $743 million. 72.0% of processing tomato were exported (CDFA 2017). Figure 25 displays the geographic distribution of California's processing tomato production.

There are a variety of horticultural practices and crop uses, especially within the fresh market category. Fresh market tomato plants are grown as bushes or on poles. Pole tomato production consists primarily of indeterminate varieties that are harvested over a long period of time during the production season, while bush tomato tends to be determinate and picked once (or at most a few times) during the season. The length of the production season has a significant impact on the pest complex and abundance of pests because insect populations tend to increase with the length of the production season. Because fresh tomatoes are typically used whole by consumers, appearance is important growers strive to produce unblemished fruit. In some cases, insecticides are applied as much to protect the appearance (quality) of fresh market tomatoes as to protect yield. Some fresh tomatoes are grown in greenhouses, which requires a different pest management program. Greenhouse production accounts for less than two percent of California fresh tomato production by yield, so we do not address it here.

Tomatoes intended for processing tend to be determinate varieties grown for a single mechanical harvest. Canneries process the tomatoes into juice, paste, diced, and whole pack products. Tomato varieties grown tend to be prescribed by the canneries for various desired processing attributes. Growers enter into contracts with canners for production of tomatoes for delivery during a window of time. Producing predictable tomato yield (volume) for delivery to canneries within a specified window of time is particularly important for growers. Tomato fruit must also pass inspection by state graders for ‘worm’ damage and ‘mold’ below specified limits. Although some pest damage can be tolerated on tomato processed for juice and paste, canners can impose restrictions for blemished fruit when it is used for diced and whole pack since this damage would potentially be apparent to consumers. Most canners also test tomatoes sent to the canneries for insecticide residues to ensure that they are in compliance not only with US regulations but also with tolerances of other countries where the products might be shipped. Because insecticide tolerances are not coordinated internationally, and some countries have lower tolerance or no tolerance for some insecticides that can be used in the US, restrictions on use permitted by a canner may well be lower than what is permissible on a product’s label.

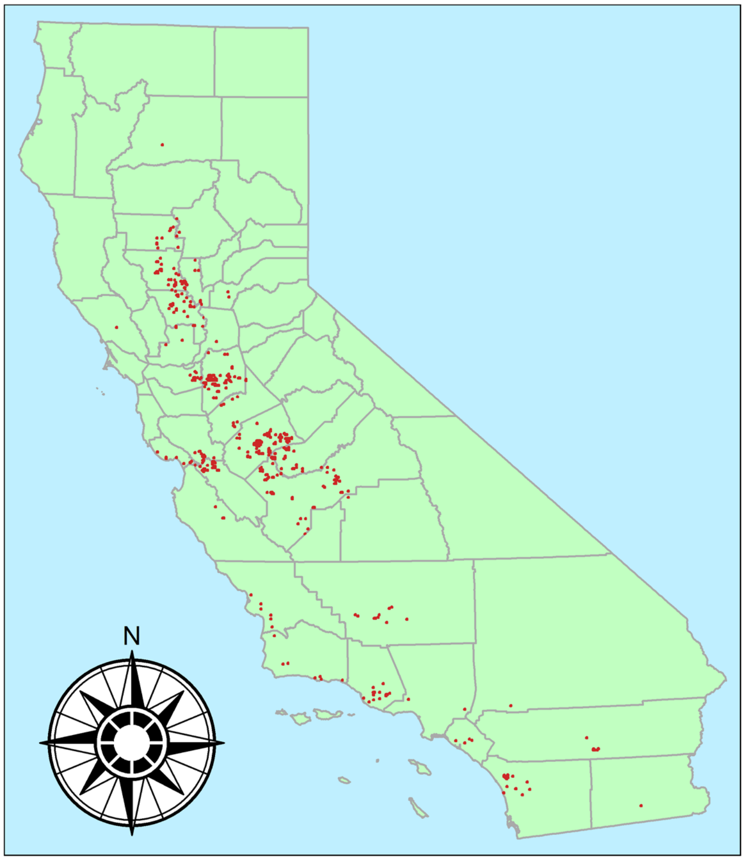

Figure 24. California fresh market tomato production: 2017

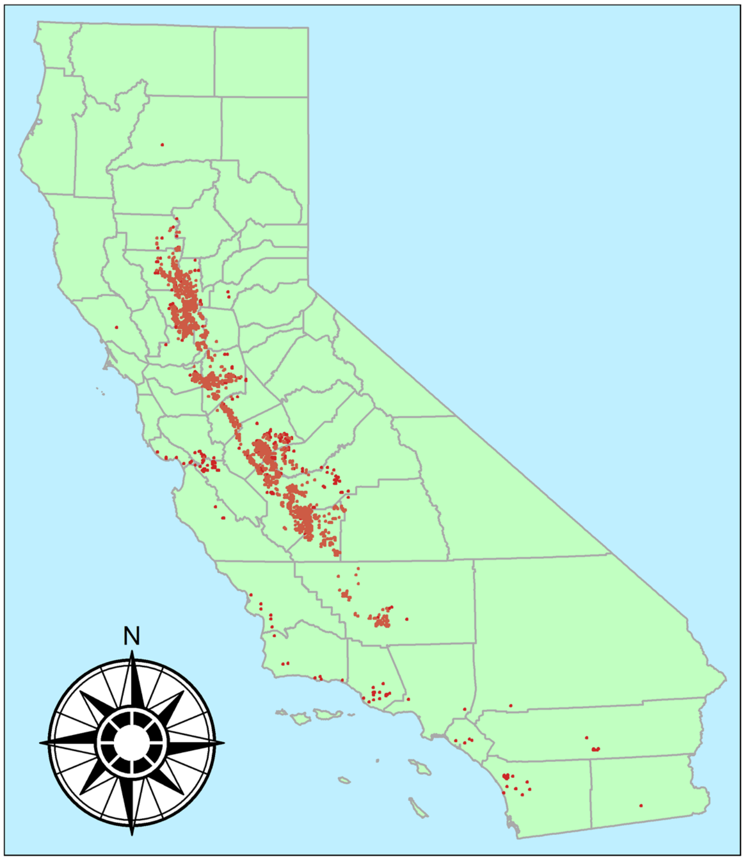

Figure 25. California processing tomato production: 2017

Tomato production varies by region of the state as does the significance of particular pest species, which is affected by climate, production season, and horticultural practices. In order to evaluate alternatives for NGNs in pest management programs, this study defines five production areas for fresh tomato and three production regions for processed tomato. The primary fresh market tomato-growing regions include the South Coast and San Joaquin Valley, with limited production in the following regions: Southern Desert, Central Coast, and Sacramento Valley. Processing tomato-growing regions include the San Joaquin and Sacramento Valleys, with limited production in the Central Coast region.

IPM Overview

Tomato in California is attacked by a variety of insects, diseases, and nematodes. With very few exceptions, NGNs are registered for and applied to control sucking insect pests. All four NGN targets for this study are registered for tomato. Imidacloprid and thiamethoxam are the most widely used. Imidacloprid is commonly applied as a soil treatment through chemigation, as a band spray during planting then sprinkled or furrow-irrigated, and as foliar sprays either as a stand-alone product, as premixes, or tank-mixed with other products. Mixes are used to enhance efficacy against certain insect species and/or to control additional target pests. Thiamethoxam can also be applied to the soil at planting as a band spray or through chemigation. It is used less commonly than imidacloprid because it is more easily moves through the soil and beyond the root zone, and its residual efficacy is not as long. Clothianidin and dinotefuran are more recently registered insecticides relative to imidacloprid and thiamethoxam and are less commonly applied. Both can be applied through chemigation or as foliar sprays.

Target Pests

Target pests for NGNs on fresh market and processing tomato include aphids (green peach aphid, potato aphid and others), flea beetles, leafhoppers (primarily beet leafhopper), leafminers, Lygus, potato psyllid, stink bugs, thrips, and whiteflies. The importance of these insects varies by region, year, and whether the crop is for the fresh or processed market.

Aphids. Several aphids affect tomato. The most important ones are the green peach aphid (*Myzus persicae*) and other early season aphids, and the potato aphid (*Macrosiphum euphorbiae*) that occurs later in the season. Feeding by green peach aphid can injure young plants that are stressed by water or other factors, but the major concern is their potential to transmit virus diseases such as alfalfa mosaic virus. Virus transmission can be a concern in all growing areas, and it is particularly important in the Southern Desert and the San Joaquin Valley. Early season aphids rarely require treatment and although they are controlled with soil-applied NGNs or chemigation they are usually not a target of these applications unless the field is located near a potential source of alfalfa mosaic virus. In practice, in the absence of virus risk these aphids are incidentally controlled by insecticides applied for other pests, and if an insecticide would need to be applied, effective alternative products include spirotetramat, pymetrozine, flonicamid, flupyradifurone, and acetamiprid.

Potato aphid feeding injures tomato plants by distorting leaves and stems and stunting plants (Hummel et al. 2004). High populations that occur six to eight weeks before harvest can significantly reduce yield, and populations that reduce the plant canopy closer to harvest can cause sunburn of fruit. Potato aphids are primarily of concern for fresh market and processing tomato in the northern San Joaquin Valley and Sacramento Valley. NGNs are not usually applied specifically for potato aphids but provide control incidentally by their application for other insects applied by chemigation or foliar sprays applied during the season. When an insecticide is needed specifically to control potato aphid, alternatives to the NGNs include spirotetramat, flonicamid, pymetrozine, pyrethroids (e.g., lambda-cyhalothrin, fenpropathrin and others), and acetamiprid.

Beet leafhopper (*Circulifer tenellus*). The beet leafhopper is a serious insect pest of both fresh market and processing tomato on the west side of the San Joaquin Valley region, and to a lesser extent in the Sacramento Valley. The major concern is transmission of beet curly top virus, which stunts young plants and can result in a virtually complete loss in heavily infected fields. About 50% of the total fresh market and processing tomato acreage in the San Joaquin Valley is at risk for infection in years when insect and virus pressure are high. Spring plantings tend to be most heavily affected. 2013 was a particularly heavy year for beet curly top virus infection. UC Farm Advisors and tomato canners attributed the relatively high early season use of NGNs in the San Joaquin Valley tomato crop in subsequent years to be the result of growers' reactions to experiencing that year's losses. A preventative soil application of imidacloprid is considered to be the most effective approach available for suppressing beet curly top virus infection of fields in years when high populations of beet leafhoppers are expected to move to fields from their overwintering sites in spring. When preventative NGN treatments are not applied, foliar applications of dinotefuran or thiamethoxam are applied if beet leafhoppers are detected in fields. Alternatives for foliar applications include dimethoate and flupyradifurone. Cyantraniliprole has been used effectively when applied to greenhouse transplants, but this has proven to be an expensive ($100-$120 per acre) approach and logistically difficult for individual growers and nurseries to do for large acreages. Chlorantraniliprole can be used, and when applied to the soil through chemigation at planting or soon thereafter produces feeding cessation, which is useful in suppression of curly top transmission.

Flea beetles. Flea beetles are a pest of seedling processing tomato in the San Joaquin and Sacramento Valley regions (Zalom 2003). They slow growth by causing damage to young leaves and stalks. The economic impact of this damage has declined with the transition from direct seeding to transplanting. Flea beetles occasionally become a late season pest when leaves are senescing, and they begin feeding on the fruit instead. Imidacloprid as a preplant application is effective for flea beetle control in direct seeded fields. Carbaryl bait is an effective alternative to NGNs for early season control. Dinotefuran, clothianidin and foliar application of thiamethoxam are effective in controlling flea beetles later in the season. Pyrethroid insecticides including lambda-cyhalothrin and esfenvalerate are also effective and generally less costly. Pyrethroid applications for flea beetles would be of more concern if applied early in the season owing to potential disruption of natural biological control for other pests but are of less concern late in the season.

Lygus bug (*Lygus hesperus*). Lygus are most common in San Joaquin Valley tomato fields and to a lesser degree in the Sacramento Valley. Adult Lygus are highly mobile insects and tend to move to tomato after the preferred hosts, such as alfalfa and safflower, are harvested. They feed on tomato fruit, causing small surface cracks that are primarily an issue for fresh market tomato and diced or whole pack processing tomato. Lygus bugs seldom reach treatable levels in tomato. NGNs targeting other insects at mid-season may provide incidental Lygus control, and, although NGNs in combination with another insecticide such a pyrethroid or clothianidin applied alone can be used to control Lygus, they are generally not applied with Lygus as the target pest species. In the relatively unusual event that Lygus populations are sufficiently great as to warrant treatment, alternative products including flonicamid, lambda-cyhalothrin, and fenpropathrin alone or in combination with acetamiprid are considered as effective as NGNs for control.

Stink bugs. Several stink bug species attack both fresh market and processing tomato, primarily in the Sacramento and central and northern San Joaquin Valley regions. About 10% of the total tomato acreage in these regions can be seriously affected. They inject saliva into fruit when feeding that results in fissures below the surface of the fruit. This damage is unacceptable for fresh market fruit and whole pack processing tomato (Zalom et. al. 1997a). Yeasts and other pathogens may also be injected into the fruit as a result of their feeding, resulting in rejection of processing tomato loads or a reduced price owing to 'mold damage' identified by state graders. Occurrence of damaging levels of stink bugs appears to be cyclical, with widespread injury occurring every 8 to 10 years followed by recurring damage for several consecutive years. Because stink bugs must reinvade tomato fields each year, usually in June or later, much of the damage occurs nearer field edges so fruit from only a portion of each field is damaged (Zalom et. al. 1997b).

Stink bugs are particularly difficult insects to control with any insecticide. NGNs are generally not as effective when applied alone as a foliar spray as they are when applied in a premix or are tank mixed with another insecticide such as a pyrethroid, such as lambda–cyhalothrin, fenpropathrin and others (Cullen and Zalom 2007), with the exception of dinotefuran and clothianidin which have shown similar control to premixes and tank mixes in some preliminary trials. Non-NGN alternatives with similar efficacy to that of the NGNs include tank mixes of lambda-cyhalothrin with novaluron, lambda-cyhalothrin with flonicamid, lambda-cyhalothrin with chlorantraniliprole, and fenpropathrin with pyriproxyfen. Although lambda-cyhalothrin is somewhat effective when applied alone, the other products are not very effective when applied individually for stink bug control.

Thrips. The primary thrips species that infests tomato in all regions of California is the western flower thrips (*Frankliniella occidentalis*) although onion thrips (*Thrips tabaci*) is often found on tomato as well, particularly on the west side of the San Joaquin Valley. Very high populations of thrips can somewhat reduce yield through flower aborting resulting from their feeding. However, the most serious damage caused by thrips is their transmission of tomato spotted wilt virus, which can seriously reduce yield (Sevik and Arli-Sokmen 2012). Tomato spotted wilt virus is an important concern on fresh market tomato in all regions, and on processing tomato in the Fresno and Merced County areas of the San Joaquin Valley. A host plant resistance-breaking strain of tomato spotted wilt virus was first found in 2016 that has made thrips control with insecticides even more critical.

NGNs are applied to some extent for thrips control in the South Coast and San Joaquin Valley regions, although soil applied imidacloprid has not been shown to lower virus incidence. Dinotefuran applied as a foliar spray can control thrips but is less effective than alternative chemicals. Spinetoram and spinosad are very effective alternatives to NGNs for thrips control. However, insecticide resistance to these spinosyns have been documented for thrips in a number of crops, so rotating insecticide classes to reduce insecticide resistance risk is an important consideration. Additionally, the total number of spinosyn applications that can be made during a season is restricted by their labels. Other products that can provide similar or better control of thrips than NGNs on tomato include methomyl, dimethoate, and flonicamid. However, methomyl and dimethoate are especially disruptive of natural biological control of other insects such as leafminers and can result in secondary outbreaks that require additional insecticide applications for those species. Abamectin is moderately effective in knocking down thrips populations, although less efficacious than NGNs or the alternatives listed above. Chlorantraniliprole suppresses foliar-feeding thrips, and when applied as a soil application through chemigation produces feeding cessation. However, more research is needed in California to determine if this will result in suppression of tomato spotted wilt virus spread by western flower thrips.

Tomato psyllid. The tomato psyllid (*Bactericera cockerelli*) has become a serious pest of fresh market tomato in coastal growing regions. It is also found in the San Joaquin Valley, but populations tend to be lower there and treatments are seldom applied for its control. Nymphs, in particular, inject a toxin while feeding on leaves that results in a disorder known as psyllid yellows that stunts plant growth. No fruit is produced if younger plants are affected, and nonmarketable fruit is produced if older plants become infected. Imidacloprid applied to soil at planting by drench or through chemigation is a preferred method of control because of its extended residual efficacy, but additional treatments of spirotetramat (which provides very good control), pymetrozine, spinetoram, and abamectin are applied to fresh market pole tomato to provide sufficient protection through the extended harvest period. A rotation scheme for reducing risk of insecticide resistance is presented by Prager et al. (2016). These alternative products can also be applied for tomato psyllid control without applying imidacloprid, but application of these products would have to begin earlier in the season and would result in a number of additional applications as well as increase potential for insecticide resistance to occur.

A rotation of methomyl and permethrin could also result in increased yield compared to imidacloprid but was less cost-effective than using imidacloprid at planting followed by the alternative materials in rotation (Prager et al. 2016). Methomyl is particularly disruptive of natural biological control and its use is discouraged due to the likelihood of secondary pest outbreaks, particularly leafminers. Pyrethroids such as permethrin are also disruptive to natural enemies in pole tomato which remain in production for an extended period.

Whiteflies. The most common whiteflies that infest California tomato are the greenhouse whitefly (*Trialeurodes vaporariorum*), which occurs in all growing regions except the South Desert, and the sweetpotato whitefly (*Bemisia tabaci* biotype B), which occurs in the desert areas and the south coast as well as in areas of the southern and central San Joaquin Valley where populations have increased dramatically in recent years. Leaf feeding by the greenhouse whitefly is not considered damaging except when they occur at high densities but feeding by the sweetpotato whitefly results in uneven ripening of fruit that renders them unmarketable. The high densities recently observed in some central San Joaquin Valley tomato fields resulted in some fields having symptoms of uneven ripening of close to 50%. Feeding also resulted in collapse of the plant canopy prior to harvest and yield losses due to sunburn of fruit.

Whiteflies are of particular concern to growers because both species are known to transmit viruses to tomato. The potential damage from viruses is much greater than the direct damage caused by whiteflies. The greenhouse whitefly transmits tomato infectious chlorosis virus, and the sweetpotato whitefly transmits tomato yellow leaf curl virus. Neither virus has caused damage to tomato in California, but tomato yellow leaf curl virus has recently been detected in the Imperial Valley and Coachella Valley in the South Desert region so there is an imminent threat to California growers, particularly given the serious recent San Joaquin Valley outbreaks of sweetpotato whitefly.

Crop losses due to viruses on both fresh market and processing tomato have reached 90% in other parts of the world where NGNs have not been applied for control of the whiteflies that transmit the viruses. NGNs are the most effective insecticides for suppressing virus transmission since they can protect young plants while providing the residual protection necessary to suppress virus spread. Imidacloprid applied at planting as a soil application or through drip is the standard method for controlling virus spread by whiteflies worldwide, and dinotefuran applied similarly is equally effective. Whiteflies can be controlled later in the season with insecticides other than NGNs, such as spirotetramat, acetamiprid, and spiromesifen. The insect growth regulators buprofezin and pyriproxyfen also provide control, but they cannot limit an already large population when used alone so they must be used strategically as part of a program. Multiple applications using AIs with different modes of action would need to be made in rotation to protect plants from virus spread.

A newly registered insecticide, flupyradifurone, appears to be a promising alternative to imidacloprid when applied at planting, and also suppresses whiteflies as a foliar application later in the season. Reflective mulches can be effective to repel whiteflies for the first 4 to 6 weeks following planting until they are obscured by the plant canopy, but this practice would be impractical to use to any great extent on the large acreages of tomato planted in the San Joaquin Valley, and insecticides would still need to be applied later in the season to protect the plants from virus spread.

Other Considerations

In addition to the direct efficacy and cost considerations of using alternatives to NGNs, secondary pest outbreaks and resistance management are key considerations.

Secondary pest outbreaks. Early season soil or drip application of NGNs are important to prevent virus transmission by beet leafhopper (Beet curly top virus) and sweetpotato whitefly (tomato yellow leaf curl virus) in areas where these pests commonly occur, as well as for tomato psyllid control for fresh market pole tomato. This NGN use provides protection for at least the first 6 weeks after planting. Growers would invariably substitute other products to control these insects soon after planting, and because alternative insecticides do not have the residual efficacy of the NGNs, multiple applications would likely be made. It is likely that two to four times as many applications would be needed to control the same pests. Most of the alternative products would be applied to foliage and many are more disruptive of natural biological control than are the NGNs. Therefore, outbreaks of other insects and arthropods, including broad mites and spider, are more likely to occur necessitating additional insecticide sprays for their control.

Resistance management. Resistance management is always of concern when applying insecticides, and the risk increases with each additional spray of products with similar modes of action. Resistance management benefits from the availability of NGN insecticides, particularly when they are applied a single time at planting because fewer applications of effective alternative insecticides will be necessary during the season due to NGN's residual efficacy when applied at this time.

Target NGN Use: 2015-2017

Most fresh tomato acreage treated with NGNs is in the San Joaquin Valley, where most fresh market tomato production occurs. Imidacloprid is overwhelmingly the primary NGN applied to tomato acreage in most regions except the South Coast and Central Coast regions, where thiamethoxam and dinotefuran are more widely used in some years. In those regions, thiamethoxam (Central Coast) and dinotefuran and thiamethoxam (South Coast) are also used, depending on year. The San Joaquin Valley is the only region where clothianidin was used to any extent, primarily in 2015, and the number of acres treated has declined to practically nil since then in the San Joaquin Valley and elsewhere. Dinotefuran was also applied to some extent in the San Joaquin Valley in 2016. Figure 26 reports monthly target NGN use for both fresh market and processing tomato. Table 58 reports annual use of target NGNs and alternative active ingredients on fresh market tomato for 2015-2017.

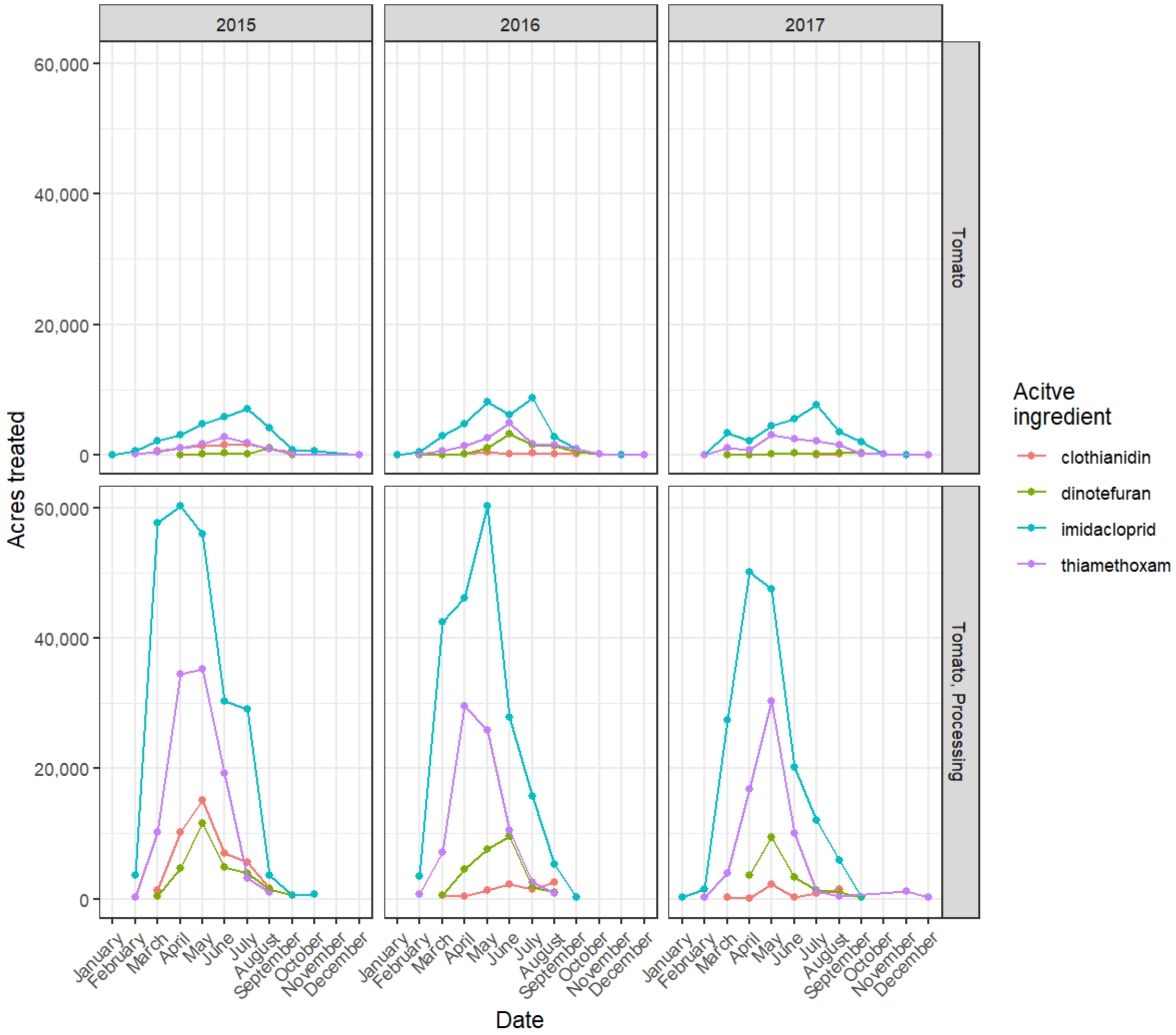

Figure 26: Monthly use of target nitroguanidine substituted neonicotinoids: fresh market and processing tomato, 2015-2017

Most acreage treated with NGNs for processing tomato is in the San Joaquin Valley where the majority of production occurs. NGNs are also used in the Sacramento Valley and on limited acres in the middle coast production area. As is the case for fresh market tomato, imidacloprid is the primary NGN used in both the San Joaquin and Sacramento Valley regions. Thiamethoxam acres treated was proportionally less in all years in the San Joaquin Valley with far fewer acres treated with either clothianidin or dinotefuran. Clothianidin was applied to relatively more acres in the Sacramento Valley than in the San Joaquin region. Table 58 reports annual use of the target NGNs and alternative active ingredients on processing tomato for 2015-2017.

Table 57: Annual Use of Target Nitroguanidine Substituted Neonicotinoids and Alternative Active Ingredients: Fresh Market Tomato, 2015-2017

Active ingredient	**--------Pounds applied---------**				**-----------Acres treated-----------**				**Use rate (lbs /ac)**
	2015	2016	2017	Total	2015	2016	2017	Total	
abamectin	94	78	85	258	7,350	4,607	5,481	17,438	0.01
acetamiprid	218	330	388	935	2,239	4,586	5,584	12,409	0.08
buprofezin	633	519	775	1,926	1,940	1,467	2,161	5,567	0.35
carbaryl	2,108	5,587	4,731	12,425	2,410	8,435	7,234	18,079	0.69
chlorantraniliprole	866	1,148	1,293	3,308	16,326	22,113	24,373	62,812	0.05
clothianidin	462	113	11	587	7,544	1,143	141	8,827	0.07
dimethoate	2,017	2,679	1,748	6,444	4,811	5,809	4,006	14,626	0.44
dinotefuran	277	1,557	209	2,043	1,618	7,703	1,290	10,611	0.19
esfenvalerate	310	346	268	924	7,140	7,277	5,739	20,157	0.05
fenpropathrin	1,014	887	418	2,319	5,279	4,619	2,335	12,233	0.19
flonicamid	121	106	186	413	842	771	1,593	3,206	0.13
flupyradifurone	256	1,335	1,222	2,813	1,552	7,976	7,263	16,791	0.17
imidacloprid	4,534	6,276	4,507	15,317	28,727	34,590	28,589	91,906	0.17
lambda-cyhalothrin	286	291	647	1,223	10,149	12,345	22,494	44,989	0.03
methomyl	2,706	3,748	4,094	10,549	4,545	5,556	5,169	15,270	0.69
novaluron	36	91	93	220	461	993	1,202	2,656	0.08
permethrin	261	428	125	814	3,054	4,032	1,194	8,280	0.10
pymetrozine	42	61	139	242	160	350	918	1,428	0.17
pyriproxyfen	35	52	113	199	581	813	1,848	3,242	0.06
spinetoram	1,116	1,395	1,411	3,923	21,043	27,292	30,113	78,449	0.05
spinosad	191	284	198	673	1,887	3,209	2,102	7,198	0.09
spiromesifen	203	170	185	558	1,609	1,323	1,456	4,388	0.13
spirotetramat	64	133	41	239	901	1,744	514	3,159	0.08
thiamethoxam*	485	745	583	1,813	8,819	13,333	11,079	33,231	0.05

* Target active ingredients (NGNs)

Table 58: Annual Use of Nitroguanidine Substituted Neonicotinoids and Alternative Active Ingredients: Processing Tomato, 2015-2017

Active ingredient	**--------Pounds applied---------**				**-----------Acres treated-----------**				**Use rate (lbs /ac)**
	2015	2016	2017	Total	2015	2016	2017	Total	
abamectin	851	999	928	2,778	77,114	74,141	64,241	215,497	0.01
acetamiprid	1,303	920	829	3,052	20,422	14,484	12,881	47,786	0.06
buprofezin	211	139	59	408	666	453	152	1,271	0.32
carbaryl	50,146	33,122	34,204	17,472	75,474	50,804	56,011	182,290	0.64
chlorantraniliprole	5,731	4,434	5,383	15,548	106,936	84,010	98,462	289,408	0.05
clothianidin*	2,973	582	339	3,894	40,641	8,311	5,109	54,061	0.07
dimethoate	37,758	35,969	31,294	105,021	85,862	80,716	72,629	239,208	0.44
dinotefuran*	6,441	5,395	3,900	15,736	27,488	25,086	19,046	71,620	0.22
esfenvalerate	1,837	1,192	1,190	4,219	41,296	27,108	25,716	94,120	0.04
fenpropathrin	319	118	285	721	1,600	589	1,500	3,689	0.20
flonicamid	15	24	14	53	183	284	156	623	0.08
flupyradifurone	260	357	499	1,116	1,468	2,513	2,818	6,798	0.16
imidacloprid*	48,119	41,274	35,121	124,514	242,036	201,425	165,164	608,625	0.20
lambda-cyhalothrin	3,139	2,347	2,304	7,790	106,702	81,991	79,083	267,775	0.03
methomyl	9,407	4,590	4,002	17,998	12,458	6,525	5,351	24,334	0.74
novaluron	216	217	344	777	2,929	3,067	4,723	10,719	0.07
permethrin	1,580	1,370	709	3,659	12,830	10,686	5,831	29,347	0.12
pyriproxyfen	174	24	38	236	2,618	352	566	3,536	0.07
spinetoram	1,350	1,902	1,590	4,841	27,067	40,546	35,803	103,417	0.05
spinosad	915	1,229	489	2,633	10,690	12,712	7,788	31,190	0.08
spiromesifen	103	63	3	168	784	476	20	1,280	0.13
spirotetramat	425	225	70	720	5,368	3,010	925	9,302	0.08
thiamethoxam*	5,685	4,055	3,153	12,893	103,703	7,185	64,474	245,362	0.05

* Target active ingredients (NGNs)

Economic Analysis

This section presents the estimated change in costs of pest management in tomato owing to the cancellation of the four NGNs. This cost includes the change in pesticide material costs. Application methods do not differ across the representative pesticide products considered, and in the absence of any anticipated effect on yields, gross revenues will not change. However, to prevent a change in yields, it's anticipated that multiple sprays of alternative insecticides will be necessary to control beet leafhopper and sweetpotato whitefly. To account for this, we estimate the acres where NGNs were used to control these pests and calculate the cost of three applications of the composite alternative to these acres.

In addition to the caveats discussed in the methods section, the costs estimated below do not account for the potential effects of increased insect resistance to pyrethroids.

Table 59: Representative Products and Costs Per Acre: Fresh Tomato

Active ingredient	**Representative product**	**Material cost ($)**	**Application cost ($)**	**Total cost ($)**
abamectin	Epi-Mek 0.15 EC Miticide/Insecticide	10.47	22.36	32.83
acetamiprid	Assail 70WP Insecticide	26.49	19.69	46.18
buprofezin	Talus 70DF	56.77	22.81	79.58
chlorantraniliprole	Dupont Coragen Insect Control	33.59	20.81	54.40
clothianidin	Belay Insecticide	9.68	23.61	33.29
dimethoate	Drexel Dimethoate 4EC	5.23	21.93	27.16
dinotefuran	Venom Insecticide	40.70	17.41	58.11
esfenvalerate	Asana XL	5.30	21.24	26.54
fenpropathrin	Danitol 2.4 EC Spray	16.66	18.84	35.50
flonicamid	Beleaf 50 SG Insecticide	49.19	23.80	72.99
flupyradifurone	Sivanto Prime	46.69	21.81	68.50
imidacloprid	Admire Pro	10.10	18.45	28.55
lambda-cyhalothrin	Besiege Insecticide	32.04	22.75	54.78
methomyl	Du Pont Lannate SP Insecticide	29.72	21.82	51.54
novaluron	Rimon 0.83 EC Insecticide	26.04	24.47	50.51
permethrin	Stiletto	182.42	24.58	206.99
pymetrozine	Fulfill	41.36	21.52	62.88
pyriproxyfen	Knack Insect Growth Regulator	0.66	21.82	22.48
spinetoram	Radiant SC	43.41	21.94	65.35
spinosad	Entrust	79.00	24.05	103.05
spiromesifen	Oberon 2SC Insecticide/Miticide	25.55	24.71	50.26
spirotetramat	Movento	42.97	21.96	64.93
thiamethoxam	Platinum 75 SG	8.37	8.20	16.56

*Target NGN

Table 60: Representative Products and Costs Per Acre: Processing Tomato

Active ingredient	Representative product	Material cost ($)	Application cost ($)	Total cost ($)
abamectin	Agri-Mek SC Miticide/Insecticide	8.02	22.01	30.03
acetamiprid	Assail 30SG Insecticide	16.87	22.10	38.97
buprofezin	Courier 40SC Insect Growth Regulator	31.08	22.34	53.42
carbaryl	First Choice Carbaryl Cutworm Bait	20.49	24.67	45.17
chlorantraniliprole	Dupont Coragen Insect Control	34.26	21.54	55.80
clothianidin	Belay Insecticide	10.49	23.67	34.16
dimethoate	Dimethoate 400	4.02	22.48	26.50
dinotefuran	Venom Insecticide	46.44	11.61	58.05
esfenvalerate	Asana XL	5.19	22.33	27.52
fenpropathrin	Danitol 2.4 EC Spray	17.19	21.86	39.05
flonicamid	Beleaf 50 SG Insecticide	32.27	22.80	55.06
flupyradifurone	Sivanto Prime	45.76	22.75	68.51
imidacloprid	Admire Pro	12.40	15.07	27.47
lambda-cyhalothrin	Besiege Insecticide	34.28	22.55	56.83
methomyl	Du Pont Lannate SP Insecticide	31.82	19.49	51.31
novaluron	Rimon 0.83 EC Insecticide	22.77	21.12	43.89
permethrin	Stiletto	231.40	21.01	252.40
pyriproxyfen	Knack Insect Growth Regulator	0.72	22.82	23.54
spinetoram	Radiant SC	40.6	23.14	63.78
spinosad	Entrust	71.33	22.41	93.74
spiromesifen	Oberon 2SC Insecticide/Miticide	26.38	20.83	47.22
spirotetramat	Movento	44.04	23.16	67.20
thiamethoxam	Platinum 75 SG	8.06	7.13	15.19

*Target NGN

Representative products for each active ingredient used on tomato and their costs per acre are presented in Table 63 (fresh market) and Table 64 (processing). The material cost per acre is the product of the average use rate (lbs/acre) over this period and the price per pound. The application cost per acre is the acre-weighted average application cost based on application method across all applications of the AI to the crop. The costs of each application method are presented in the methods section. The total treatment cost per acre is the sum of the material and application cost per acre.

There is substantial variation in the price per acre of AIs, ranging from $16.56 per acre to $206.99 per acre for fresh market tomato and from $15.19 per acre to $252.40 per acre for processing tomato.

Table 61: Average Annual Acreage Shares of Alternative Insecticides with and without Target Nitroguanidine Substituted Neonicotinoids (NGNs): Fresh Market Tomato, 2015–2017

Active ingredient	Target NGNs available (%)	Target NGNs cancelled (%)
abamectin	3.6	5.2
acetamiprid	2.6	3.7
buprofezin	1.2	1.7
chlorantraniliprole	13.1	18.8
dimethoate	3.1	4.4
esfenvalerate	4.2	6.0
fenpropathrin	2.6	3.7
flonicamid	0.7	1.0
flupyradifurone	3.5	5.0
lambda-cyhalothrin	9.4	13.5
methomyl	3.2	4.6
novaluron	0.6	0.8
permethrin	1.7	2.5
pymetrozine	0.3	0.4
pyriproxyfen	0.7	1.0
spinetoram	16.4	23.5
spinosad	1.5	2.2
spiromesifen	0.9	1.3
spirotetramat	0.7	0.9
total	70.0	100

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

Table 61 reports the average acreage shares for each non-NGN alternative AI used on fresh market tomato with and without NGNs being available. Averaged over the three-year period, 2015–2017, when NGNs were available, NGNs were used on 30.0% of total fresh market tomato acreage treated with insecticides and alternative AIs were used on 70.0% of fresh market tomato acreage treated with insecticides.

If NGNs were cancelled, 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 chlorantraniliprole, lambda-cyhalothrin and spinetoram for fresh market tomato, together accounting for 38.9% of the acres treated without NGNs.

Table 62. Average Annual Acreage Shares of Alternative Insecticides with and without Target Nitroguanidine Substituted Neonicotinoids (NGNs): Processing Tomato, 2015–2017

Active ingredient	Target NGNs available (%)	Target NGNs cancelled (%)
abamectin	8.5	13.8
acetamiprid	1.9	3.1
buprofezin	0.1	0.1
carbaryl	7.2	11.7
chlorantraniliprole	11.4	18.5
dimethoate	9.4	15.3
esfenvalerate	3.7	6.0
fenpropathrin	0.1	0.2
flonicamid	0.0	0.0
flupyradifurone	0.3	0.4
lambda-cyhalothrin	10.5	17.1
methomyl	1.0	1.6
novaluron	0.4	0.7
permethrin	1.2	1.9
pyriproxyfen	0.1	0.2
spinetoram	4.1	6.6
spinosad	1.2	2.0
spiromesifen	0.1	0.1
spirotetramat	0.4	0.6
total	61.2	100

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

Table 62 reports the average acreage shares for each non-NGN alternative AI used on processing tomato, with and without NGNs being available. Averaged over the three-year period, 2015–2017, when NGNs were available, NGNs were used on 38.8% of total acres treated with insecticides and alternative AIs were used on 61.2% of acreage treated with insecticides. Note that total acres treated with insecticides does not correspond to total acres of tomato grown since some growers may have used multiple AIs on the same field.

The three most common alternative AIs were chlorantraniliprole, lambda-cyhalothrin and spinetoram for fresh market tomato, together accounting for 38.9% of the acres treated without NGNs. The three most common alternative AIs for processing tomato were chlorantraniliprole, lambda-cyhalothrin, and dimethoate, together accounting for 31.3% of the acres treated without NGNs.

Table 63: Costs Per Acre for Target Nitroguanidine Substituted Neonicotinoids and the Composite Alternative: Fresh Tomato

Active ingredient	Material cost ($)	Application cost ($)	Total cost ($)	Cost increase for switching (%)
clothianidin	9.68	23.61	33.29	73.54
dinotefuran	40.70	17.41	58.11	-0.59
imidacloprid	10.10	18.45	28.55	102.35
thiamethoxam	8.37	8.20	16.56	248.85
composite alternative	35.97	21.80	57.77	-

Table 63 reports average per acre costs for the NGNs and the composite alternative for fresh market tomato. Switching to the alternative would lead to a 73.5% increase in cost on acres using clothianidin, a negligible 0.59% decrease for dinotefuran, a 102.3% increase for imidacloprid, and a 248.8% increase for thiamethoxam.

Table 64. Costs Per Acre for Target Nitroguanidine Substituted Neonicotinoids and the Composite Alternative: Processing Tomato

Active ingredient	Material cost ($)	Application cost ($)	Total cost ($)	Cost increase for switching (%)
clothianidin	10.49	23.67	34.15	44.36
dinotefuran	46.44	11.61	58.05	-15.07
imidacloprid	12.40	15.07	27.47	79.47
thiamethoxam	8.06	7.13	15.19	217.84
composite alternative	26.85	22.45	49.30	-

Table 64 reports average per acre costs for the target NGNs and the composite alternative. Switching to the alternative would lead to a 44.4% increase in cost on acres using clothianidin, a 15.1% decrease for dinotefuran, a 79.5% increase for imidacloprid, and a 217.8% increase for thiamethoxam.

Table 65. Change in Treatment Costs due to Cancellation of Target Nitroguanidine Substituted Neonicotinoids (NGNs): Fresh Market Tomato, 2015–2017

Year	Cost with target NGNs ($)	Cost without target NGNs ($)	Change in cost ($)	Change in costs (%)	Change in material cost (%)	Change in application cost (%)
2015	1,311,510	6,326,846	5,015,336	382.4	68.5	31.5
2016	1,694,178	7,873,339	6,179,161	364.7	66.6	33.4
2017	1,079,484	5,650,869	4,571,385	423.5	67.4	32.6

Table 66. Change in Treatment Costs due to Cancellation of Target Nitroguanidine Substituted Neonicotinoids (NGNs): Processing Tomato, 2015–2017

Year	Cost with target NGNs ($)	Cost without target NGNs($)	Change in cost ($)	Change in cost (%)	Change in material cost (%)	Change in application cost (%)
2015	11,208,085	48,127,994	36,919,909	373.2	56.0	44.0
2016	8,445,867	36,299,081	27,853,215	352.2	55.3	44.7
2017	6,796,644	29,531,353	22,734,709	358.8	55.3	44.7

Table 65 (fresh market tomato) and Table 66 (processing tomato) report the change in insecticide material and application costs due to the cancellation of NGNs. Costs increase for both. Substituting for the cancelled NGNs would result in a 364.7% to 423.5% increase in total treatment costs for fresh market tomato acreage treated with the NGNs, with an absolute value of $4.6 million to $6.2 million. For processing tomato, the increase would be 352.2% to 373.2%, with a total cost increase of $22.7 million to $36.9 million on acres treated with NGNs. Comparing the two tables, the cost increase is smaller in absolute value, but larger in percentage terms, for fresh market tomato. The smaller absolute increase in costs for fresh market tomato is due to differences in acreage treated between the two types of tomato: fresh market tomato averaged 48,192 annual acres treated with NGNs from 2015-2017, compared to 326,556 average annual acres for processing tomato. The higher percentage increase for fresh tomato is due to the higher cost of the composite alternative relative to the NGNs.

The percentage and absolute value increases for both types of tomato are large, which makes it particularly useful to compare these costs to gross revenues. In 2016, statewide average revenues per acre were $8,829 for fresh tomato, and $4,000 for processed tomato (CDFA, 2017). On a per acre basis, the cost of the composite alternative is $57.77 per acre for fresh tomato, less than 1% of gross revenues, and $49.30 for processing tomato, 1.2% of gross revenues. For the acres where NGNs are used to treat beet leafhopper, western flower thrips, and sweet potato whitefly, three applications of the composite alternative would be necessary to maintain yields, and the cost per acre rises to $173.31 for fresh tomato, 2% of gross revenues, and $147.90 for processing tomato, 3.7% of gross revenues. On average, 20.8% of fresh market tomato acreage and 26.2% of processing tomato would require these additional treatments.

Conclusions and Critical Uses

In the case of tomato, utilizing alternative pesticides for the target pests due to the cancellation of NGNs increases costs for both fresh market and processing tomato. The two types face different impact from cancellation. Fresh market tomato have a larger increase percentage increase in costs per acre than processing tomato, but due to the larger acreage treated with NGNs, processing tomato realize a higher total cost.

Walnut

California accounts for all national production of walnut and is the second largest producer of walnut in the world, second only to China. For 2018-2019, California was forecasted to account for 31.3% of world production and 56.4% 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 is 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 was 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 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.

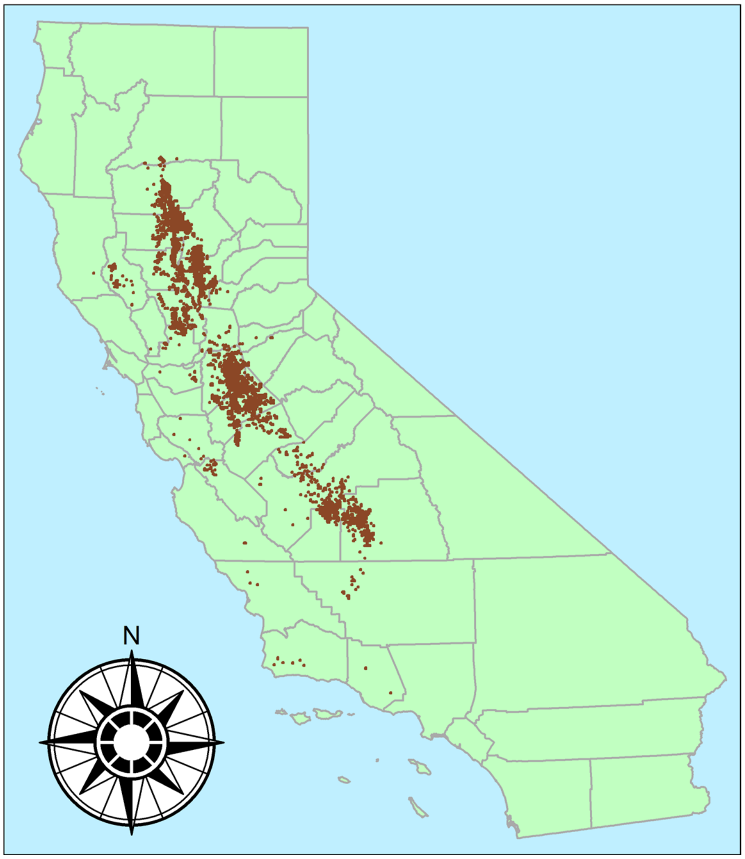

Figure 27: California walnut production: 2017

IPM Overview

California walnut are attacked by a variety of primary and secondary pests. Primary pests—codling moth, navel orangeworm and walnut husk fly—attack the nuts and cause direct damage to the marketable crop. Secondary pests—twospotted spider mite, walnut and dusky-veined aphid, walnut, European fruit lecanium and frosted scale—attack the tree's foliage, twigs and small limbs, which damage the tree through leaf drop and reduced vigor. Primary pests may require annual application of some control measures, while secondary pests require occasional (less frequent than annual) control measures. A number of minor walnut pests, which can do significant damage to the tree under special conditions, require treatment if they become abundant.

There are two NGN insecticides registered for use on walnut: clothianidin and imidacloprid. DPR determined that imidacloprid at maximum label rates is harmful to bees throughout the whole year (Troiano et al. 2018). Thus, we consider a year-round ban on imidacloprid. Clothianidin was determined to be harmful to bees at maximum label rates only if applied before or during bloom (Troiano et al. 2018). For this analysis, we consider pre-bloom as January to February and bloom March to April. Thus, we consider a January to April ban on clothianidin. Note that this implies clothianidin is a post-bloom (May to December) alternative to imidacloprid.

Target Pests

Aphids. Walnut aphid (*Chromaphid juglandicola*) and dusky-veined aphid (*Callaphis juglandis*) can reduce tree vigor and nut size, resulting in lower yield quantity and quality. Additionally, the aphids produce honey dew, which encourages the growth of sooty mold. Sooty mold reduces nut value by changing its color to black and increasing nut sunburn. Both aphid species overwinter as eggs on the walnut trees, hatch in the spring, and settle onto leaves. They reproduce by cloning and can have multiple generations during the summer. Prior to the 1970s, walnut aphid was a significant pest; however, introduction of the parasitic wasp *Trioxys pallidus* brought it under control statewide. Dusky-veined aphids are not a host for *T. pallidus* but are preyed upon by a variety of generalist natural enemies. Research has established economic injury levels for aphids on walnut, which informs growers on when insecticide applications may be necessary. Generally, aphids are 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 the natural enemies and cause aphid outbreaks. Equally effective alternatives to imidacloprid are acetamiprid, cyantraniliprole, clothianidin, sulfoxaflor, flupyradifuone, and flonicamid (Van Steenwyk et al. 2016b). Chlorpyrifos would have been considered an alternative before it is scheduled to be cancelled (CDPR 2019).

Walnut husk fly (Rhagoletis completa). Walnut husk fly is a visually striking insect that can damage walnut yields in several ways. Large populations in the early season can lead to kernels being shriveled and moldy at harvest. Larvae feeding can cause significant staining of the walnut shells and make the shells difficult to cancel (an issue primarily for in-shell sales). For walnut husk fly, the alternatives to imidacloprid are acetamiprid, bifenthrin, *burkholderia*, clothianidin, fenpropathrin, lambda-cyhalothrin, phosmet, and spinosad (Van Steenwyk et al. 2016a, 2018b). Chlorpyrifos would have been considered an alternative before it is scheduled to be cancelled (CDPR 2019). Cultural practices of control are not widely used, even by organic growers.

Scale insects. Walnut scale (*Quadraspidiotus juglansregiae*), European fruit lecanium (*Parthenolecanium corni*) and frosted scale (*Parthenolecanium pruninosum*) feed in the phloem of twigs and small branches. Scale populations are usually held under control by a number of parasitoids and reduce tree vigor only at high populations. More importantly, walnut scales infestations increase the likelihood of a *Botryosphaeria* infestation, which results in cankers. Neither imidacloprid nor clothianidin is particularly effective against scale, but both AIs are cheaper than more effective alternatives and appear to be used in April against scale to some extent. Acetamiprid, buprofezin, and pyriproxyfen are more effective alternatives (Van Steenwyk et al. 2016d).

Target NGN Use: 2015-2017

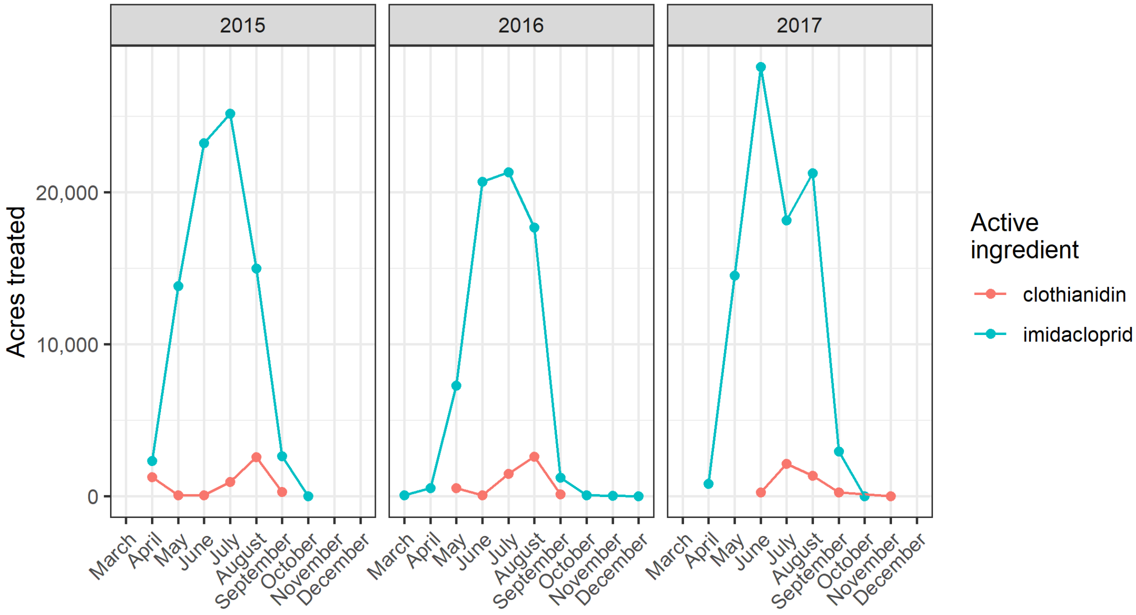

Figure 28: Monthly use of target nitroguanidine substituted neonicotinoids: walnut 2015-2017

Figure 28 illustrates the treated acreage of NGNs on walnut for 2015-2017 by year, month, and AI. The vast majority of imidacloprid is applied in June-August for aphids and walnut husk fly. Neither product is used much in the pre-bloom season (January-April).

Small amounts of imidacloprid and clothianidin were applied in April, likely to address problems with scale. Imidacloprid, which is much more widely used than clothianidin, was applied to more acres in 2017 than the preceding two years.

Table 67: Annual Use of Target Nitroguanidine Substituted Neonicotinoids and Alternative Active Ingredients: Walnut 2015-2017

(May-December)

Active ingredient	**------------ Lbs applied -------------**				**------------- Acres treated -------------**				**Use rate (lbs/ac)**
	2015	*2016*	*2017*	Total	*2015*	*2016*	*2017*	Total	
acetamiprid	11,160	11,641	13,588	36,389	90,039	88,472	103,561	282,072	0.13
bifenthrin	13,975	17,356	20,396	51,727	98857	113,737	130,322	342,915	0.15
burkholderia sp	0	0	9,081	9,081	0	0	1,099	1,099	8.26
clothianidin	341	398	398	1,137	3,990	4,841	4,075	12,906	0.09
fenpropathrin	400	405	651	1456	1,336	1,460	2,550	5,345	0.27
flupyradifurone	4	9	5	18	21	55	24	100	0.18
imidacloprid	6,402	5,729	7,164	19,295	79,878	68,347	85,148	233,374	0.08
lambda-cyhalothrin	2,136	1,552	4,011	7,699	59,055	44,119	106,564	209,737	0.04
phosmet	6,500	3,336	3,738	13,573	2,096	1,145	1,375	4,616	2.94
spinosad bait	1	1	1	4	5,366	6,460	6,061	17,888	0.0002
spinosad spray	661	247	450	1,359	7,269	3,171	4,537	14,978	0.09

(January-April)

Active ingredient	**------------ Lbs applied -------------**				**------------- Acres treated ------------**				**Use rate (lbs/ac)**
	2015	*2016*	*2017*	Total	*2015*	*2016*	*2017*	Total	
acetamiprid	312	250	48	609	2,825	1,883	494	5,201	0.12
buprofezin	22,154	10,611	18,055	50,821	12,448	6,150	10,215	28,812	1.76
clothianidin	105	0	0	105	1,252	0	0	1,252	0.08
imidacloprid	223	42	95	360	2,338	617	817	3,771	0.10
pyriproxyfen	3,139	1,434	1,469	6,042	29,913	14,919	14,812	59,644	0.10

As discussed in the IPM Overview section above, there are alternatives to imidacloprid use in walnut. Clothianidin was determined to be high risk to bees only in the pre-bloom season (Troiano et al. 2018), when it is sparsely used for scale insect. The alternatives AIs for both imidacloprid and pre-bloom clothianidin use and their representative products are presented in Table 3. Representative products are the products most often used in walnut for the pests targeted by imidacloprid.

Economic Analysis

This section presents the estimated change in costs to walnut for a year-round cancellation of imidacloprid and a January to April (pre-bloom and bloom periods) cancellation of clothianidin. Because many of the alternatives are equally effective as the NGNs, we assume the portfolio of alternatives would have no negative yield consequences compared to the use of the NGNs. The cost of the proposed policy is the difference in material costs and application costs though the caveats discussed in the methods section apply.

Table 68: Representative Products Cost per Acre in 2018: Walnut

(January to April)

Active ingredient	**Representative product**	**Material Cost per acre($)**	**App Cost per acre($)**	**Total Cost per acre($)**
acetamiprid	Assail 30sg Insecticide	30.94	25.07	56.01
bifenthrin	Brigade WSB Insecticide/Miticide	35.17	25.12	60.29
burkholderia sp†	Venerate	--	--	--
clothianidin*	Belay	12.18	25.00	37.18
fenpropathrin†	Danitol 2.4 EC Spray	--	--	--
flupyradifurone†	Sivanto	--	--	--
imidacloprid*	Leverage	14.12	24.98	39.01
lambda-cyhalothrin	Lambda-Cy EC Insecticide	2.82	25.15	27.97
Phosmet	Imidan 70-W	42.45	25.00	57.45
spinosad bait†	GF-120	--	--	--
spinosad spray	Success	27.86	25.00	52.86
sulfoxaflor**	Transform	--	--	--

*Target NGN

**Sulfoxaflor was not used on walnut during 2015-2017 as it was not registered in California. It is expected that it will be registered for and used in walnut in the future.

†No historical use of this ai during January to April, 2015–2017.

(May to December)

Active ingredient	**Representative product**	**Material Cost per acre($)**	**App Cost per acre($)**	**Total Cost per acre($)**
acetamiprid	Assail 30sg Insecticide	34.07	25.00	59.07
bifenthrin	Brigade WSB Insecticide/Miticide	37.98	24.85	62.83
burkholderia sp	Venerate	125.95	25.53	151.48
clothianidin*	Belay	12.83	25.02	37.85
fenpropathrin	Danitol 2.4 EC Spray	23.94	25.47	49.41
flupyradifurone	Sivanto	50.05	25.00	75.05
imidacloprid*	Leverage	12.22	24.36	36.58
lambda-cyhalothrin	Lambda-Cy EC Insecticide	2.85	25.24	28.09

phosmet	Imidan 70-W	59.44	25.57	85.01
spinosad bait	GF-120	19.63	25.16	44.79
spinosad spray	Success	27.08	25.05	52.13
sulfoxaflor**	Transform			--

*Target NGN

**Sulfoxaflor was not used on walnut during 2015-2017 as it was not registered in California. It is expected that it will be registered for and used in walnut in the future.

†No historical use of this ai during January to April, 2015–2017.

Table 68 reports separately the representative products for each active ingredient used on walnut pre-bloom/bloom (January–April) and post-bloom (May–Dec) for 2015-2017. Because the use rates may change between the pre-bloom/bloom and the post-bloom periods, we calculate separate costs per acre for each of these periods. The cost per acre is the product of the average observed use rate (pounds per acre) and price per pound. The material cost is calculated as the product of the three-year average use rate (lbs/ac) and the price per pound of product. The application cost per acre is the average of the application cost of each method used for an AI, weighted by the share of that application method in the total acres treated with that AI. In the pre-bloom period, four active ingredients in the set of alternatives were not applied to any acres in the 2015–2017 period. Therefore, we cannot calculate a cost per acre for these AIs during this period. Furthermore, these AIs were not included when creating the cost for the composite alternative. Cost per acre ranges from $27.97 to $60.29 in the pre-bloom/bloom period, and from $28.09 to $151.48 in the post-bloom period. Growers consider a number of factors including cost per acre in determining which pesticide to apply. Chlorpyrifos is not considered an alternative as it is scheduled to be cancelled (CDPR 2019).

Table 69. Average Annual Acreage Shares of Alternative Insecticides with and without Target Nitroguanidine Substituted Neonicotinoids (NGNs): Walnut 2015–2017

Active ingredient	**Acreage share with target active ingredients available (%)**		**Acreage share without target active ingredients available (%)**	
	----Jan to Apr--	**----May to Dec--**	**----Jan to Apr---**	**----May to Dec---**
acetamiprid	25.46	24.87	32.76	31.3
bifenthrin	30.76	30.05	39.57	37.81
burkholderia sp	--	0.29	--	0.36
clothianidin*	--	1.23	--	1.54
fenpropathrin	--	0.46	--	0.58
flupyradifurone	--	0.01	--	0.01
lambda-cyhalothrin	19.77	20.53	25.44	24.31

phosmet	0.41	0.40	0.53	0.50
spinosad bait	--	1.55	--	1.95
spinosad spray	1.33	1.30	1.71	1.63
Total	77.73	80.69	100	100

*Clothianidin is a target insecticide in January to April only

Table 69 provides the average acreage shares for each non-NGN alterative for walnut. Both the columns for acreage share with and without target AI available are divided into two columns, the first for the January to April period when clothianidin is prohibited, the second for May to December when clothianidin is available as an alternative. Averaged over the three-year period 2015–17 when NGNs were available, in the pre-bloom/bloom period, clothianidin and imidacloprid were used on 22.27% of total walnut acres treated with insecticides, and imidacloprid was used on 19.31% of total walnut acres treated with insecticides in the post-bloom period.

When imidacloprid and/or clothianidin are cancelled, the other alternative AIs scale up to compensate for their absence. For example, the most commonly used AI, bifenthrin, is used on a slightly higher percentage of acres pre-bloom at 39.57% than post-bloom at 37.81%. The other major AIs used as alternatives were acetamiprid and lambda-cyhalothrin. Of note, *Burkholderia sp* products were not used in walnut before 2017, one reason they were applied only a very small share of the acreage. Their use has likely increased since then, particularly in organic production.

Table 70: Costs per Acre for Target NGNs and the Composite Alternative: Walnut

Active ingredient	**Material Cost per acre($)**	**App Cost per acre($)**	**Total Cost per acre($)**	**Cost Increase for Switching (%)**
----Jan to Mar----				
Clothianidin	12.18	25.00	37.18	35.96
Imidacloprid	14.12	24.98	39.10	29.28
Composite Alternative	25.44	25.11	50.55	-
---Apr to Nov---				
Imidacloprid	12.22	24.36	36.58	42.97
Composite Alternative	27.28	25.01	52.30	-

Table 70 shows the average per acre costs for clothianidin and imidacloprid in the pre-bloom/bloom period and imidacloprid only in the post-bloom period, as well as the cost of the composite alternative in each of these periods. For walnut in the pre-bloom/bloom period, switching to the alternative would lead to a 35.96% increase in cost on acres using clothianidin and a 29.28% increase in cost on acres using imidacloprid. In the post-bloom period, switching to the alternative would lead to a 42.97% increase in cost on acres using imidacloprid.

Table 71. Change in Treatment Costs due to Cancellation of Nitroguanidine Substituted Neonicotinoids (NGNs): Walnut Pre- and Post-Bloom, 2015–2017

Year	Cost with target active ingredients ($)	Cost without target active ingredients ($)	Change in cost ($)	Change in cost (%)	Share of change due to material costs (%)	Share of change due to application costs (%)
2015	3,060,004	4,387,176	1,327,171	43.4	96.0	4.0
2016	2,524,342	3,629,706	1,105,364	43.8	96.0	4.0
2017	3,146,754	4,524,392	1,377,638	43.8	96.0	4.0

Table 71 reports the change in material costs due to a year-round cancellation of imidacloprid and a January to April (pre-bloom and bloom periods) cancellation of clothianidin. For walnut, insecticide material and application costs increase by a little over 40% under the policy. The change in costs is consistent from one year to the next and exceeds $1M all three years.

Table 72. Change in Treatment Costs due to Cancellation of Nitroguanidine Substituted Neonicotinoids (NGNs): Walnut Pre- and Post-Bloom, 2015–2017, Excluding Venerate and Entrust 2015–2017

Year	Cost with target active ingredients ($)	Cost without target active ingredients ($)	Change in cost ($)	Change in cost (%)	Share of change due to material costs (%)	Share of change due to application costs (%)
2015	3,060,004	4,358,755	1,298,751	42.4	96.0	4.0
2016	2,524,342	3,605,441	1,081,099	42.8	95.9	4.1
2017	3,146,754	4,494,161	1,347,407	42.8	95.9	4.1

There are two alternative products that are used disproportionally by organic growers: Venerate, a *Burkholderia sp* product, and Entrust, a spinosad product. While we do not know the exact proportion of these products used by organic growers and they are legitimate alternatives for conventional growers, their inclusion in calculating the composite alternative is likely to overestimate their use by conventional growers. Table 72 reports the change in material costs due to the cancellation of NGNs when Venerate and Entrust are excluded from the composite alternative. If Venerate and Entrust are included, costs would increase by approximately an additional 1 percent.

Conclusions and Critical Uses

For walnut, there are effective alternatives for imidacloprid in post-bloom season and imidacloprid and clothianidin in the pre-bloom period. Using the alternatives in proportion to their current use to fill in for imidacloprid the post bloom season and both clothianidin and imidacloprid in the pre-bloom season would increase walnut material and application costs by approximately 40 percent.

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