Economic and pest management evaluation of nitroguanidine-substituted neonicotinoid insecticides: eight 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

In 2018 the California Department of Pesticide Regulation (DPR) released its risk determination for four nitroguanidine-substituted neonicotinoid (NGN) insecticides: clothianidin, dinotefuran, imidacloprid, and thiamethoxam (Troiano et al. 2018). This was followed in 2020 by a draft proposed regulation detailing mitigation measures to protect managed pollinators. Our report uses economic data and pesticide use data from 2015-2017 to analyze the economic and pest management implications of the draft proposed regulation for eight focal crops: almond, cherry, citrus, cotton, grape, strawberry, tomato, and walnut. From 2015-2017, these crops accounted for approximately 90% of total acres treated with NGN and 89% of NGN use by pounds of active ingredient (AI) applied in treatments that would have been affected by the draft proposed regulation (not all crops would be affected). They also accounted for over 60% of the value of California's field crop, fruit, nut, vegetable, and melon production and over half of its agricultural exports in 2017 (CDFA 2018a; UCAIC 2018). The draft proposed regulation includes limitations on the number of NGN active ingredients applied to a field in a season, timing restrictions on applications, and use rate restrictions. The applicable restrictions are crop-specific.

Overall, annual net return losses for the crops considered would have totaled $13.603 million in 2015, $12.785 million in 2016, and $11.085 million in 2017 if the draft proposed regulation had been in effect (Table ES-1). Net return losses occur if gross revenues decline as a result of decreased yield or if costs increase. The net return loss in this study is due entirely to cost increases because no yield losses are anticipated for these eight crops with the proposed restrictions. The costs considered are the treatment costs of replacing NGNs with alternative AIs during times in which they are restricted or prohibited by this regulation, including material and application costs. We calculate the total annual loss for each of the three years by comparing the cost of an alternative treatment to that of each application of an NGN actually made that would have been prohibited under the draft proposed regulation.

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 based on its use in 2015-2017, but, due to the withdrawal of all non-granular chlorpyrifos products in 2019, it was omitted here.

Table ES-1. Estimated Changes in Costs by Crop and Year ($1,000s)

Crop	2015	2016	2017
Almond	-20.8	11	-4.6
Cherry	-12.5	1.8	-8.6
Citrus	2,906	3,272	2,888
Cotton	755	1,439	1,839
Grape			
Raisin and table	194	267	256
Wine	354	382	617
Strawberry	384.5	193.8	207.4
Tomato			
Fresh market	1,267	1,516	1,229
Processing	7,776	5,703	4,781
Walnut	0.31	0.38	0.16
Total	**13,603**	**12,785**	**11,805**

Almond. Almond is California's second largest agricultural commodity in terms of value of production, ranked behind milk and cream. Gross revenues totaled $5.6 billion in 2017 and exports were $4.5 billion (CDFA 2018a; UC AIC 2018). Clothianidin is the only NGN currently registered in almond. Imidacloprid was registered until 2015 and growers are allowed to exhaust inventory, so some use was reported during 2015-17. Neither NGN 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 alternative AIs for each pest. Under the draft proposed regulation, roughly 77% to 90% of the pounds of AI applied and 81% to 94% of the acres treated would be permitted per year. Switching to alternatives for treatments that would have been prohibited would lead to a 22.2% increase in cost on acres using imidacloprid and a 17.9% decrease in cost on acres using clothianidin. Based on acres treated annually for the years 2015-2017, the change in treatment costs for acres treated with NGNs when alternatives must be used ranges from -6.9 to 4.8% 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, ranging from a cost decrease of $20,800 to an increase of $11,000 over all affected applications. This is due to the off-setting effects of the reduction in treatment costs for some alternatives and the small acreage treated with NGNs. Costs due to the regulation would decline once existing imidacloprid product is exhausted.

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. Under the draft proposed regulation only 1.6% to 5.1% of acres treated and 1.5% to 12.6% of pounds of AI applied would have been allowed per year. Imidacloprid and thiamethoxam are mainly used against black cherry aphid, cherry leafhopper, and mountain leafhopper. If the target NGNs were restricted in cherry, the percent change in total treatment cost on all acres that would have used alternatives instead would range from -2.2% (2015) to 0.3% (2016). These percentages correspond to a total cost decrease of $12,469 and a cost increase of $1,750, respectively. The net effect is small because switching to imidacloprid alternatives increases costs due while switching to the thiamethoxam alternatives decreases costs.

Citrus. Citrus—specifically grapefruit, lemon, orange, mandarin, and their hybrids—constitute one of California's top ten most economically important commodities by value, 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 (GWSS), citricola scale, citrus leafminer, Fuller rose beetle, and Asian citrus psyllid (ACP). They are also used to treat harvested citrus before it is shipped to combat the spread of insect pests. Controlling GWSS, which vectors Pierce's disease, in citrus is essential to keep it from invading vineyards, where the disease is devasting. In addition, NGNs are part of the area-wide programs for managing GWSS in citrus. Two NGNs are registered for California citrus, imidacloprid and thiamethoxam; both would be restricted. There would be more restrictions on imidacloprid than on thiamethoxam. Under the proposed regulation, only 31.1% to 33.1% of acres treated, and 9.9% to 11.3% of pounds applied would have been allowed per year. The substantial difference between the acreage and volume shares is due to the prohibited treatments having relatively high application rates. Switching to alternatives for applications that would have been prohibited would lead to a cost increase of 51% to 55% for those applications. The cost increase is small in dollar terms, however, leading to a total cost increase ranging from $2.9 to $3.3 million on acreage treated with imidacloprid or thiamethoxam.

There are two critical caveats regarding this estimate. One is that while there are fewer impacts of the thiamethoxam restrictions during the growing season, its pre-shipment use in citrus would be hit hard. The specific economic effects of pre-shipment use are not included here because that type of use cannot be differentiated from other uses. Second, 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, ACP. Imidacloprid is a vital component of ACP control programs for commercial and residential citrus. Without the use of imidacloprid, the deadly bacterial disease vectored by ACP, huanglongbing (HLB, or citrus greening disease), will spread at a faster rate in the state, jeopardizing the entire industry. HLB kills citrus trees and there is no known cure once trees are infected. Managing ACP populations is one of the only ways to slow the spread of HLB. Economic losses from widespread HLB would be significant and are not included in this report. Emergency pest control programs run by CDFA, such as for HLB, would be exempt from this regulation. Growers, however, would not be exempt unless they were under a declared emergency for HLB, which only covers a small number of growers currently. For the purposes of estimating pest management costs in this analysis, growers were not assumed to be under a declared emergency, which makes the cost estimate an overestimate to an unknown extent.

Cotton. Cotton generated $475 million in gross revenues and $377 million in exports in 2017 (CDFA, 2018a; UCAIC 2018). Acreage had been decreasing gradually until it recently 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. Restrictions would limit growers to choosing one of the four to use on a given field each year. Applications would only be allowed prior to bloom. 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 with restrictions on NGNs. Under the draft proposed regulation, only 34.4% to 41.4% of acres treated, and 34.6% to 39.5% of pounds applied would have been allowed per year. The percent change in costs from replacing the NGN applications that would have been prohibited with alternatives ranges from 31% in 2015 to 40.2% in 2016, with associated annual losses ranging from $755,000 to over $1.8 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 NGN and 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 vine mealybug, leafhoppers, sharpshooters, 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 concentrated in warmer growing areas than wine grape, and, as a result, tend to have more problems with vine mealybug. Controlling sharpshooters is vital because they vector Pierce's disease, which is untreatable and devasting to vineyards. CDFA has a Pierce's disease program, with USDA funding, that addresses GWSS. There are alternatives to the NGNs for sharpshooters, leafhoppers and mealybugs, but they are more expensive. Phylloxera management does not have good alternatives for NGNs. Restrictions would limit growers to choosing one of the four NGNs to use on a given field each year. PUR data separate grape into two categories, grape, including table and raisin, and wine. Under the draft proposed regulation, 77% to 80% of acres treated, and 76% to 86% of pounds applied would have been allowed on table and raisin grape, and 83% to 88% of acres treated, and 87% to 91% of pounds applied would have been allowed on wine grape. For table and raisin grape, the percent change in costs on affected acreage ranges from 37.1% in 2017 to 44.8% in 2015. The associated total cost increase on affected acres summing over all NGNs would be $194,000 to $267,000. For wine grape, the percent change in costs ranges from 64.9% in 2015 to 74.1% in 2017. The associated total cost increase would be $354,000 to $617,000. The changes are driven mainly by the restriction of treating a field with only one NGN per year.

Strawberry. In 2017, strawberry was California's fourth largest agricultural commodity by value of production, with gross revenues of over $3 billion (CDFA, 2018a). Exports in 2017 were $415 million (UCAIC 2018). Two NGNs are used to control sucking insect pests in California strawberry: imidacloprid and thiamethoxam. Target insect pests include aphids, leafhoppers, lygus bug, root weevils and grubs, and whiteflies. The importance of these insects may vary by region and year. Provided a grower is not using managed pollinators, the only applicable proposed restrictions limit a grower to using one active ingredient and one application method per field per year. It is likely that only thiamethoxam use would be restricted as it is only used after bloom. Under the proposed regulation, 27.0% to 39.5% of acres treated, and 73.2% to 80.7% of pounds applied, consisting entirely of imidacloprid applications, would have been allowed per year. This would result in a $194,000 to $385,000 increase in total costs. This is a 30.6% increase in costs on acres treated with thiamethoxam. Although imidacloprid is not nearly as widely used as thiamethoxam for strawberry, it is vital for control of disease vectors; its use would be largely unchanged by the proposed regulation because it occurs before bloom.

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 in the U.S. and the second largest producer of fresh tomato, behind only Florida. Provided a grower is not using managed pollinators, the only applicable restrictions would limit them to using one AI and one application method per field per year. 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 effective control for an extended period of time. 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 67.6% to 76.1% increase in treatment costs for fresh tomato and a 121.1% to 130.0% increase for processing tomato. In absolute terms, the total annual cost increase ranges from $1.2 million to $1.5 million for fresh market and $4.8 million to $7.8 million for processing.

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). Two NGN insecticides are registered for use on walnut: clothianidin and imidacloprid. Provided that a grower is not using managed pollinators, the restrictions would only limit a grower to using one active ingredient for a field each year. They are used mostly against aphids and walnut husk fly with minor use against scale insects. Under the draft proposed regulation, 98% of acres treated and 98% of pounds applied would have been allowed per year. Insecticide material and application costs for applications using alternative active ingredients compared to applications using NGNs increase by 1.3% under the policy. The increase in cost ranges from $160,000 to $375,000.

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 slightly more than 60% of California's field crop, fruit, nut, vegetable and melon production and 89-90% of NGN use that could be affected by the regulation. 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. One change that has already occurred is the cancellation of chlorpyrifos, effective January 1, 2020. 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 restriction of the target NGNs. Finally, the development of pest resistance to AIs can increase the cost of restriction by reducing the number of modes of action available. Even if there are efficacious alternatives for a target NGN for the management of specific pests, using alternatives may limit their availability for controlling other pests and ultimately increase pest management costs and/or reduce yields.

Contents

Table of Tables

Table of Figures

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. 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.

Food and Agricultural Code (FAC) section 12838 required the California Department of Pesticide Regulation (DPR) to issue a risk determination on its reevaluation of the NGNs, which it 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. Among the risks considered were those to the colony as a whole from sub-lethal exposure (Troiano et al. 2018). The draft proposed regulation is meant to mitigate the risks to managed pollinators (honeybees) that were identified in the risk determination. This report evaluates the economic effects of the draft proposed regulation on eight major California crops: almond, cherry, citrus, cotton, grape, strawberry, tomato and walnut. These crops accounted for over 60% of the value of California's field crop, fruit, nut, vegetable and melon production and over half of its agricultural exports in 2017 (CDFA 2018a; UCAIC 2018).[1]

The draft proposed regulation (presented in Appendix A: Draft Text of Proposed Regulation) will be referred to as the "proposed regulation" throughout the remainder of this report. The proposed regulation includes several specific restrictions. First, it would allow only one NGN AI to be applied to a field each year. Growers could choose from the permitted options but could not switch AIs mid-year. Second, applications would be restricted to only foliar applications or only soil applications.[2,3] Third, no applications would be allowed to crops in bloom. And lastly, no applications would be allowed to indeterminate blooming citrus crops. In addition to these four primary restrictions, there are additional use rate restrictions and prohibitions for a set of crops that are highly attractive to honeybees and/or fields that use managed pollinators. Combined, these restrictions can significantly impact when and how NGN products can be used. Accordingly, for cotton, grape, strawberry, and tomato, which rarely use managed pollinators,

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

[2] Foliar applications refer to ground and aerial applications in which the product is applied to the leaves or stems of a plant. Soil applications refer to applications of product directly to the soil by chemigation, side dressing, or other methods.

[3] In stone fruit both foliar and soil would be allowed to be applied to the same field.

we focus on the impacts of the four general restrictions only. The extent of timing and use rate restrictions are in Table 1 and detailed in each crop section.

Table 1. Target Nitroguanidine-substituted Neonicotinoid Proposed Regulations by Focal Crop

	Imidacloprid	Thiamethoxam	Clothianidin	Dinotefuran
Almond	No current products registered but growers could use existing stock during the study timeframe.	No current products registered.	No soil application. Foliar application allowed if no other NGN is used from end of bloom to harvest up to 0.2 lb AI/acre/season	No current products registered.
Cherry	Allowed end of bloom to harvest (soil - 0.38lb AI/acre/season, foliar - 0.5 lb AI/acre/season)	Foliar allowed end of bloom to harvest (0.172 lb AI/acre/season)	No current products registered.	No current products registered.
Citrus	Allowed* (soil-after petal fall to 1/31, up to 0.086 lb AI/acre/season; foliar – after petal fall – 12/1, 0.172 lb AI/acre/season)	Allowed (soil-after petal fall to 1/31, up to 0.172 lb AI/acre/season; foliar – after petal fall – 12/1, 0.172 lb AI/acre/season)	No current products registered.	No current products registered.
Cotton**	Allowed prior to bloom if no other NGN is used. Either foliar or soil per season.	Allowed prior to bloom if no other NGN is used. Either foliar or soil per season.	Allowed prior to bloom if no other NGN is used. Either foliar or soil per season.	Allowed prior to bloom if no other NGN is used. Either foliar or soil per season.
Grape**	Allowed if no other NGN is used. Either foliar or soil per season. No applications during bloom.	Allowed if no other NGN is used. Either foliar or soil per season. No applications during bloom.	Allowed if no other NGN is used. Either foliar or soil per season. No applications during bloom.	Allowed if no other NGN is used. Either foliar or soil per season. No applications during bloom.
Strawberry	Allowed if no other NGN is used. Either foliar or soil per season. No applications during bloom. No use with managed pollinators.	Allowed if no other NGN is used. Either foliar or soil per season. No applications during bloom. No use with managed pollinators.	No current products registered.	No current products registered.
Tomato	Allowed if no other NGN is used. Either foliar or soil per season. No applications during bloom. No use with managed pollinators.	Allowed if no other NGN is used. Either foliar or soil per season. No applications during bloom.	Allowed if no other NGN is used. Either foliar or soil per season. No applications during bloom.	Allowed if no other NGN is used. Either foliar or soil per season. No applications during bloom.
Walnut**	Allowed if no other NGN is used. Either foliar or soil per season. No use in bloom.	No current products registered.	Allowed if no other NGN is used. Either foliar or soil per season. No use in bloom.	No current products registered.

*While technically allowed, the new maximum use rate is below what would be effective for pest management.

**While there are use rate restrictions with managed pollinators for these crops, they rarely use managed pollinators.

In 2014, Assembly Bill 1789 (which added section 12838(b)(1) to the California Food and Agriculture Code), required DPR to issue a determination with respect to its reevaluation of neonicotinoids by July 1, 2018. After making this determination, the bill gave the department two years to identify and adopt measures necessary to protect pollinator health. After the risk determination was released, the Office of Pesticide Consultation and Analysis (OPCA) in the California Department of Food and Agriculture (CDFA) began working with DPR to assess the economic and pest management effects of potential changes in the availability of NGNs. Additional information regarding mitigation measures was provided by DPR in January, February, and March 2020. This report evaluates the potential economic impacts on eight major California crops of a specific possible change driven by DPR's proposed regulation to mitigate risk. It is part of the interagency consultation between DPR and OPCA. 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.

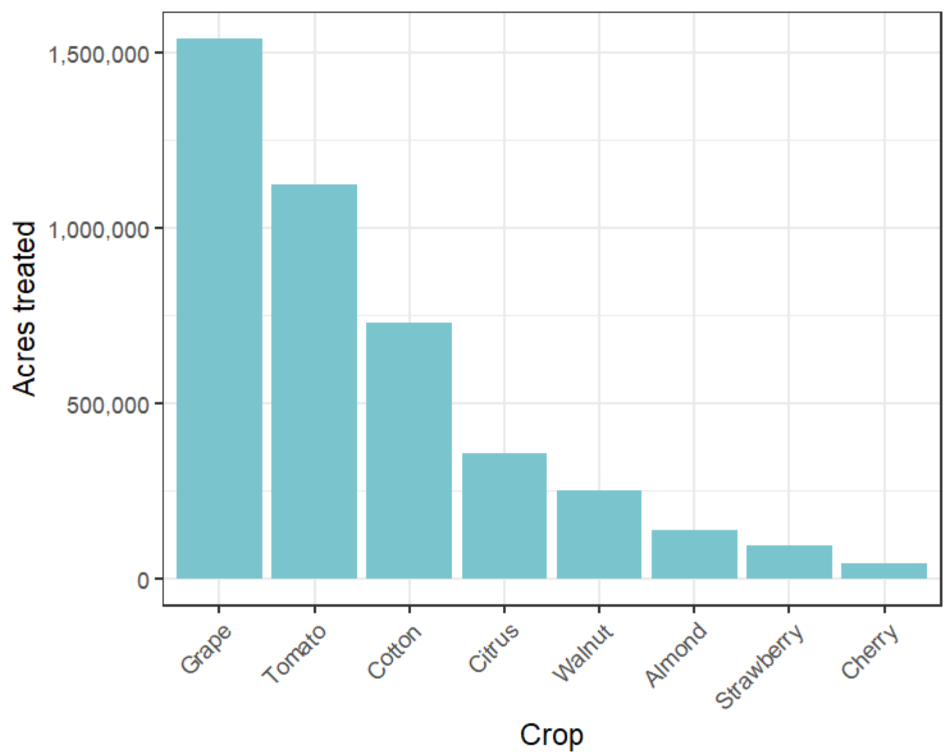

Figure 1. Total acres treated with nitroguanidine-substituted neonicotinoids by focal crop: 2015-2017

For the eight focal crops, we discuss 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 proposed regulation of NGNs.

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 four criteria: their acreage treated with the AIs relative to their total acreage, their use of the AIs relative to the total use of that AI across crops, the potential impact of the regulations on their pest management practices and costs, and their economic importance to California agriculture (see page 25). 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 restricting specific uses of the NGNs.

Considerations across All Crops

There are several issues that are common across crops: the 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 more of these are particularly important; however, none are entirely absent for any crop.

Withdrawal of chlorpyrifos. Chlorpyrifos was listed as a toxic air contaminant by the California Department of Pesticide Regulation in 2018, which led to an agreement between Dow AgroSciences and DPR to discontinue the use of all chlorpyrifos, except granular products, within two years. Apart from granular formulations, chlorpyrifos products are no longer sold in California as of January 2020 and all use must end by December 31, 2020.[4] Chlorpyrifos could have served as a substitute for NGNs in some cases. This report restricts attention to evaluating the economic impacts of restricting NGNs for specific uses based on acres treated with NGNs. Economic impacts of canceling chlorpyrifos essentially concurrently are not considered directly.[5]

Resistance management. Resistance is when insects become less susceptible 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).[6] These classifications are routinely used by growers and pest control advisors (PCAs). One of the best ways to slow the development of resistance is to limit the exposure of insect populations to specific MoAs by rotating what is applied in a given location. Guidelines are available to growers and PCAs about how to rotate insecticides to reduce the risk of resistance.

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[4] https://www.cdpr.ca.gov/docs/chlorpyrifos/index.htm

[5] See https://www.cdfa.ca.gov/files/pdf/ChlorpyrifosReport.pdf for an assessment of the cost to California agriculture of the cancellation of chlorpyrifos.

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

Neonicotinoids, including the four NGNs addressed here, are often used in rotation with insecticides with other MoAs, particularly for pests that are known to develop or have already developed resistances to some AIs. Even if a variety of AIs are effective against a pest, it is likely that resistance would develop more quickly if NGNs are removed from the rotation. 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, or key, pests generally attack a crop on a perennial basis, requiring regular management. Secondary pests cause infrequent damage, needing only occasional control measures. Secondary pests can quickly become damaging if an insecticide applied for a key pest eliminates natural enemies that were keeping the secondary pest in check. This is a common situation with spider mites, which are often well controlled by natural enemies. Broad spectrum insecticides, like pyrethroids, destroy natural enemies, allowing mite populations to explode. 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 insecticides for 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. Restricting use of 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 could be substantial. Additionally, it could worsen the problem of resistance development.

Cucurbits

Cucurbits were not included in the focal crops (see methods section for crop selection), and no economic impacts were estimated for them. Owing to specific pest management constraints, however, it is likely that cucurbits would be significantly affected by the proposed regulation. Like strawberry and tomato, in cucurbit crops – melon, cucumber, squash – NGNs are used to manage insects that vector diseases, specifically aphids. Unlike strawberry and tomato, cucurbit crops do use managed pollinators. For fields using managed pollinators, there are significant proposed restrictions on NGN use. In melons, no use would be allowed. The systemic nature of NGNs make them critical tools for managing vectors. Without access to these tools, it is likely that multiple sprays of alternatives would be needed to control aphids, and it is possible that these crops would nonetheless sustain yield loses. These potential economic impacts are not included in this report.

Caveats

There are a number of caveats regarding the estimates in this report. Here we mention the most significant ones. In addition, the individual crop analyses include crop-specific considerations. The first set of caveats regards methodology, starting with the selection of crops we analyzed. While they are economically important crops that apply the target NGNs to a substantial amount of acreage, they account for only slightly more than 60% of the value of

California's field crop, fruit, nut, vegetable and melon production and 90% of acres treated with NGNs that could be subject to restrictions each year. 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.

Another methodological caveat is that the proposed restrictions are complicated and sometimes related to crop development (e.g., allowed after bloom or between petal fall and December 1). These phenological phases do not always occur at the same time each year. We used estimates of when those events would likely occur to conduct these analyses. It is possible that our estimates are either too broad, thereby allowing applications that should not be allowed, or too narrow, thereby disallowing applications that should be allowed. Similarly, in order to analyze the restriction to only one NGN per field per year, we had to select which one growers would be most likely to choose based on use during the base years and the role(s) each plays in an integrated pest management program for the crop in question.

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 may change the number of individual AIs applied in total. Second, new regulations may change the availability of alternative AIs. We were able to control for one regulatory action in this report; chlorpyrifos was excluded as an alternative due to its cancellation. 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, beta-cyfluthrin is included as an alternative, though it may not be available in the future. 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. Third, growers could reduce their cumulative use rate to comply the new limits with only moderate changes to their use patterns in some cases. For this analysis, we assumed that growers were using the minimum amount they considered effective. As such, we assumed that no one would change their use to adjust to the regulations. This is likely overly conservative. Growers near the cumulative use rate would likely be able to adjust downward with no loss of efficacy. Even so, the cumulative use rate was not usually the most restrictive part of the proposed regulation in terms of eliminating applications from the set that would remain feasible. Often timing restrictions and full prohibitions eliminated more applications.

A third set of caveats is that biological changes may occur. Invasive species may increase the cost of the restriction of the target NGNs. For example, the restriction of imidacloprid for citrus would limit a critical tool for the management of Asian citrus psyllid. The proposed regulation has an exemption for use in emergencies that would mitigate some of these impacts by allowing CDFA to apply NGNs in declared emergencies, such as for ACP; however, growers would not be able to do the same unless they were under mandated application programs, such as exists for ACP. The development of pest resistance to AIs can also increase the cost of regulation. 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 integrated pest management (IPM) methods, and finally the components of the economic analysis.

Crop Selection

DPR used the federal Environmental Protection Agency's crop group categories in the proposed regulations. Accordingly, we utilized those categories to select crops for analysis. For each crop group, Table 2 reports the crop that treated the most acres with all NGNs from 2015-2017 along with its total acres treated for that three-year period, and whether 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 berry crop group, grape (wine, table, and raisin) was the top user and strawberry was also included owing the potential large impact of prohibiting imidacloprid use. Pistachio is the heaviest user in the tree nut group but would not be subject to any restrictions. Lettuce and cole crops (Brussels sprout, cabbage, collard green, and kale) are heavy users but would not be restricted unless the crops are allowed to flower.[7] Potato would not be restricted. Artichoke, carrot, sugarbeet, turnip, parsnip, radish, rutabaga, and skirret would not be restricted unless they are being grown for seed. In total, eight 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, 8, 9, 11, and 17. These crops represent 63-66% by acres treated and 54-68% by pounds applied of total NGN use. However, they represent approximately 89 or 90% of use, for pounds and acres respectively, for crops that would be affected by the regulation.[8]

[7] If these crops are allowed to flower, all use of NGNs would be prohibited. This would only happen in crops grown for seed.

[8] Crops that would be affected only if being grown for seed are excluded from this calculation because the acreage dedicated to seed production is small.

Table 2. Crop Selection Decision Information

Crop group	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	Potato	64,764 (14)	None	No	Small acreage
3: Bulb vegetables	Artichoke	20,784 (24)	None	No	Not restricted
4: Leafy vegetables	Lettuce	827,402 (3)	None	No	Not restricted
5: Cole crops	Aggregated	576,859 (6)	None	No	Not restricted
6: Legume vegetables	Dried bean	26,703 (22)	None	No	Not restricted
8: Fruiting vegetables	Tomato	1,124,244 (2)	None	Yes	
9: Cucurbit vegetables	Cantaloupe	74,807 (13)	None	No	Small acreage
10: Citrus fruit	Aggregated	822,564 (4)	None	Yes	
11: Pome fruits	Apple	6,255 (37)	None	No	Small acreage
12: Stone fruits	Cherry	42,782 (17)	None	Yes	
13: Berry	Grape	1,539,802 (1)	Strawberry (11)	Yes	
14: Tree nuts	Pistachio*	317,807 (7)	Walnut (8), Almond (9)	Yes	
15: Cereal grains	Wheat, fodder	478 (83)	None	No	Small acreage
19: Herbs and spices	Cilantro	7,367 (35)	None	No	Not restricted
20: Oilseed group	Cotton	730,708 (5)	None	Yes	
24: Tropical and subtropical fruit	Persimmon	392 (92)	None	No	Small acreage

*Pistachio not subject to the proposed regulation. Walnut and almond are and are included in this report.

Pesticide Use Data

Pesticide use data from 2015-2017, specifically pounds applied, and acres treated by AI, were obtained from DPR's pesticide use reporting (PUR) database.[9] 2017 is the most recent year of data available and any shifts in usage since then are not captured in our analysis. Use of the target NGNs was examined at various time intervals within a year depending on how the proposed regulations might affect the crop.

Regions. Table 3 presents the standard growing regions for California defined in the PUR.

Table 3. 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. We determined target pests based on UC Cooperative Extension (UCCE) scientists' and other experts' detailed knowledge of the crops. UCCE personnel also provided lists of alternative AIs, which were used in the economic analyses, and information on intra-year and inter-year variations in use.

[9] https://www.cdpr.ca.gov/docs/pur/purmain.htm

Maps

The maps presented in each crop section depict the spatial distribution of production 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 plot 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 acres treated of the crop within a square mile. The map would show the same result if there were one acre or 100 acres treated within the square mile.

Determining allowed and prohibited applications

For each crop, we assessed which applications would have been allowed and which would have been prohibited under the proposed regulations. The economic impacts are based on what would have happened in place of the applications that would have been prohibited (e.g. one or more applications of alternative insecticides) and if yield losses would be expected under that scenario. Due to the complex and layered nature of the restrictions, we defined applications as allowed using a stepwise process: within the allowed timeframes, an allowed AI, one AI applied to the field, only one application method with the allowed AI, and a use rate no higher than the maximum rate. Those applications would have been unaffected by the proposed regulation (Figure 2). We estimate the cost of prohibiting the remaining applications.

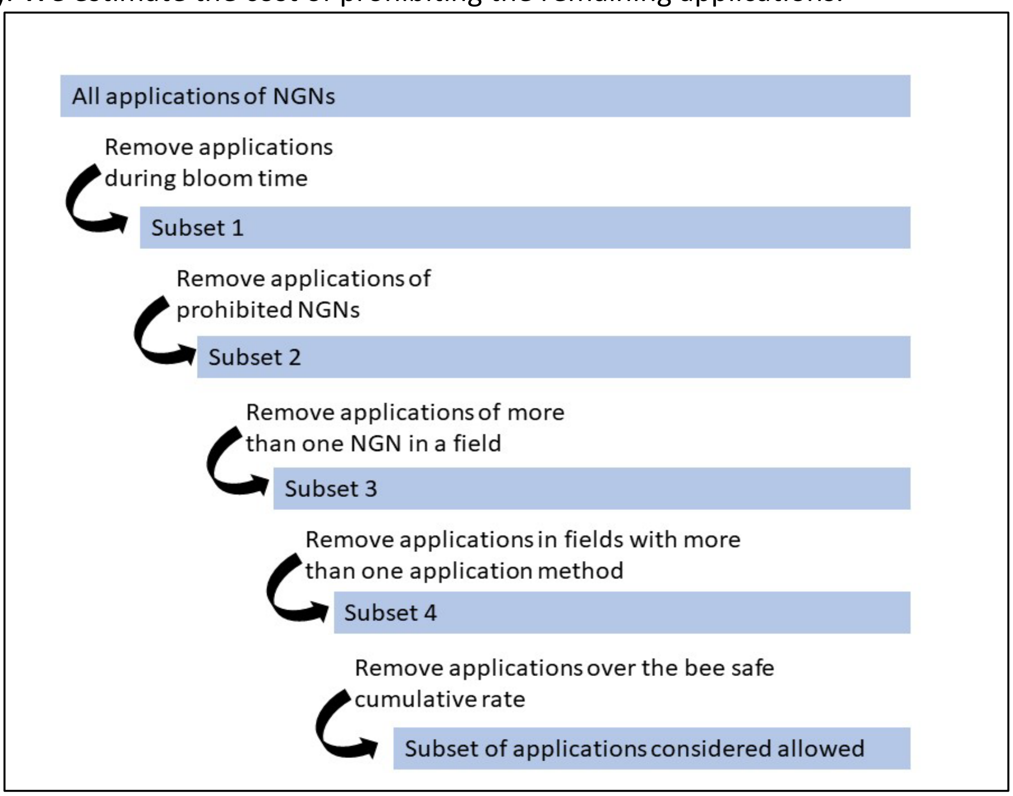

Figure 2. Stepwise process for labeling applications as allowed

The timing restrictions in the proposed regulations are mostly based on crop phenology. When possible, we estimated the approximate annual timing of the relevant crop development stages (i.e., bud burst, bloom, petal fall, berry size, harvest). The estimates of crop development are broad approximations that are unlikely to be exactly right for every year. When the proposed regulation gave dates (e.g., December 1), we used those dates. Applications outside of the allowed times were considered prohibited.

Only one AI of the four NGNs would be allowed on a given field in a given year. For fields that used more than one NGN AI, only applications from one AI were considered allowed. Which applications would be kept (allowed) and which would be considered prohibited was determined on a crop-by-crop basis based on pest management requirements. Specific decisions for each crop are presented in each crop section.

Only one application method (foliar or soil) would be allowed on a given field in a given year. PUR method codes were used to determine if an application was foliar or soil applied. Foliar applications refer to either ground or aerial applications in which the product is applied to the above-ground portions of a plant. Soil applications refer to applications of product directly to the soil by chemigation, side dressing, or other methods. Under the proposed regulations, a grower would have to choose between only foliar applications or only soil applications. Based on pest management needs, we determined which method growers using both would be more likely to choose. On a crop-by-crop basis, these applications were marked as either allowed or prohibited. Specific decisions for each crop are presented in the crop sections.

Prohibitions on AIs and application methods were straightforward. If an AI or application method is prohibited in the proposed regulations, applications using that AI and/or application method are considered prohibited.

New maximum use rates, which we refer to as bee safe use rates, are included in the proposed regulation. The use rates set limits on single application use rates and cap the cumulative use rate on a single field in a given season. We first marked as prohibited any single applications that were over the maximum allowed rate. We then calculated the cumulative use rate for each field by summing the use rate for each allowed application over the course of the growing season. Once a field accrued the maximum cumulative allowed use rate, further applications were marked as prohibited. (Applications that had been marked as prohibited by previous steps were not included in the calculation of the cumulative maximum rate.)

Economic Analysis

We estimated the change in pest management costs due to the proposed restrictions. Applications that would be allowed under the proposed regulations were assumed to not change. For applications that would have been prohibited, we estimated the change in pest management costs for each crop based on the acres treated, the available alternatives, and the costs per acre of the AIs (Steggall et al. 2018). The baseline total cost was established by multiplying the cost per acre for each target NGN by the acres treated with that target NGN from applications that would be prohibited. This was compared to the cost of the regulated scenario. In the regulated scenario we evaluated, applications of the target AIs would be restricted as outlined in Table 1. To estimate the cost, we assigned all the acres that had been treated with the target NGNs in prohibited applications to the alternative AIs in proportion to the acreage treated with the alternative AIs in 2015-2017 (Steggall et al. 2018).[10] Below we provide 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. No yield declines are anticipated for these eight crops as a result of the proposed regulation, so changes in pest management costs determine the change in net returns.

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 and 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 AI in each crop, we identified a representative product to use in determining the cost of the proposed regulations. The representative product for an AI was generally the 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 decisions by growers. In tomato, for most acres treated with spinetoram, it was applied as a pre-mix product that was not used for the target pests. In this case, the most used product that was applied for management of 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 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).

[10] Because chlorpyrifos was is no longer an alternative, acres treated with chlorpyrifos are not included in this calculation even for crops in which chlorpyrifos would have been an alternative in 2015-2017.

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 4). 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, 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 these crops.

Table 4. 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 crops and 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. As such, in this report, aerial and ground applications are foliar and 'Other' are soil.

When an AI can be applied to a crop using a variety of application methods, we calculated the average application cost per acre based on the frequency at which each application method is used across acres treated with applications that would be prohibited under the proposed regulations. For example: if half of the prohibited applications of an AI on a crop were ground applied ($25/acre) and the other half were aerial applied including helicopters ($27.50/acre), the average application method cost would be $26.25/acre. Only applications that would be affected by the policy change were included in the calculation because only those applications would need to be replaced.

Net returns scenarios. In order to calculate the cost of the loss of the NGNs for each crop, we compared net returns under the status quo to net returns under the proposed regulation. In this study, available alternatives would allow growers to avoid yield losses for all crops, so the change in net returns is simply 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 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 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 defined a composite alternative: each AI was 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. A minor caveat is that, if applications were identified as being restricted under the proposed regulation in a different order (i.e., multiple application methods before multiple AIs), status quo costs may change by very small amounts, ultimately resulting in in very small differences (less than 1%) in the calculated total cost for the change in cost. Another caveat is that because use is scaled up based on all acres treated, the share of a given alternative in overall use of alternatives may not represent its use as a substitute for NGNs for any specific pest.

Crop-specific considerations. Table 5 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 restrictions.

As reported in the second column of Table 5, the analyses for three crops are conducted separately for subsets of prohibited applications: grape, tomato, and walnut. 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 alternative AIs are different, therefore, the acreage shares need to be calculated separately across these two subsets. For walnut, the subset is based on the timing of the application: pre-bloom (January to March) and post-bloom (April to December). This is because pests targeted by NGNs in walnut in the pre-bloom period are different than those in the post-bloom period.

The third column of Table 5 reports other assumptions or features of the analysis unique to a specific crop. For almond, pyriproxyfen bait was not considered an alternative AI. For walnut, spinosad cost per acre was calculated separately for bait and spray because the use rate for 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 3.

Table 5. Summary of Methodological Refinements by Crop

Crop	Subsets for defining representative product	Crop-specific considerations
almond		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
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 from 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 and is by far the largest producer and exporter 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 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 (Figure 3). The three largest almond producing counties, Kern ($1.2 billion), Fresno ($1.2 billion), and Stanislaus ($1.0 billion), accounted for 61.2% of state production in 2017. Almond was a top four agricultural commodity by value in 13 counties (Kern, Fresno, Stanislaus, Merced, San Joaquin, Kings, Madera, Colusa, Glenn, Butte, Yolo, Tehama, and Solano), the second most important agricultural commodity in three of these counties (Kern, Merced, and Tehama), and the top agricultural commodity in six (Fresno, Stanislaus, Madera, Colusa, Glenn, and Yolo).

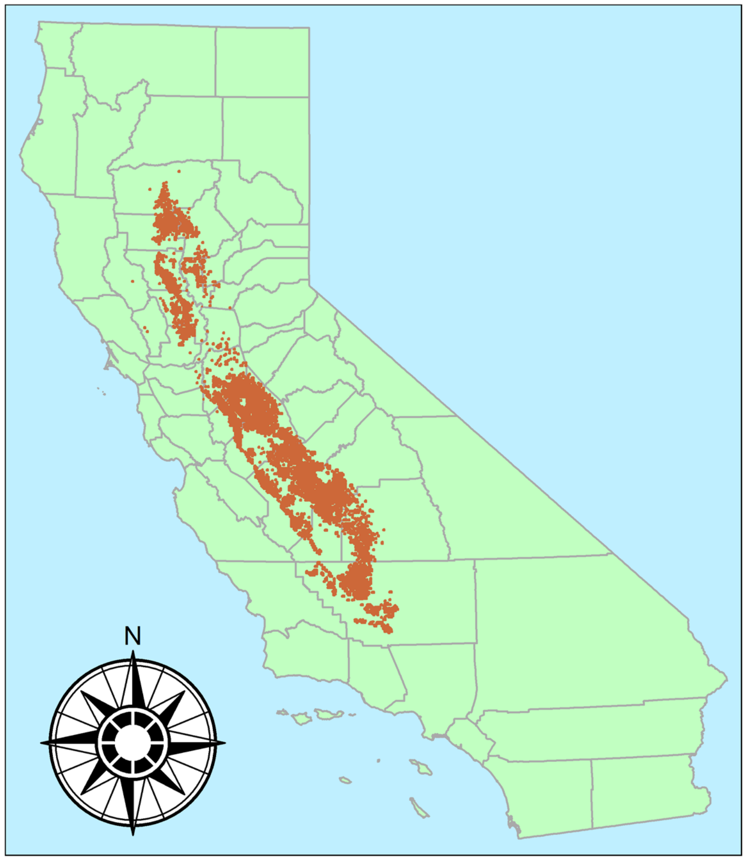

Figure 3. California almond production: 2017

IPM Overview

Given the broad geographic distribution of almond acreage in California, production 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 currently registered, and imidacloprid was registered until 2015 and growers are allowed to exhaust inventory, so some use was reported during 2015-17. Clothianidin is used more often, and approximately 85% of the time it is tank mixed as a secondary AI along with major AIs like abamectin and/or methoxyfenozide (or alternatively chlorantraniliprole). Though clothianidin is considered an alternative AI for the control of plant bugs like leaffooted bug (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% of imidacloprid use), which is not surprising given its registration ended in 2015. 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. Growers report occasionally using chemigated imidacloprid against nematodes. This is rare and not effective. As such, alternative AIs for management of nematodes are not considered in this analysis. 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 in sheltered areas near almond orchards and migrate into orchards in April and May in search of food. Populations of these insects can vary annually across regions, 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. 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 more effective. Alternatives include abamectin, bifenthrin, lambda-cyhalothrin, and esfenvalerate. Chlorpyrifos has historically been used to control leaffooted bugs, however, non-granular chlorpyrifos is no longer being sold in California and 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 orchards as adults. Like leaffooted bugs, their piercing mouthparts damage the nuts. Stink bug damage appears in May through 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 for this spray timing include pyriproxyfen, buprofezin, and carbaryl.

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

Target NGN Use: 2015-2017

Neonicotinoids were applied to less than 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 (2%) of the total almond acres planted. NGN use primarily consists of acres treated with clothianidin but also a small number of acres treated with imidacloprid (Table 6). 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 4).

Table 6. Annual Use of Target Nitroguanidine-substituted Neonicotinoids and Alternative Active Ingredients: Almond, 2015-2017

Active ingredient	**--------Pounds applied------**				**------------Acres treated------------**				**Use rate (lb/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

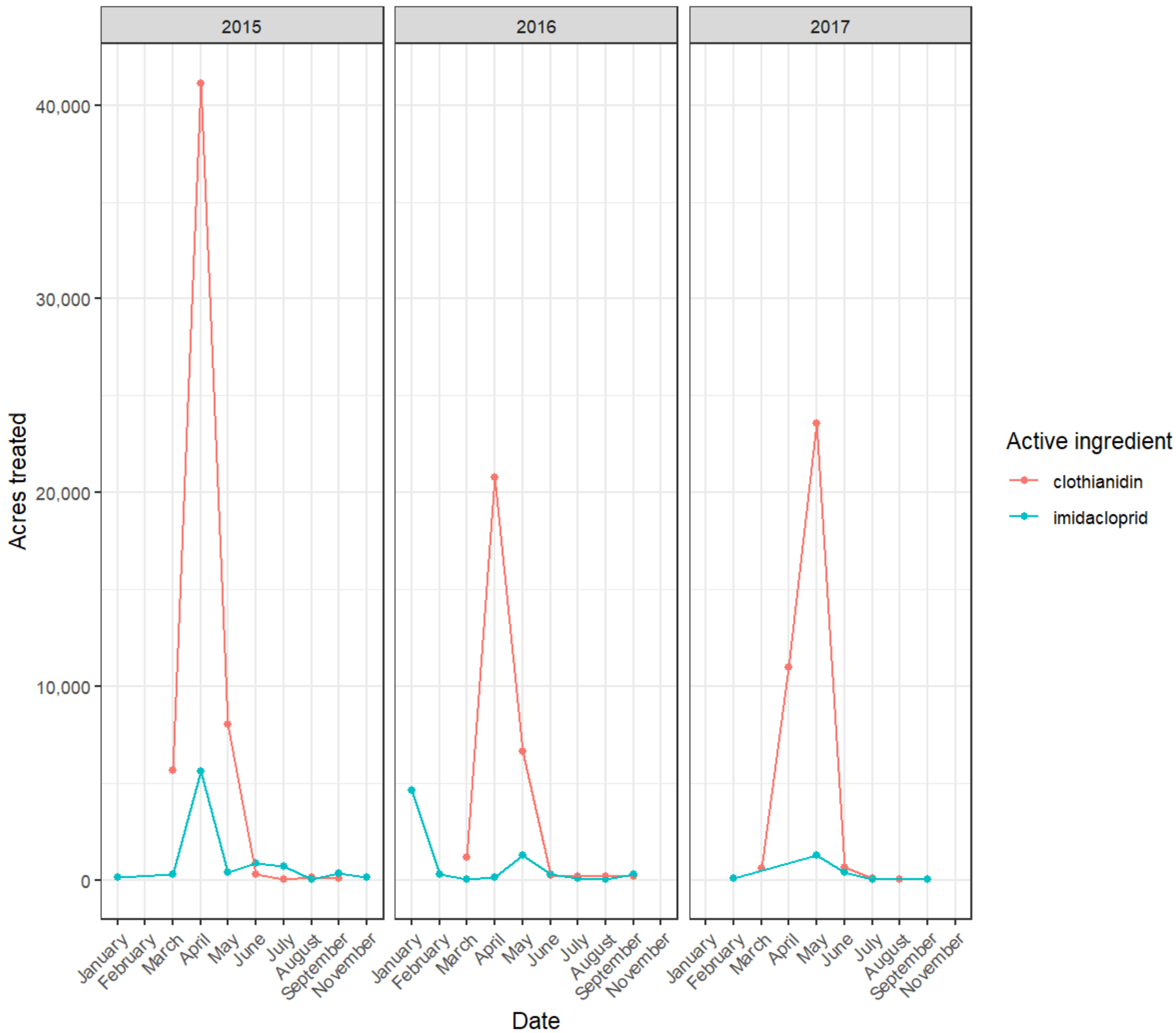

Figure 4. Monthly use of target nitroguanidine-substituted neonicotinoids: Almond, 2015-2017

Proposed Restrictions

Almond is in the tree nut crop group but has more stringent restrictions than other major tree nuts owing to the regular presence of pollinators. Under the proposed regulations, the use of both NGNs would still be allowed to a limited extent. Only foliar NGN applications would be allowed and only after bloom and before harvest. This is roughly equivalent to the beginning of April until the end of August each year. Additionally, neither single applications nor the cumulative use rate can exceed 0.2 lb/acre. Only a single NGN AI and a single application method would be allowed per orchard per year.

Despite having more restrictions that other nut crops, it is unlikely that these restrictions would impact pest management significantly. Historically, only a relatively small share of annual use has occurred during the restricted period (Figure 4). Because imidacloprid is no longer registered, applications of imidacloprid in orchards also applying clothianidin were replaced with clothianidin applications up to the cumulative use rate of 0.2 lb/acre; after the cumulative use rate was reached, all further applications were moved to the alternatives. Applications before 1 April and after 31 August where reallocated to the alternatives. The proposed regulation would still allow roughly 77-90% of lb of AI previously used and 81-94% of acres treated previously treated.

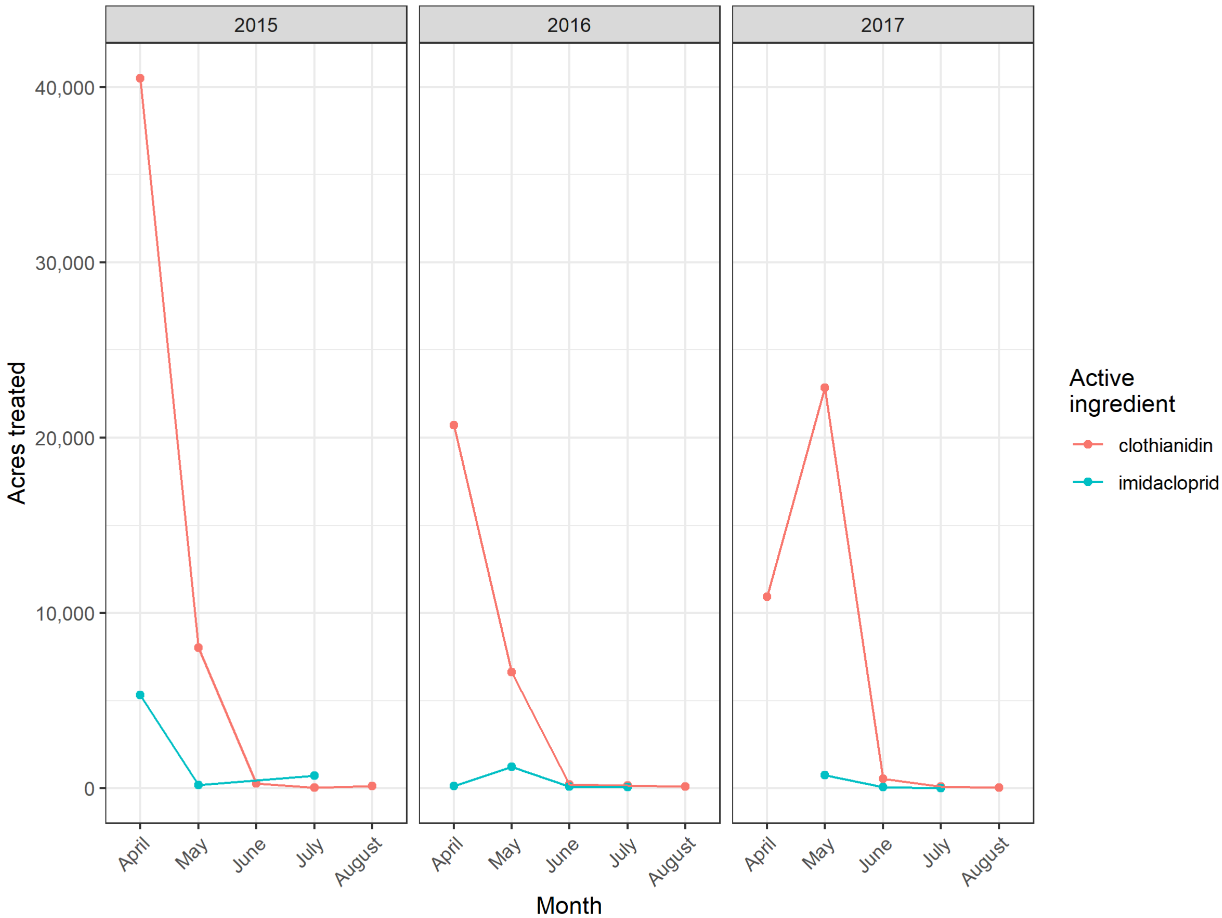

Figure 5: Monthly use of target nitroguanidine-substituted neonicotinoids that would have been allowed under the proposed restrictions: Almond, 2015-2017

Economic Analysis

This section presents the anticipated change in net returns to almond if the use of clothianidin and (remaining stocks of) imidacloprid was restricted. This cost includes the change in pesticide material and application costs.

Table 7. Representative Products and Costs Per Acre: Almond

Active ingredient	Representative product	Material cost ($)	Application cost ($)	Total cost ($)
abamectin	Abba Ultra Miticide/Insecticide	6.32	24.96	31.28
acetamiprid	Assail 30 SG Insecticide	31.90	25.01	56.91
bifenthrin	Bifenture EC Agricultural Insecticide	8.18	25.30	33.48
buprofezin	Centaur WDG Insect Growth Regulator	20.45	25.05	45.50
carbaryl	Sevin Brand XLR Plus Carbaryl Insecticide	27.77	25.66	53.42
clothianidin*	Belay Insecticide	14.45	25.04	39.49
esfenvalerate	Asana XL	7.37	24.97	32.34
imidacloprid*	Wrangler Insecticide	5.74	20.80	26.53
lambda-cyhalothrin	Warrior II	7.35	25.11	32.45
pyriproxyfen**	Seize 35 WP Insect Growth Regulator	11.24	24.96	36.20

*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 7 presents representative products for each active ingredient used on almond in 2015–17 and their costs per acre. The total cost per acre is the sum of the material and application costs per acre. The material cost is calculated as the product of the three-year average use rate (lb/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 acres treated with that AI that would have been prohibited (i.e., excludes allowed applications). The total cost per acre ranges from $26.56 to $56.91. Growers consider other factors in addition to price per acre when deciding which insecticides to use, as discussed above.

Table 8. Average Annual Acreage Shares of Alternative Insecticides with and without Prohibited Applications of Target Nitroguanidine-substituted Neonicotinoids (NGNs): Almond, 2015–2017

Active ingredient	Target NGNs available (%)	Target NGNs restricted (%)
abamectin	48.7	49.7
acetamiprid	0.8	0.8
bifenthrin	23.9	24.3
buprofezin	0.4	0.5
carbaryl	0.1	0.1
esfenvalerate	10.8	11.1
lambda-cyhalothrin	12.0	12.3
pyriproxyfen	1.3	1.3
Total	98.0	100.0

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

Table 8 shows the average acreage shares for each alternative AI used on almond, with and without NGNs being available. Averaged over the three-year period 2015–2017 when the NGNs were available, the target NGNs were used on 2% of total almond acres treated with insecticides and alternative AIs were used on 98% of almond acres treated with insecticides.

If target NGNs were restricted, the use of alternative AIs is scaled up in proportion to their acreage shares, as discussed in the methods section. The two most common alternative AIs were abamectin and bifenthrin, which together accounted for 72.6% of total almond acres treated with insecticides, which would be 74.0% of acres treated without the target NGNs. Because use is scaled up based on all use, their shares in the overall use of alternatives may not represent their use as a substitute for NGNs for any specific pest.

Table 9. 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 to composite alternative (%)
clothianidin	14.45	25.04	39.49	-17.9
imidacloprid	5.74	20.80	26.53	22.2
composite alternative	7.36	25.06	32.42	-

Table 9 shows the per-acre costs for the two target NGNs and the composite alternative, whose price we use as a representative pesticide cost if the NGNs were restricted. The total cost per acre of the composite alternative is $32.42, compared to $39.49 for clothianidin and $26.53 for imidacloprid. Material costs per acre for the composite alternative would decrease for clothianidin users and increase for imidacloprid users. Application costs per acre would increase for imidacloprid users and be virtually unchanged for clothianidin users. Clothianidin users would decrease total per-acre costs by 17.9% while imidacloprid users would see a 22.2% increase.

Table 10. 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 (%)	Share of change due to material costs (%)	Share of change due to application costs (%)
2015	300,897	280,146	-20,751	-6.9	220.7	-120.7
2016	218,437	229,023	10,586	4.8	60.2	39.8
2017	75,098	70,525	-4,573	-6.1	272.7	-172.7

Table 10 reports the projected changes in total cost due to the restrictions on clothianidin and imidacloprid. Total change in costs for 2015-2017 range from -6.9% to 4.8%, corresponding to a cost decrease of $20,751 to a cost increase of $10,586. 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. Overall, the absolute value of the costs is relatively small because very few almond acres are treated with NGNs and the composite alternative is cheaper than clothianidin.

Conclusions and Critical Uses

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 some alternatives being cheaper and the relatively small acreage treated with NGNs. As noted earlier, the simple cost of alternatives does not reflect other reasons growers might choose or prefer to use a specific AI as part of their pest management programs. For almond, this is particularly important. Three of the four top alternatives by use are pyrethroids, which can cause secondary pest outbreaks that require additional treatment. In addition, bifenthrin specifically is being detected in exceedance of allowable levels in multiple waterways through the state, which could conceivably lead to regulations restricting its use. Increasing the use of pyrethroids could drive more pest resistance to this insecticide class.

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 is grown throughout the Central Valley, with some orchards scattered in the foothills (Figure 6). Cherry production is concentrated in San Joaquin County, which produced over $185 million in cherry, which was 42.2% of total 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.

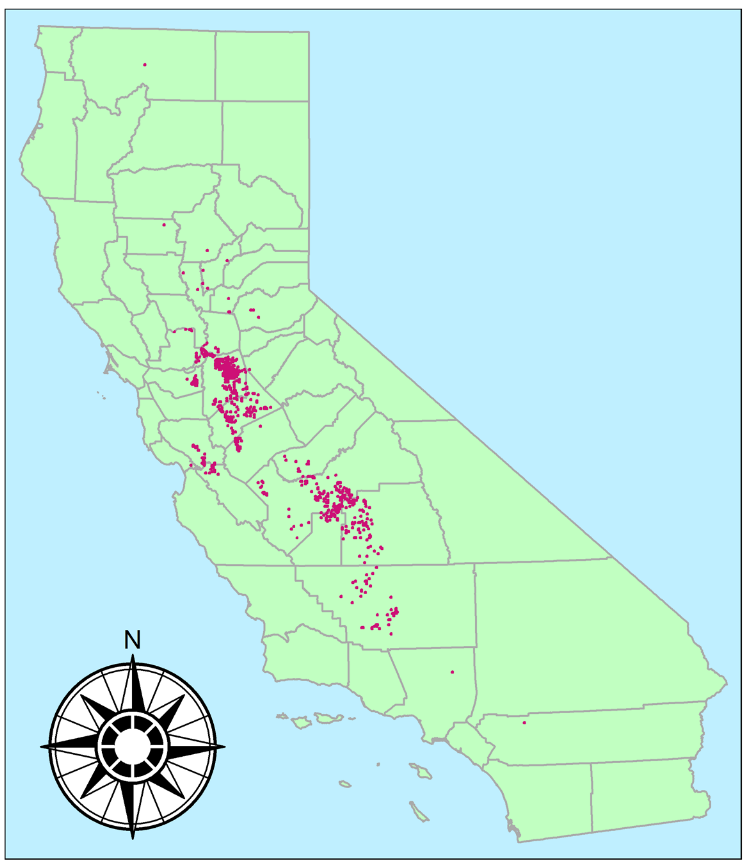

Figure 6. California cherry production: 2017

IPM Overview

Cherry in California is attacked by a variety of insects, diseases, and nematodes. Only imidacloprid and thiamethoxam are registered and used regularly. Imidacloprid and thiamethoxam are used against black cherry aphid (*Myzus cerasi*), cherry leafhopper (*Fieberiella florii*) and mountain leafhopper (*Colladonus montanus*).

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 orchards as they migrate to mustard weeds. There are a number of effective alternative insecticides for black cherry aphid: acetamiprid, beta-cyfluthrin, diazinon (delayed dormant treatment or in season), esfenvalerate, flupyradifuone, and lambda-cyhalothrin. Chlorpyrifos was an alternative before its use in California was discontinued in 2020. 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 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, esfenvalerate, and lambda-cyhalothrin are quite damaging to natural enemies of black cherry aphid, disrupting biological control. Diazinon is as effective as NGNs but is a water contaminant 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. 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). Additionally, in-season application of pyrethroids, acetamiprid, and diazinon can disrupt control of black cherry aphid by killing natural enemies. As noted above, there are water quality concerns with diazinon.

Other Considerations: Resistance Management

If imidacloprid is not available, pest populations may develop resistance to pyrethroids. A major pest in cherry is spotted winged drosophila (SWD). Though imidacloprid is 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, including SWD, that are resistant to pyrethroids. The greater the use, the more risk of resistance. If growers increased the use of pyrethroids in response to NGN restrictions, then there is greater risk of resistance pest populations, including resistant SWD.

Target NGN Use: 2015-2017

Imidacloprid is the most heavily used NGN in cherry, followed by thiamethoxam. Clothianidin is not registered and rarely used (Figure 7).

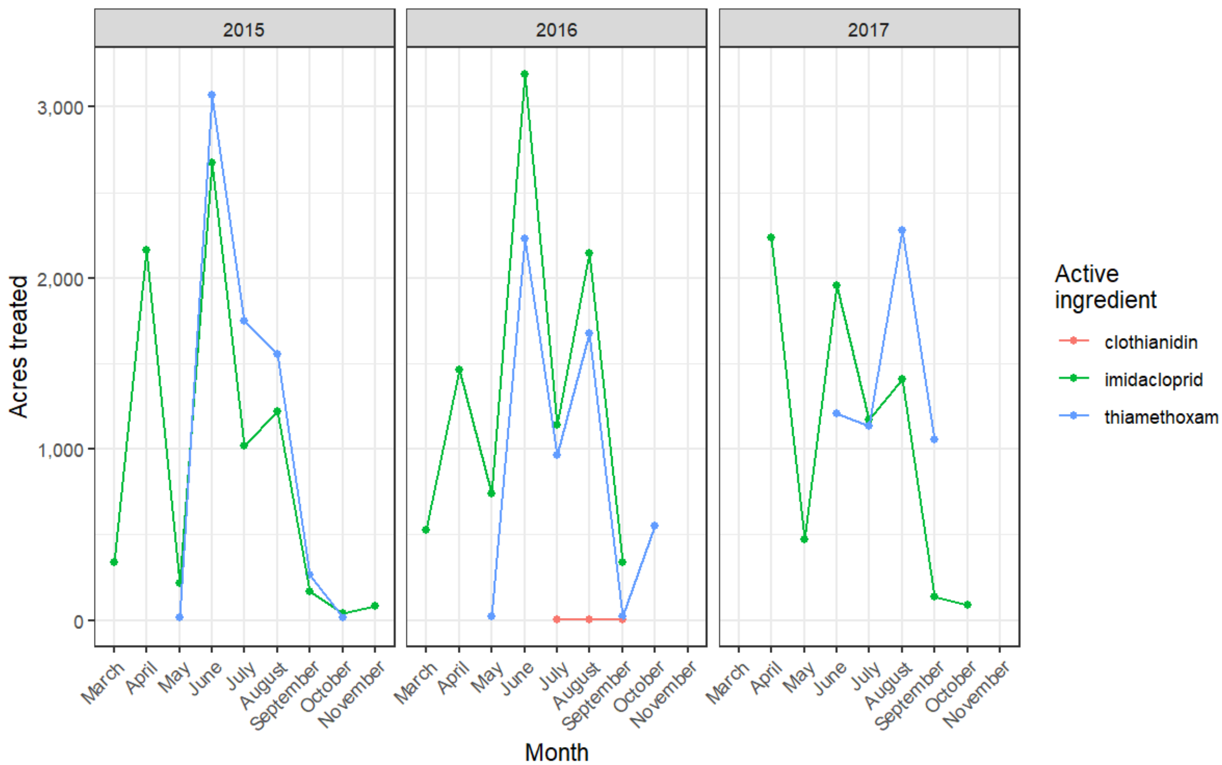

Figure 7. Monthly use of target nitroguanidine-substituted neonicotinoids: Cherry, 2015-2017

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

Table 11 reports annual use of NGNs and alternative AIs 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 11. Annual Use of Target Nitroguanidine Substituted Neonicotinoids and Alternative Active Ingredients: Cherry, 2015-2017

Active ingredient	**---------Pounds applied---------**				**--------------Acres treated------------**				**Use rate (lb/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

Proposed Restrictions

Cherry is in the stone fruit crop group. Under the proposed regulation, the use of all four NGNs would still be allowed to a very limited extent compared to use in 2015-2017. The most restrictive aspect is timing. NGN applications would only be allowed between post bloom and harvest. This is roughly the month of May in most years. Historically, only a small share of annual use has occurred in May (Figure 7). Applications outside of this time frame were reallocated to alternative AIs. On top of the restrictive timing, the general restrictions still apply. In a given field, any number of applications of one (and only one) NGN AI would be allowed (subject to label restrictions). The vast majority of use in May was imidacloprid applied with a foliar method, and there were no fields that applied more than one NGN during May. In addition to timing and general restrictions, cherry is also subject to use rate restrictions; neither single applications nor the cumulative use rate can exceed 0.5 lb/acre (foliar imidacloprid), 0.38 lb/acre (soil imidacloprid) or 0.172 lb/acre (foliar thiamethoxam). None of the applications in May exceeded the new allowable rates. Figure 8 shows the acres treated in allowable applications if the new restrictions had been in effect in 2015-2017. Only 1.6-5.1% of treated acres and 1.5-12.6% of lb applied would have been allowed.

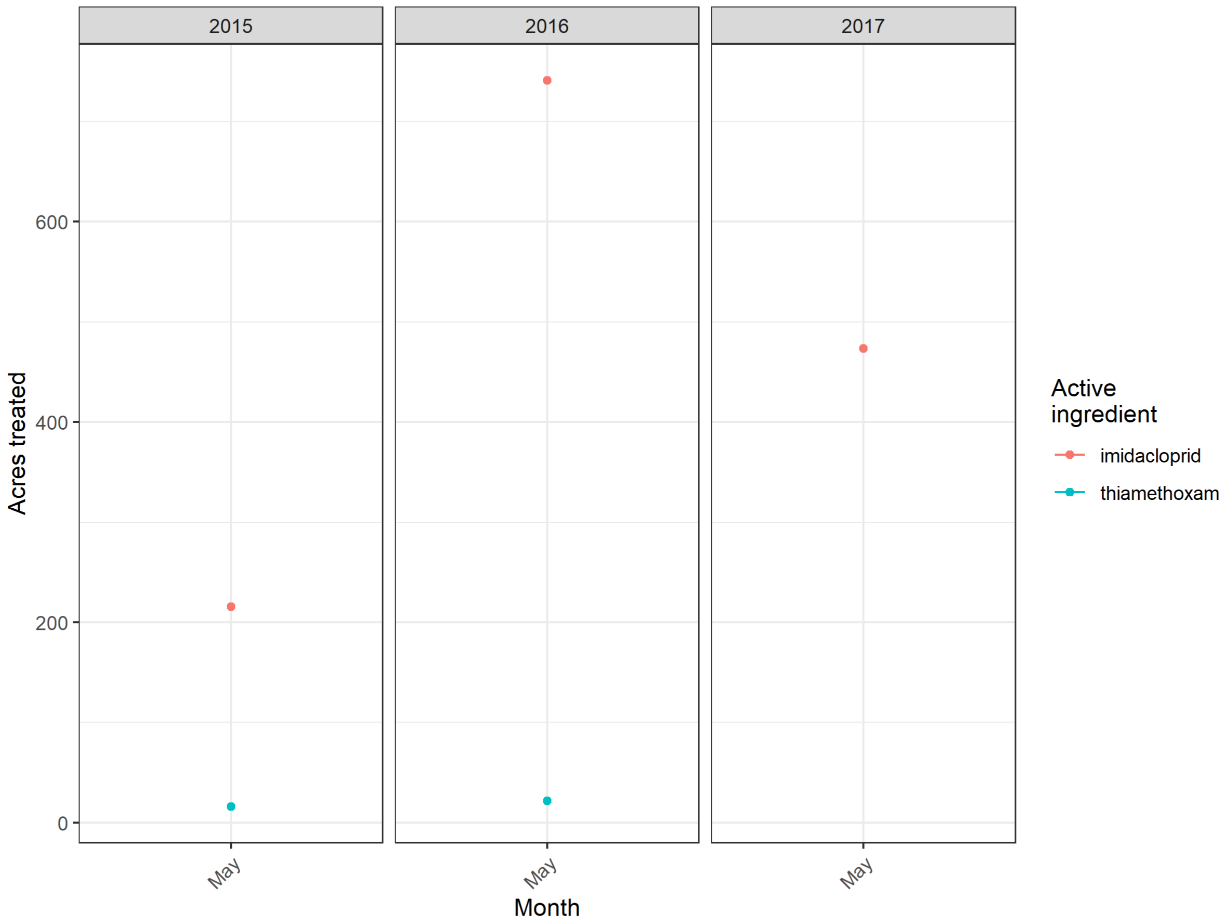

Figure 8. Monthly use of target nitroguanidine-substituted neonicotinoids that would have been allowed under the proposed restrictions: Cherry, 2015-2017

Economic Analysis

This section presents the estimated change in costs to cherry due to the proposed regulation. 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 12. 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	14.73	25.00	39.73
diazinon	Diazinon 50W	25.66	25.00	50.66
esfenvalerate	Asana XL	6.37	24.96	31.33
fenpropathrin	Danitol 2.4 EC Spray	28.03	25.00	53.03
imidacloprid	Admire Pro	9.90	23.27	33.27
lambda-cyhalothrin	Warrior II	8.18	25.02	33.20
thiamethoxam	Platinum 75SG	20.58	25.00	45.58

Table 12 presents representative products for each active ingredient used on cherry in 2015–2017 and their average costs per acre. Average cost per acre for target AIs is calculated using all applications affected by the policy change (i.e., excluding allowed applications). Average cost per acre for AIs in the composite alternative is based on all applications. The material cost is calculated as the product of the three-year average use rate (lb/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 acres treated with that AI that would have been prohibited, i.e., excluding allowed applications. Most applications on cherry are ground spraying, so the variation in application cost is minimal. The total cost per acre ranges from $31.33 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 13. Average Annual Acreage Shares of Alternative Insecticides with and without Prohibited Applications of Target Nitroguanidine-substituted Neonicotinoids (NGNs): Cherry, 2015–2017

Active ingredient	Target NGNs available (%)	Target NGNs restricted (%)
acetamiprid	0.6	0.8
beta-cyfluthrin	0.4	0.5
diazinon	1.1	1.4
esfenvalerate	3.5	4.4
fenpropathrin	18.2	22.9
lambda-cyhalothrin	55.4	69.9
Total	79.2	100

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

Table 13 shows the average acreage shares for each alternative AI used on cherry, with and without NGNs available. Averaged over the three-year period 2015–2017 when the NGNs were available, the target NGNs were used on 20.8% of total cherry acres treated with insecticides and alternative AIs were used on 79.2% of cherry acreage treated with insecticides.

If target NGNs were restricted, 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 92.8% of acres treated without the target NGNs.

Table 14. Costs Per Acre for Target Nitroguanidine-substituted Neonicotinoids and 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	-4.1
imidacloprid	9.90	23.37	33.27	14.5
thiamethoxam	20.58	25.00	45.58	-16.4
composite alternative	13.09	25.02	38.10	-

Table 14 shows the per-acre costs for the target NGNs as well as the cost of the composite alternative, whose price we use as a representative pesticide cost if the NGNs were restricted. For cherry, switching to the alternative would lead to an increase in both material cost and application cost for acres treated with imidacloprid. Material cost for clothianidin and thiamethoxam users will decrease when switching to the composite alternative while the application cost is essentially unchanged. Imidacloprid users will incur a total per acre cost increase of 14.5% while clothianidin and thiamethoxam users will incur cost decreases of 4.1% and 16.4%, respectively.

Table 15. Change in Treatment Costs due to Restriction of Target Nitroguanidine-substituted Neonicotinoids (NGNs): Cherry, 2015–2017

Year	Cost with target NGNs ($)	Cost without target NGNs ($)	Change in cost ($)	Change in cost (%)	Share of change due to material costs (%)	Share of change due to application costs (%)
2015	559,694	547,225	-12,469	-2.2	202.6	-102.6
2016	542,552	544,302	1,750	0.3	-733.4	833.4
2017	491,854	483,296	-8,557	-1.7	235.8	-135.8

Table 15 reports the calculated change in costs due to the restriction of NGNs. The final two columns of Table 15 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 percent change in total cost for 2015-2017 ranges from -2.2% to 0.3%, corresponding to a cost decrease of $12,469 and a cost increase of $1,750, respectively. The net effect is small because increases in cost due to switching to the imidacloprid composite alternative are offset by the decreases in cost due to switching to the thiamethoxam composite alternative. (Clothianidin 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 at most 0.3% and could decrease by as much as 2.2%, due to alternatives being cheaper than thiamethoxam. 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. When there are fewer modes of action that remain available for managing a given pest or set of pests, it is more like that resistance will develop and that it will develop faster. In cherry, an additional complication to this fundamental biological process is that resistance is a concern for a pest not managed with NGNs directly, mainly spotted winged drosophila (SWD). Using NGNs for aphids and leafhoppers allows growers to save other products for use against SWD. Unlike the target pests considered here, SWD can result in substantial yield losses, reducing gross revenues significantly (Walsh et al. 2011).

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).[11] 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 16. 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 16 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 12.5 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 15.9 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 9). Though 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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[11] 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 16 for more information.

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

Figure 9. 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 10). 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.

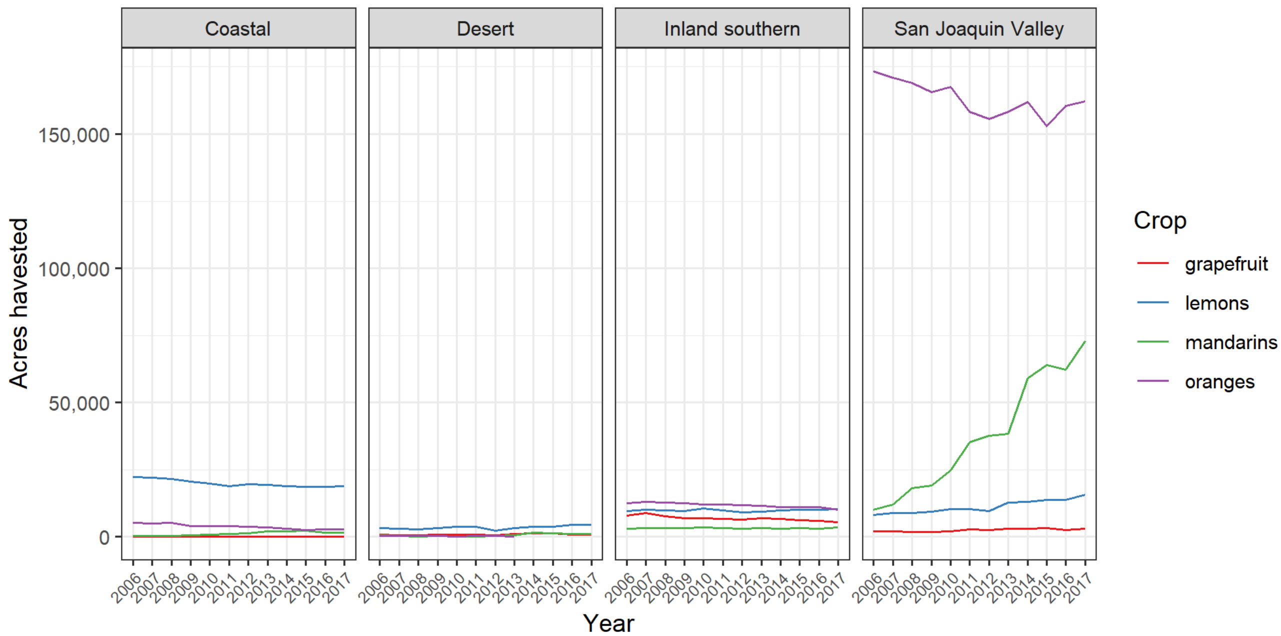


Figure 10. Acres planted to orange, mandarin, lemon and grapefruit by region, 2006-2017

Figure 11 and Figure 12 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.

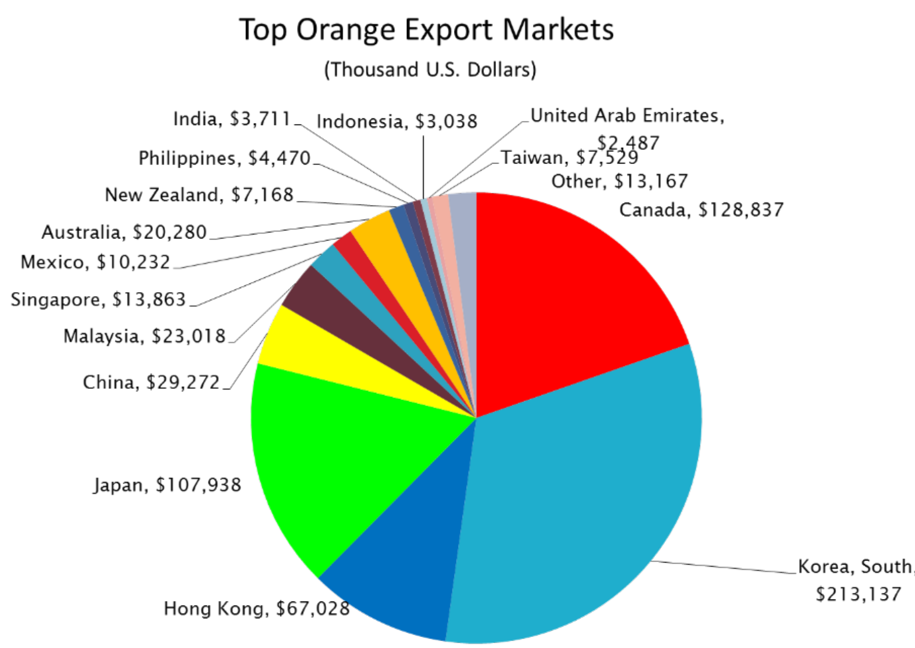


Figure 11. Top export markets: Orange, 2017

Source: https://ccqc.org/

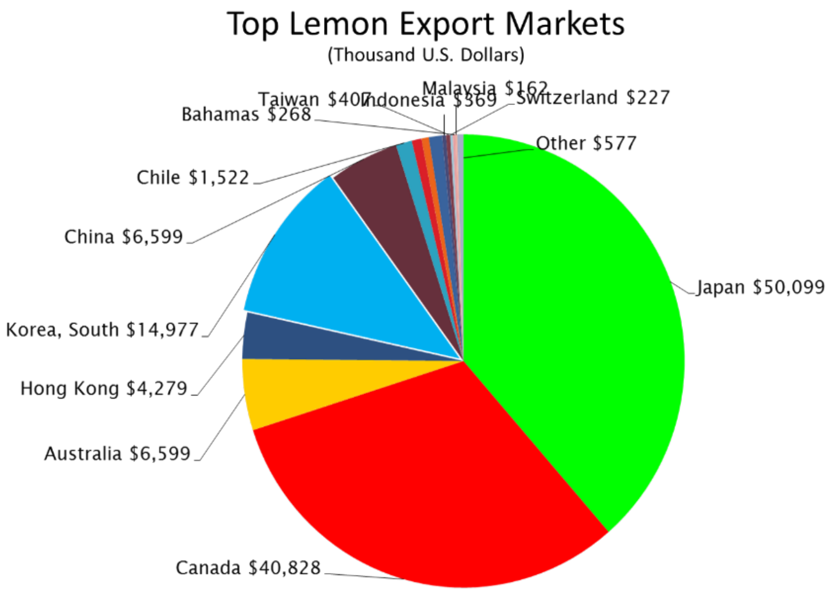


Figure 12. Top export markets: Lemon, 2017

Source: https://ccqc.org/

Not all of the importing countries have fully established maximum residue levels (MRLs) or the levels are below the established US tolerances. 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 (ACP). 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 for California citrus: imidacloprid and thiamethoxam. Both would be restricted under the proposed regulations, with imidacloprid being more restricted than thiamethoxam.

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 ACP in 2008, and its spread throughout southern California by 2012, has intensified insecticide treatments in the southern region, where treatments were previously infrequent. It has also initiated eradicative treatments in other regions of the state. Asian citrus psyllid is the vector of huanglongbing (HLB, also known as citrus greening), 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 ACP control for multiple reasons: 1) it is used as a systemic where eradication of the pest is occurring because 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 transported 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. As a soil application, 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 in order to keep populations from migrating into vineyards. 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). In response, the treatment program is replacing imidacloprid with alternative insecticides. For a variety of reasons, including data on uptake (Byrne and Morse 2012), 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, 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 it 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 impacts 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 non-bearing trees would be any time the trees are producing new leaf flush from March-October.

Fuller rose beetle (*Naupactus godmani*). Fuller rose beetle (FRB) 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 growers must 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 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 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 transported.[12] Alternatives for this spray and move program include cyfluthrin, beta cyfluthrin, fenpropathrin, zeta cypermethrin, and thiamethoxam. The difficulty is that there are seasonal limits for each of these insecticides – lemon are often size-picked gradually over time, and the treatments have to be applied within 14 days of harvest. Growers can exhaust their insecticide options if they harvest an orchard frequently. Alternative programs are to wash or mechanically disinfest fruit after harvest, but these methods can damage the fruit. Systemic imidacloprid is also used by citrus nurseries as a protectant prior to shipping to prevent spread of psyllids and their establishment in retail nurseries (Byrne et al. 2016, 2017). However, nurseries are not considered in this analysis.

[12] 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 17. Annual Use of Target Nitroguanidine-substituted Neonicotinoids and Alternative Active Ingredients: Citrus, 2015-2017

Active ingredient	**----------Pounds applied---------**				**------------Acres treated------------**				**Use rate (lb/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

*Target NGN

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 (Figure 13). This change in timing is associated with a shift in the target pest. In the early years, imidacloprid was used primarily for GWSS control and to encourage vigorous spring growth. During the last 20 years of use, GWSS developed resistance to imidacloprid. 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 caused growers to shift use to later in the season (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).

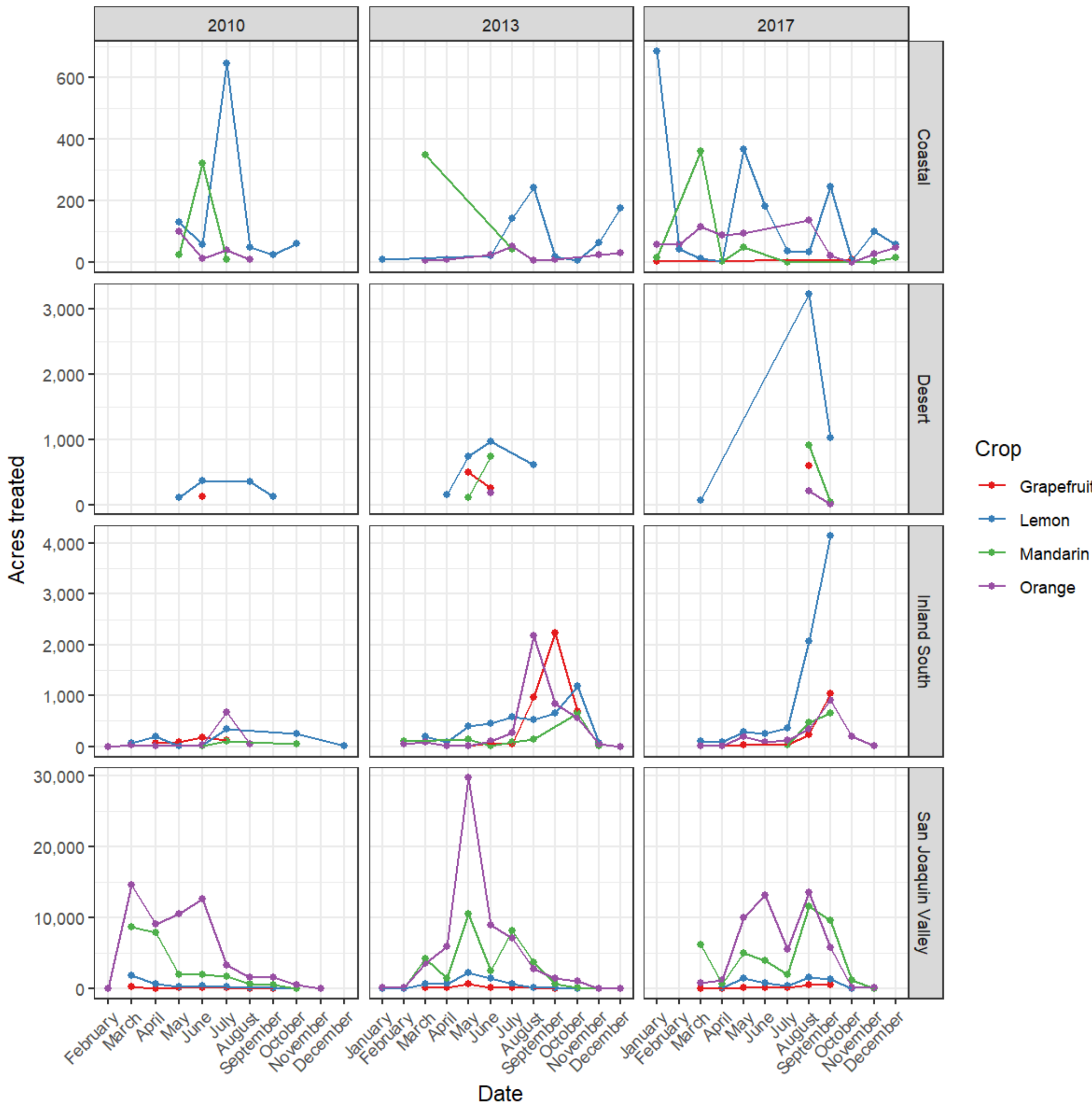
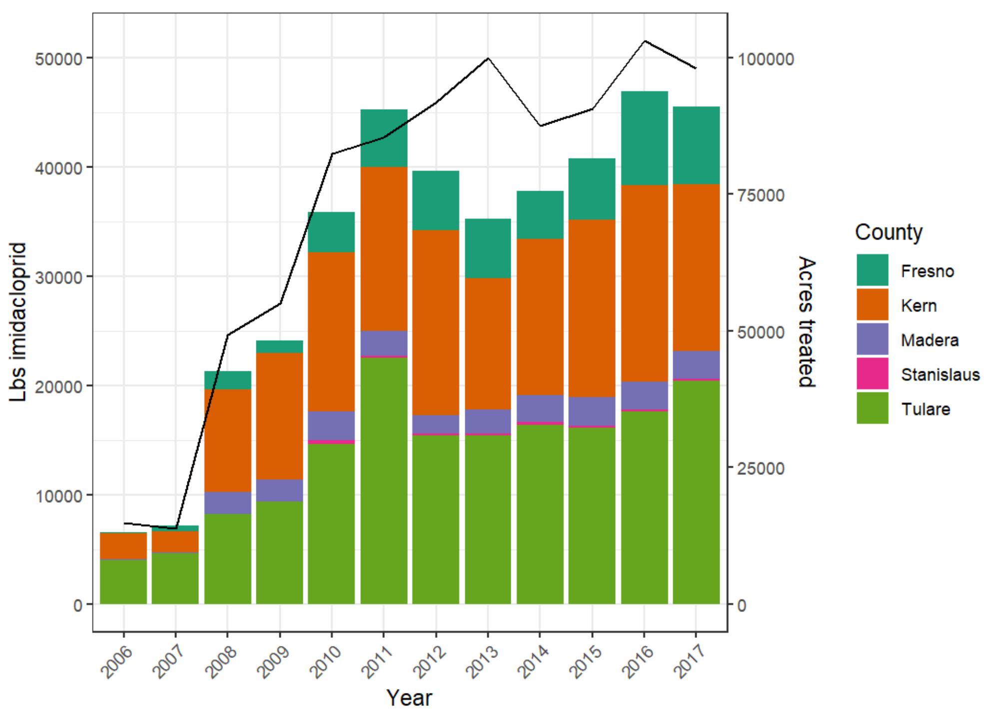


Figure 13. Imidacloprid use by month, region, and crop: Citrus acres treated, 2010, 2013 and 2017

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 14). Imidacloprid use since 2010 has fluctuated, ranging between 35,000-45,000 lb per year on an average of 90,000-100,000 acres (Table 17). 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 non-bearing 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.[13] These treatments are still low in number in this region, and so the increased use relative to 2010-2015 has changed only slightly. This treatment pattern will change significantly if ACP becomes more widely established in the San Joaquin Valley.



[13] https://ucanr.edu/sites/ACP/Grower_Options/Grower_Management/Eradication_Strategies/

Figure 14 Pounds of imidacloprid used (bars) and acres treated (line): San Joaquin Valley region, 2006-2017

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 lb of imidacloprid were applied on 12,000 acres of citrus (Figure 15). Since that time, imidacloprid has been applied to fewer than 2,000 acres, mostly 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 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.

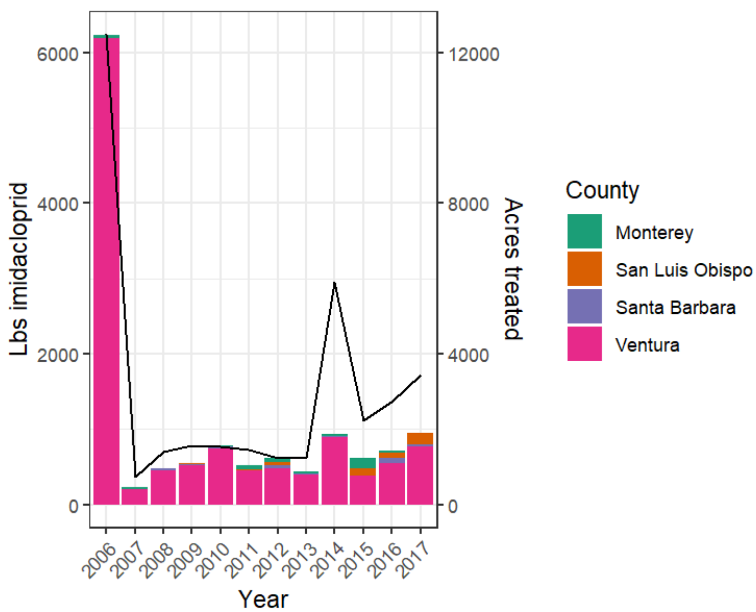


Figure 15. Pounds of imidacloprid used (bars) and acres treated (line): Coastal region, 2006-2017

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 (Figure 16). The Imperial and the Coachella Pest Control Districts coordinate the growers to treat during August and September (Figure 16) 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.

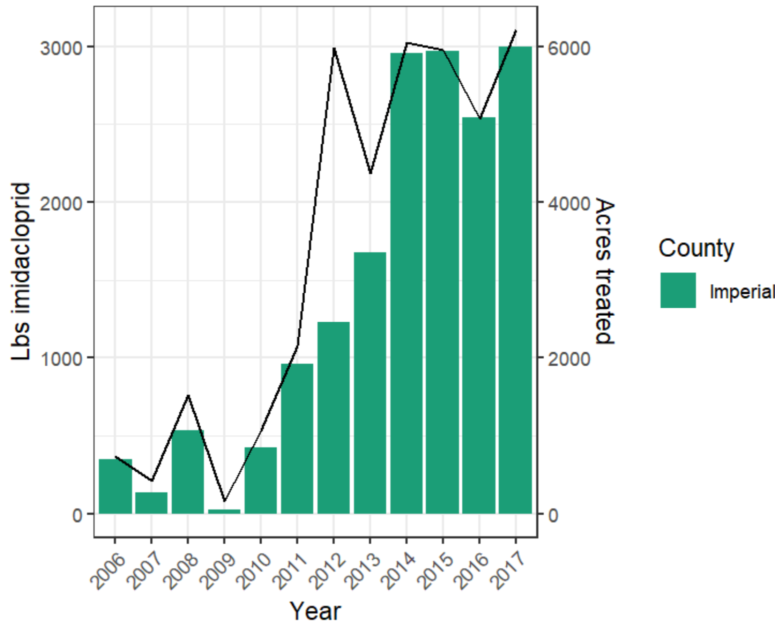


Figure 16: Pounds of imidacloprid used (bars) and acres treated (line): Desert region, 2006-2017

Inland southern California. In the Inland southern California region (San Diego, central Riverside, and San Bernardino), uses of imidacloprid were very limited until the Asian citrus psyllid appeared and established. Treatments increased from less than 1,000 lb AI/year to more than 5,000 lb AI/year from 2006-2017 (Figure 17). Imidacloprid treatments are applied primarily during July-September for areawide management of Asian citrus psyllid.

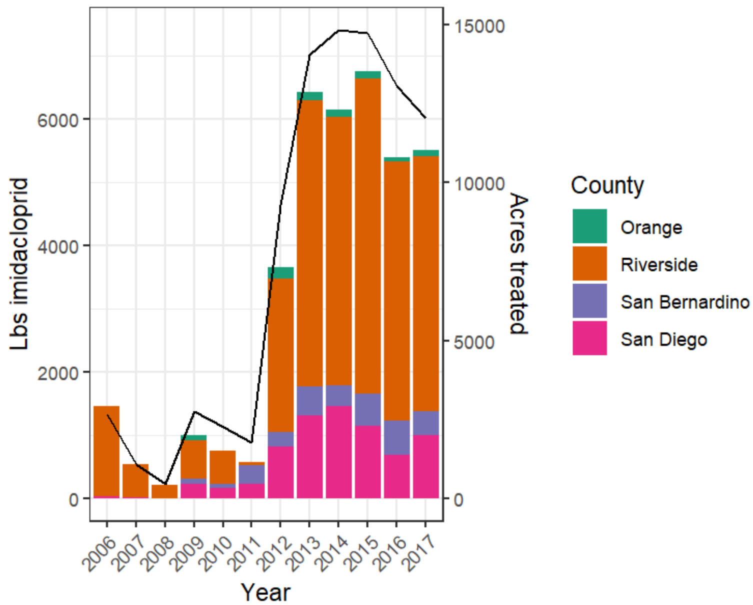


Figure 17: Pounds of imidacloprid used (bars) and acres treated (line): Southern California region, 2006-2017

Overall use in citrus is presented in Figure 18.

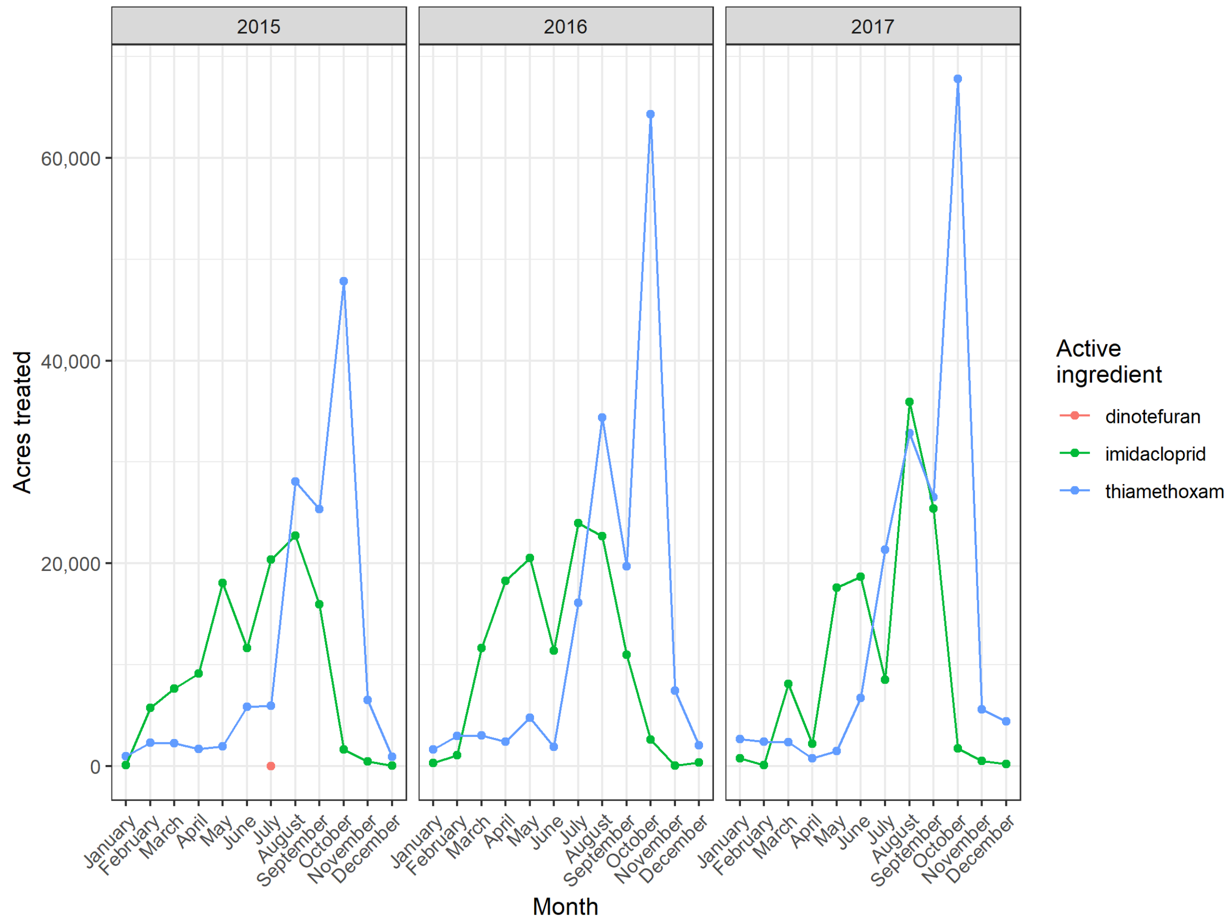


Figure 18: Monthly use of target nitroguanidine-substituted neonicotinoids: Citrus, 2015-2017

Proposed Restrictions

Grapefruit, lemon, orange, and tangerine/tangerine hybrids – the crops that comprise the citrus group in this analysis – are in the citrus fruit crop group. Only imidacloprid and thiamethoxam are registered for use in citrus. For imidacloprid, soil applications would be allowed from petal fall (late April or early May) until January 31 up to a cumulative application rate of 0.086 lb of AI/acre. This effectively prohibits soil-applied imidacloprid because it is not efficacious at the proposed maximum rate. For the purposes of this analysis, we considered this restriction to be the equivalent of a prohibition on soil imidacloprid use. Therefore, all imidacloprid applied to soil was reallocated to the alternatives. This is the most restrictive aspect of the proposed regulation for citrus. Foliar applications of imidacloprid would be allowed from petal fall until December 1 up to a cumulative application rate of 0.172 lb AI/acre. This restriction also would essentially prohibit foliar applications for Asian citrus psyllid and scales because this low rate lacks efficacy. The only application that would be effective at this rate would be foliar applications for citrus leafminer in newly planted, nonbearing citrus. Thus, foliar applications of imidacloprid would be mostly ineffective for mature citrus. An exemption to the use rate restriction is discussed below. Soil and foliar applications of thiamethoxam would be permitted up to a cumulative application rate of 0.172 lb/ac/season with the same timing restrictions as imidacloprid. We assume the timing restrictions imply a prohibition on applications from December 1 to May 1. Applications during this time were reallocated to alternatives. These early season restrictions would eliminate uses for Asian citrus psyllid (except as covered by an exemption), aphids and citrus leafminer control. In a given field, any number of applications of one (and only one) NGN AI would be allowed. Because of efficacy issues, we assume that if a grower was using both imidacloprid and thiamethoxam, they would continue to use thiamethoxam and switch imidacloprid to the alternatives. If the proposed restrictions had been in place from 2015-2017, 31.1-33.1% of treated acres and 9.9-11.3% of lb applied would have been allowed under the new restrictions. Figure 19 plots the applications that would have been allowed by month.

Applications to indeterminant blooming varieties would be prohibited year-round. The only commercially grown indeterminant citrus are varietals of lemons that are not widely produced. PUR data do not differentiate between varietals, so the costs of losing these applications are not included here, which biases the estimated losses downward although the impact is likely small.

The effective prohibition of soil-applied systemic imidacloprid would cause substantial issues because it is used extensively and is vital for combating ACP as discussed in the IPM Overview section above. However, there is an exemption in the regulation for the use of NGNs in declared emergencies, including invasive pest emergencies. The exemption means that growers' applications mandated in CDFA-declared emergency areas would be permitted. PUR data do not allow us to make the distinction between these applications and other applications of imidacloprid, so losses are overestimated to an unknown extent.

The timing restrictions would not cause significant disruption for most citrus production. However, there are two specific uses for ACP between December and bloom that could be impacted by the timing restrictions. One is that citrus needs to be treated prior to harvest, if it is being moved from one bulk citrus regional quarantine zone to a packinghouse in another quarantine zone.[14] The list of approved pesticides includes foliar imidacloprid and thiamethoxam.[15] These treatments are needed year-round for all types of citrus and sometimes occur during the time that would be restricted. Losing two AIs would increase the use of alternatives and, thereby, increase the risk of resistance. Additionally, there are limits to the number of times each AI can be applied, and, with fewer AIs to use, growers could hit those limits. Potential impacts of this are not considered here. The other is area-wide foliar treatments for ACP in residential citrus, which can include treatments during this time. This would be covered under the exemption for declared emergencies.

[14] http://maps.cdfa.ca.gov/QuarantineBoundaries/ACP/ACP_BulkCitrus_Overview.pdf
[15] http://phpps.cdfa.ca.gov/PE/InteriorExclusion/pdf/acpgrowerinformation.pdf

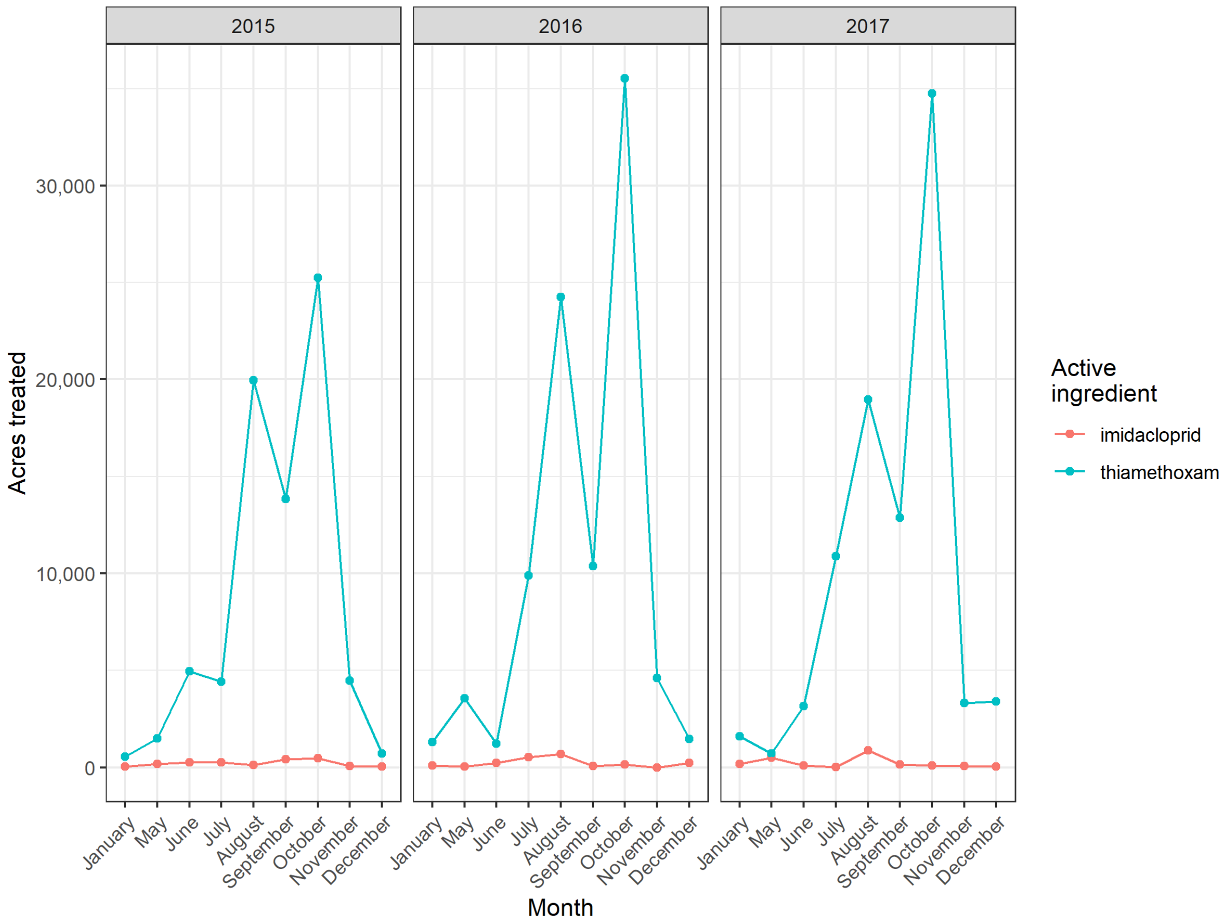


Figure 19. Monthly use of target nitroguanidine-substituted neonicotinoids that would have been allowed under the proposed restrictions: Citrus, 2015-2017

Economic Analysis

This section presents the estimated change in pest management costs for citrus fruits arising from the proposed restrictions. The cost of the proposed regulation is the difference in material costs and application costs, although the caveats discussed in the methods section apply.

Table 18. 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	42.03
acetamiprid	Assail 70WP Insecticide	64.35	24.96	89.31
beta-cyfluthrin	Baythroid XL	16.40	25.05	41.44
bifenthrin	Brigade WSB Insecticide/Miticide	96.59	25.00	121.59
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	43.46	24.92	68.39
cyantraniliprole	Exirel	99.59	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	30.66	25.32	55.98
flupyradifurone	Sivanto 200 SL	45.02	25.02	70.05
imidacloprid*	Admire Pro	27.77	11.69	39.47
malathion	Malathion 8 Aquamul	12.08	25.00	37.08
spinetoram	Delegate WG	57.39	25.03	82.42
spinosad	Success	32.89	24.99	57.87
spirotetramat	Movento	87.18	24.98	112.16
thiamethoxam*	Actara	22.60	24.71	47.31

*Target NGN

Table 18 reports the representative products for each active ingredient used on citrus from 2015 to 2017 and the average cost per acre. Average cost per acre for target AIs is calculated using applications affected by the proposed regulation (i.e., excludes allowed applications of target NGNs), while average cost per acre for AIs in the composite alternative is based on all applications. 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 19. Average Annual Acreage Shares of Alternative Insecticides with and without Prohibited Applications of 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	5.8
abamectin	14.1	18.6
acetamiprid	1.9	2.6
beta-cyfluthrin	8.2	10.8
bifenthrin	0.6	0.8
buprofezin	1.1	1.5
carbaryl	0.5	0.7
chlorantraniliprole	2.2	2.9
cyantraniliprole	2.0	2.7
cyfluthrin	2.3	3.1
diflubenzuron	3.0	3.9
dimethoate	0.6	0.8
fenpropathrin	4.5	5.9
flupyradifurone	0.3	0.4
malathion	0.6	0.8
spinetoram	15.4	20.2
spinosad	1.8	2.4
spirotetramat	12.4	16.3
Total	76.9	100

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

Table 19 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 and thiamethoxam are available. On average, 23.1% of citrus acreage was treated with imidacloprid and thiamethoxam each year. The third column reports rescaled acreage shares if the proposed restrictions on applications on the target NGNs were in effect. The three most applied alternative AIs are spinetoram, abamectin, and spirotetramat, which together would account for 55.1% of treated acreage under the proposed restrictions. Note that because use is scaled up based on all use, their shares in the overall use of alternatives may not represent their use as a substitute for NGNs for any specific pest. Note also that total acreage of citrus treated with insecticides may not correspond to total citrus acreage because some orchards may receive multiple insecticide applications.

Table 20. 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	27.77	11.70	39.47	77.4
thiamethoxam	22.60	24.71	47.31	48.0
composite alternative	44.97	25.04	70.01	-

Table 20 reports the average per acre costs for imidacloprid, thiamethoxam and the cost of the composite alternative. For citrus, switching to alternatives would lead to increases in material cost and application cost. Total cost per acre would rise by $30.54 (77.4%) on imidacloprid-treated acreage and $22.70 (48.0%) on thiamethoxam acreage.

Table 21. Change in Treatment Costs due to Restriction 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 (%)	Share of change due to material costs (%)	Share of change due to application costs (%)
2015	5,292,985	8,199,191	2,906,207	54.9	50.6	49.4
2016	6,039,955	9,311,247	3,271,293	54.2	53.3	46.7
2017	5,691,361	8,579,699	2,888,339	50.7	45.2	54.8

Table 21 summarizes the annual change in total pesticide costs owing to restriction of imidacloprid and thiamethoxam for each of the three base years. The total increase in costs would have been between $2.89 million and $3.27 million, or in percentage terms costs would have increased between 50.7% and 54.9%.[16]

Conclusions and Critical Uses

The restrictions from the proposed regulation would raise the cost of pest management by $2.89 to $3.27 million, a 50.7% to 54.9% increase. However, the increase is relatively small in absolute value on a per acre basis: $30.54 for imidacloprid and $22.70 for thiamethoxam. It is likely an overestimate because some unknown amount of imidacloprid use would be allowed to

[16] The reported costs exclude the cost of restricting multiple applications in a grove to one application method, which would have affected 190 applications from 2015-2017 and would have altered the total change in cost by roughly 0.1% (one-tenth of one percent). For example, if the first application was soil and the grower switched their subsequent applications from foliar to soil, the average annual change in costs would be -$12,736. Analogously, if the first application was foliar and subsequent applications were switched to foliar, the average annual change in costs would be +$34,025.

continue in certain areas as long as the grower was in an HLB quarantine zone and covered by the exemption. Two important policy considerations regarding the use of imidacloprid in ACP control and thiamethoxam use for transport of lemons are outside the scope of this analysis, as the data do not enable us to identify applications for ACP control or transport. These factors indicate that costs to the citrus industry could potentially be larger. Additionally, future problems may be exacerbated by the restrictions on imidacloprid. 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.

Imidacloprid is especially important in vector-pathogen situations such as with ACP 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 are why it is vital to CDFA's control efforts in both commercial and home citrus. It is one of only two insecticides 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 efficacious and cost-effective control agent. Without imidacloprid, HLB will spread at a much faster rate in the state. The proposed regulation has an exemption allowing NGN use in a CDFA-declared emergency, including an invasive pest emergency. This would allow CDFA's and citrus growers' area-wide management programs to continue as long as the emergency declaration remained in place and allow growers in HLB quarantine areas to continue use. However, this only covers a small percent of growers. Outside of those areas, ACP will spread faster without access to imidacloprid, posing a risk to the $2 billion per year citrus industry.

Cotton

The vast majority of cotton in California is grown in the San Joaquin Valley, though some is also 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 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 3.

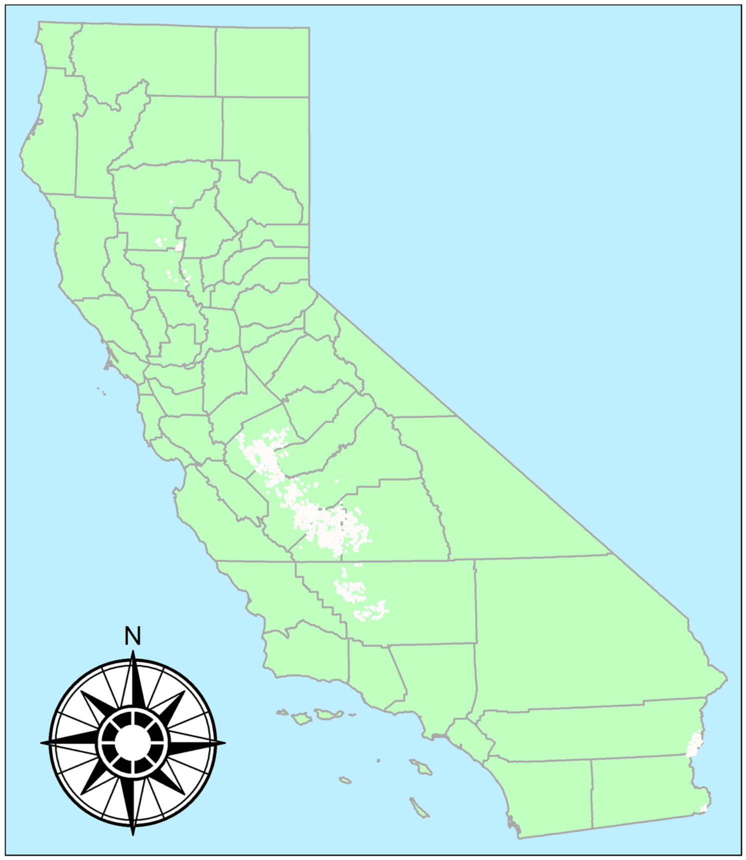


Figure 20. California cotton production: 2017

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 mature and dry, 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 historically important caterpillar pests, pink bollworm, has been eliminated through an intensive area-wide management program. Stink bugs can also be pests, attacking buds, flowers, and bolls. This includes native stink bugs as well as the invasive 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 arrives at a textile mill, processing efficiency and product quality diminish, and shutting down the mill is a possibility. This 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 IPM 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 vary, 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. The challenge for California is that the three to four-week period immediately before harvest is critical for managing these pests because this is when lint is in danger of being contaminated. However, insecticides do not work as well in this time window 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 often interconnected due to the simultaneous presence of multiple pests throughout the season. In addition, insecticide applications targeting one pest can damage natural enemy communities and lead to secondary pest outbreaks. 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 primary pests, including 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 than 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. The share of cotton acreage using drip irrigation varies by region due to differences in water availability. UCCE experts estimate that around 20% of statewide acreage uses drip irrigation. Unlike furrow irrigation, drip irrigation allows chemigation, i.e., 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 a full plant canopy can be challenging.

Target Pests

Lygus bug (*Lygus hesperus).* Lygus is a perennial problem and usually the most important arthropod pest, particularly in the San Joaquin Valley but also in other regions. 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, it 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, which is problematic from an agronomic standpoint. 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. An extended season also prevents completion of groundwork before winter rains and increases the period during which open bolls are susceptible to late-season aphid and whitefly issues.

Insecticides 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 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 requiring one to three applications, with other insecticides rotating 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 occasionally 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 and it appears that some resistance is present. Imidacloprid will often be tank-mixed with another material (e.g., bifenthrin or other pyrethroids, dimethoate, or novaluron) to improve efficacy and residual and/or control both adults and nymphs. 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. An additional constraint 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 are on rotation for that field.

Several other active ingredients are used for managing lygus, including pyrethroids (lambda-cyhalothrin, beta-cyfluthrin, bifenthrin, (s)-cypermethrin). Pyrethroids were relied on for lygus control in the 1990s and 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. Late season applications can also target aphids or whiteflies. Indoxacarb can be used for lygus management, although it only provides suppression and is utilized mostly as a backup material. In 2017 and 2018, another very effective and selective material, sulfoxaflor, was used for lygus management. It was only available under a Section 18 emergency exemption in 2017 and 2018. The emergency exemption has not since been renewed and sulfoxaflor is not included as an alternative in this analysis.

Cotton aphid (*Aphis gossypii*). Cotton aphid can be a nearly season-long pest in some areas and is extremely important to manage, with mid- to late-season being the most critical. Aphids siphon off plant nutrients, stunting plants and competing with developing squares and bolls for resources. Infestations on seedling cotton and pre-reproductive cotton generally do not warrant treatment as plants can compensate for injury and natural enemies often effectively reduce aphid populations. During the reproductive growth phase, aphid feeding uses resources otherwise available to developing squares or bolls, reducing yield. After bolls have opened and until harvest, aphids can contaminate exposed lint with honeydew. As discussed, sticky cotton and lint contamination is a severe problem, necessitating low action thresholds during the late-season. The amount of stickiness in lint is not easily quantifiable but sticky cotton can decrease lint prices over entire production regions or cause issues selling cotton for 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. An early season application will depress aphid and lygus populations and prevent them from building. In the southeast region of California, imidacloprid is sometimes used early as a pre-plant 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, 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 will be used sometimes 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 large aphid and whitefly populations. Decreasing fertilizer rates 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 cotton 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 contaminate lint later in the season. This pest has become more of an issue in recent years, appearing 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 whitefly management does not drive variety choice 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 moderate whitefly pressure, insect growth regulators (IGRs) are the primary tools. 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 NGNs for managing 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 small and their growth can be disrupted. These compounds are 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 similar 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 adult aphids 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 significant feeding and late season rains, then there is a possibility for damage.

Primary tools for managing stink bugs are broad-spectrum insecticides, 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's plant-back label restriction.

Target NGN Use: 2015-2017

Statewide for 2015-2017, imidacloprid was the most-applied NGN by a substantial margin for cotton (by acreage and pounds of AI), followed by clothianidin, thiamethoxam, and dinotefuran (Table 22). Among the alternatives to the NGNs, only flonicamid and acetamiprid were applied to more acres than imidacloprid (445,073 acres), with 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, owing to resistance considerations and maximum use restrictions, it cannot necessarily be used throughout the entire season. The label for Carbine 50 WG specifies no more than three applications at the maximum recommended rate for cotton per year. Acetamiprid can be used as part of a program for managing cotton aphid and silver leaf whitefly.

Table 22. Annual Use of Target Nitroguanidine-substituted Neonicotinoids and Alternative Active Ingredients: Cotton, 2015-2017

Active ingredient	--------- Pounds applied ----------				---------- Acres treated -----------				Use rate (lb/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
thiamethoxam*	1,782	1,485	3,084	6,352	28,677	23,798	51,734	104,209	0.06

*Target NGN

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, with imidacloprid being the most popular, 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 21). Clothianidin is the second most-used NGN in cotton by treated acreage from 2015-2017, followed by thiamethoxam. Use of clothianidin drops off precipitously after June because the label restricts applications to the early season.

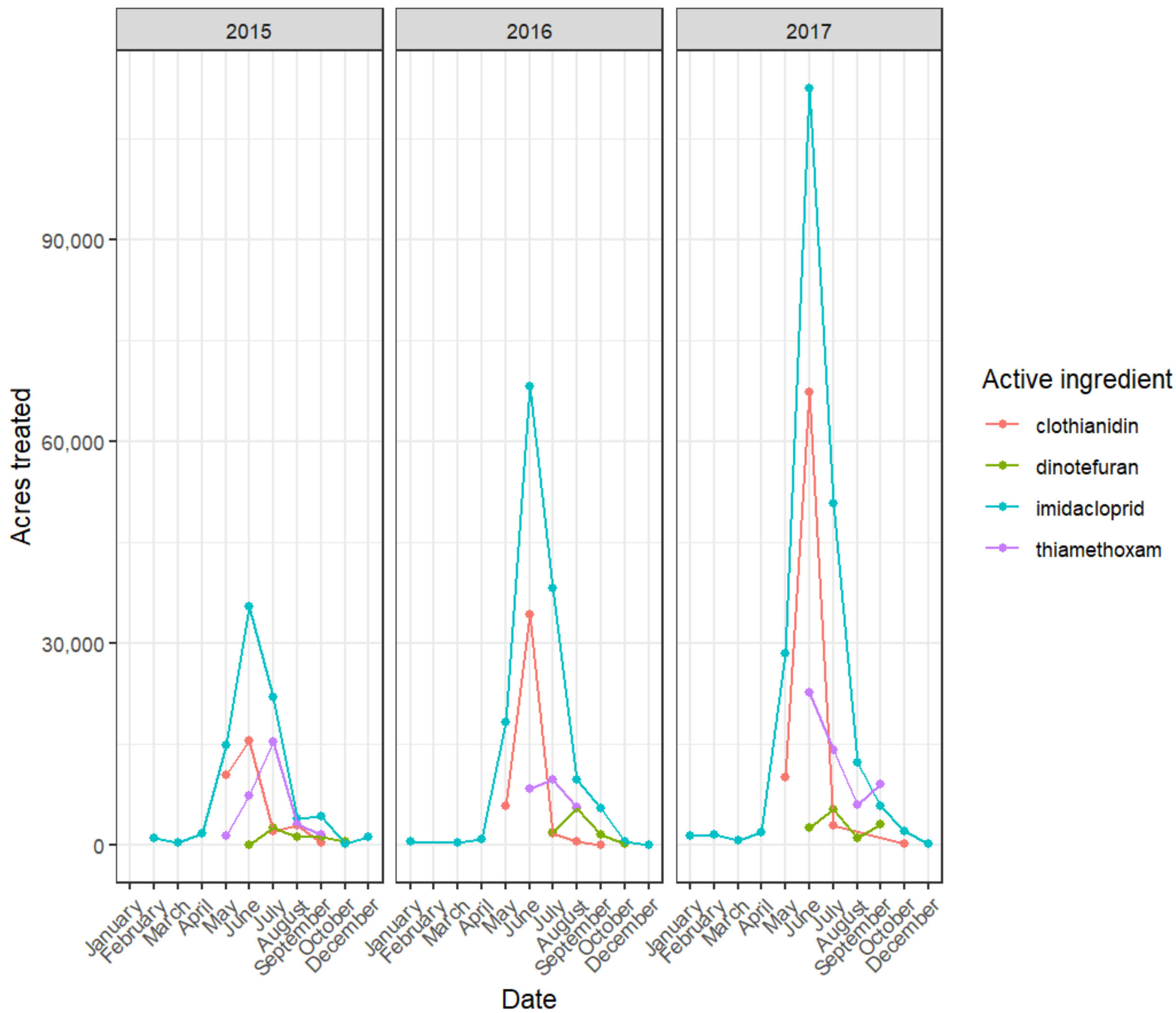


Figure 21. Monthly use of target nitroguanidine-substituted neonicotinoids: Cotton, 2015-2017

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 must account for how applications targeting one pest will affect populations of other pests and natural enemies. Effects can be almost immediate as is the case with spider mites, which reproduce very quickly. Additionally, there can be longer-term effects such as late season outbreaks owing 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 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 develop resistance 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 that insecticide resistance will develop.

Proposed Restrictions

Cotton is in the oilseed crop group. Under the proposed regulations, only the general restrictions would apply unless a grower is using managed pollinators, which is not a practice in cotton. Accordingly, the use of clothianidin, dinotefuran, thiamethoxam, and imidacloprid would be restricted to only one AI and one application method (soil or foliar) per field per year, with as many applications as needed up to the maximum season total number of applications or of pounds of active ingredient. All applications would be prohibited during bloom. For cotton this starts around June 21, continues through harvest, and includes the most consequential management period of aphids and whiteflies. Whiteflies tend to be managed less than aphids earlier in the season (i.e., before June 21). The June 21 date is an estimate and is likely on the early side for much of the state in most years. This makes it a conservative estimate for the analysis.

We assume that applications after June 21 would be prohibited and alternatives would be used. For fields that only had one NGN AI applied before June 21, those applications would have all been allowed. For fields where multiple AIs were applied before June 21, growers are more likely to choose imidacloprid over clothianidin because imidacloprid is more often used for managing aphids, which are more likely to occur early in the season compared to whiteflies, and because of its lower cost. Accordingly, for fields using multiple AIs with one of those being imidacloprid, imidacloprid is considered allowed and the other application(s) prohibited and redistributed to the alternatives. For fields where multiple AIs were used that include clothianidin but not imidacloprid, the application of clothianidin is considered allowed and the other applications of NGNs prohibited and redistributed to the alternatives. Another possibility would be that prohibited applications of other NGNs would be replaced by additional applications of imidacloprid or clothianidin. That scenario was not evaluated here; imidacloprid, being the cheapest option, is likely already used to its maximum potential. In cotton, growers rarely use both soil and foliar applications. For fields in which both soil and foliar applications were made of the same AI, the application method used first was considered allowed and the other was replaced with alternatives. Under the proposed regulation, only 34.4-41.4% of treated acres and 34.6-39.5% of pounds applied would have been allowed per year. Figure 22 shows the applications that would have been allowed.

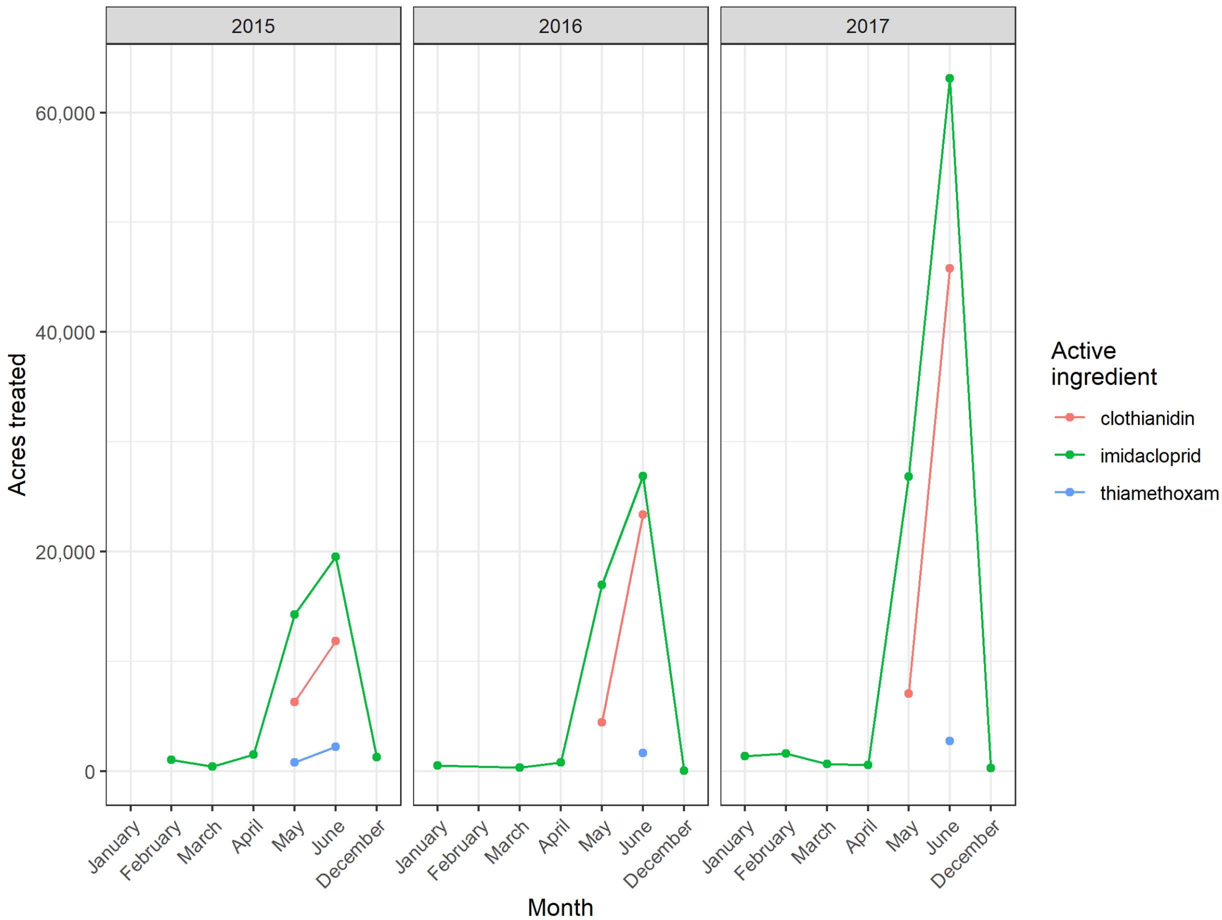


Figure 22. Monthly use of target nitroguanidine-substituted neonicotinoids that would have been allowed under the proposed restrictions: Cotton, 2015-2017

Economic Analysis

This section presents the estimated change in net revenues in cotton due to the restrictions on the use of the four NGNs.

Table 23. 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	14.08	21.09	35.17
acetamiprid	Assail 70WP Insecticide	30.21	18.83	49.04
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	55.20
clothianidin	Belay Insecticide	13.41	23.38	36.79
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	2.74	19.41	22.15
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	9.54	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	49.22	20.17	69.39
thiamethoxam	Centric 40WG	13.07	19.54	32.61

Table 23 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/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 material and application costs per acre. 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 acres treated with that AI that would have been prohibited (i.e., excluding allowed applications). There is substantial variation in the total cost per acre of AIs, which ranges from $20.41 to $69.39.

Table 24. Average Annual Acreage Shares of Alternative Insecticides with and without Prohibited Applications of Target Nitroguanidine-substituted Neonicotinoids (NGNs): Cotton, 2015–2017

Active ingredient	Target NGNs available (%)	Target NGNs restricted (%)
(s)-cypermethrin	2.8	3.4
acephate	2.7	3.2
acetamiprid	11.8	14.3
beta-cyfluthrin	2.6	3.2
bifenthrin	8.8	10.7
buprofezin	3.0	3.6
dimethoate	5.9	7.1
flonicamid	24.2	29.3
flupyradifurone	3.4	4.2
indoxacarb	4.5	5.5
lambda-cyhalothrin	4.5	5.4
naled	4.5	5.4
oxamyl	1.1	1.3
pyriproxyfen	1.7	2.0
spiromesifen	1.1	1.4
total	82.7	100

Table 24 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 17.3% of total cotton acres treated with NGNs and alternative AIs.

If NGNs were restricted, the use of alternative AIs is scaled up in proportion to their acreage shares, as discussed in the methods section. Flonicamid and acetamiprid were used the most, together accounting for 36% of total cotton acres treated with insecticides, or 43.6% of acres treated with non-NGN alternative AIs. Because use is scaled up based on all use, their shares in the overall use of alternatives may not represent their use as a substitute for NGNs for any specific pest.

Table 25. 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	13.41	23.38	36.79	1.9
dinotefuran	22.28	18.30	40.58	-7.6
imidacloprid	2.74	19.41	22.15	69.2
thiamethoxam	13.07	19.54	32.61	14.9
composite alternative	17.72	19.76	37.48	-

Table 25 shows the average costs per acre for the four target NGNs and the composite alternative, whose price we use as a representative pesticide cost that would be paid by growers if NGNs were restricted. 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 clothianidin. Overall, dinotefuran users would reduce their costs by 7.6% when switching to the alternative. Clothianidin users would incur the lowest cost increase (1.9%) and imidacloprid users would incur the largest cost increase (69.2%). Thiamethoxam users would incur a 14.9% cost increase.

Table 26. Change in Treatment Costs due to Restriction 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 (%)	Share of change due to material costs (%)	Share of change due to application costs (%)
2015	2,451,084	3,192,368	754,900	31.0	102.2	-2.2
2016	3,581,103	5,023,648	1,439,264	40.2	100.3	-0.3
2017	5,437,286	7,286,746	1,839,126	33.8	101.9	-1.9

Table 26 reports the anticipated changes in total cost due to the proposed restriction 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 31% in 2015 to 40.2% 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 per acre between imidacloprid ($22.15), the most widely used NGN in cotton, and specific alternatives that account for a large share of non-NGN treated acreage: flonicamid ($37.15) and acetamiprid ($49.04).

Conclusions and Critical Uses

A substantial cost increase per treatment is anticipated as a result of the proposed restrictions in cotton. The cost per acre would increase by 69.2% on acres that were treated with imidacloprid, and there would be a small decrease in cost (1.9%) on acres that were treated with clothianidin. Total costs would have increased by $0.75 million to $1.84 million. In addition, secondary pest infestations and faster development of resistance to other active ingredients in cotton pests are important factors influencing future costs that are not addressed here.

Grape

Grape 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 on 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 accounted 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 within the main 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. Not all table grapes are sold fresh to market or raisin grapes are dried, indicating 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 23 maps raisin and table grape production, and Figure 24 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.

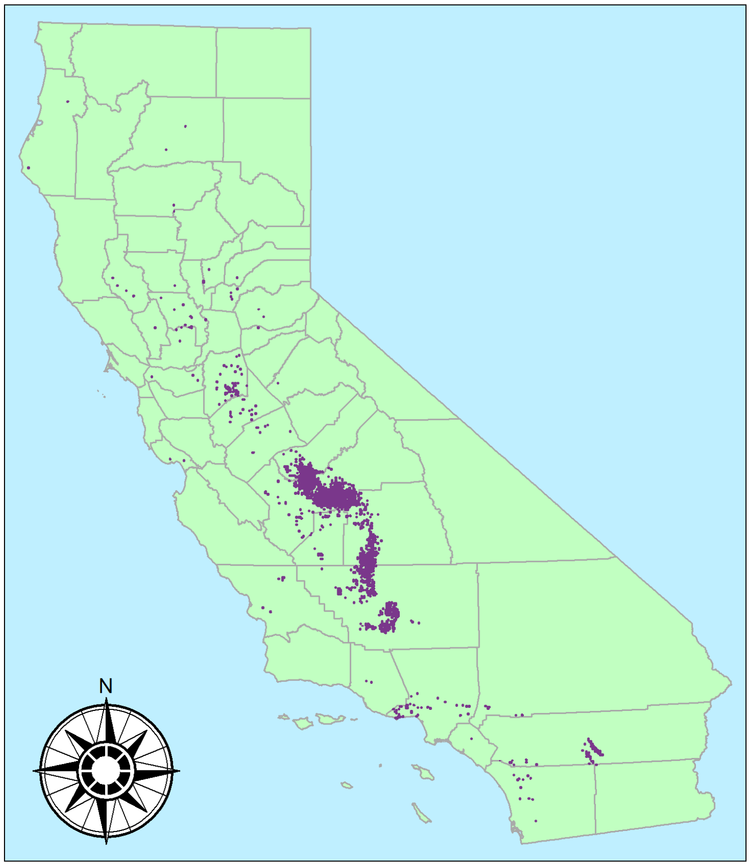


Figure 23. California raisin and table grape production: 2017

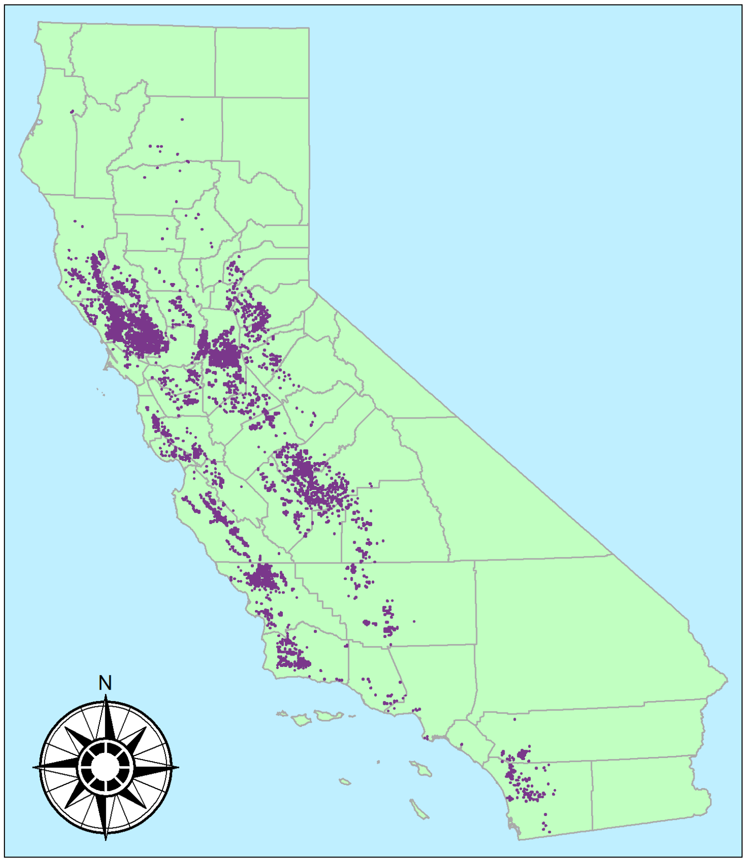


Figure 24. California wine grape production: 2017

IPM Overview

Grape growers use NGN products against leafhoppers (western grape, variegated, Virginia creeper), mealybugs (grape, obscure, long tail, pink hibiscus and vine), sharpshooters, and grape phylloxera. Vine mealybug is a problem in all grape growing areas but can be especially damaging in warmer areas, such as the southern San Joaquin Valley. Raisin grape and table grape are concentrated in the warmer growing areas than wine grape, and, accordingly, 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 subject to the proposed restrictions in grape.

Target Pests

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 more difficult to control because, unlike the *Pseudococcus* mealybugs, which only produce two generations per year, vine mealybug can produce multiple generations per year. Thus, vine mealybug can develop large 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 insecticides. This is especially an issue in warmer regions as higher temperatures allow for even more generations of vine mealybug.

Alternatives to NGNs for mealybug control are spirotetramat, acetamiprid, flupyradifurone, fenpropathrin, and beta-cyfluthrin. Chlorpyrifos was an alternative, but it is no longer available for use in California. 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 and growers are already encouraged to rotate it with other active ingredients to prevent this. As spirotetramat is the primary effective AI 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 it in pest control.

Sharpshooters. Blue-green sharpshooters (*Graphocephala atropunctata*) and glassy-winged sharpshooters (*Homalodisca vitripennis*) are serious pests in vineyards because they vector Pierce's disease (*Xylella fastidiosa*), for which there is no treatment. CDFA has a Pierce's disease program, with USDA funding, that addresses glassy-winged sharpshooter. The best strategy is to keep sharpshooters from entering the vineyards in the first place and remove infected vines immediately. This is done by managing and treating surrounding areas and crops, especially citrus and avocado, and releasing biological control agents. Over the past 20 years, Riverside's area-wide management program focused on citrus has demonstrated the effectiveness of these types programs (CDFA 2019). However, if sharpshooters are present in a vineyard, NGNs can be used to knock down the populations. This is most effective if done immediately after sharpshooters arrive. Insecticides do not kill the eggs, and accordingly, populations are difficult to manage once reproduction commences. The alternatives are acetamiprid, flupyradifurone, and fenpropathrin.

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 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, causing 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, and pyrethrin. 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. 2018). 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.

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 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 25). 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 similar. 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.

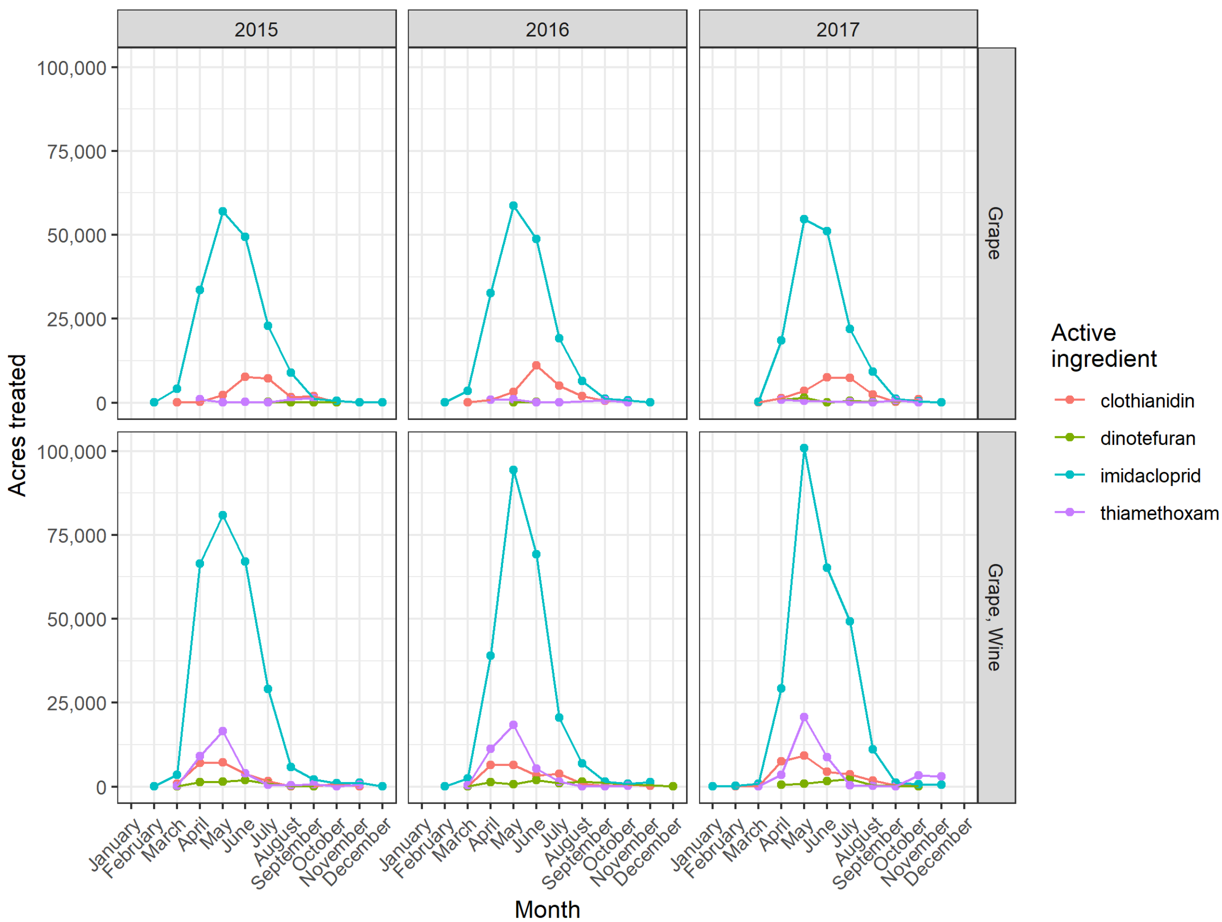


Figure 25. Monthly use of target nitroguanidine-substituted neonicotinoid use: Raisin and table grape and wine grape, 2015-2017.

Table 27 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 28 reports the same information for wine grape. Over 1 million acres in total were treated with NGNs over the three-year period. Restriction 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 effects on use patterns.

Table 27. Annual Use of Nitroguanidine-substituted Neonicotinoids and Alternative Active Ingredients: Raisin and Table Grape, 2015-2017

Active ingredient	----------**Pounds applied**-----------				--------------**Acres treated**--------------				**Use rate (lb/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 NGNs

Table 28. Annual Use of Nitroguanidine-substituted Neonicotinoids and Alternative Active Ingredients: Wine Grape, 2015-2017

Active ingredient	----------**Pounds applied**-----------				--------------**Acres treated**--------------				**Use rate (lb/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 NGNs

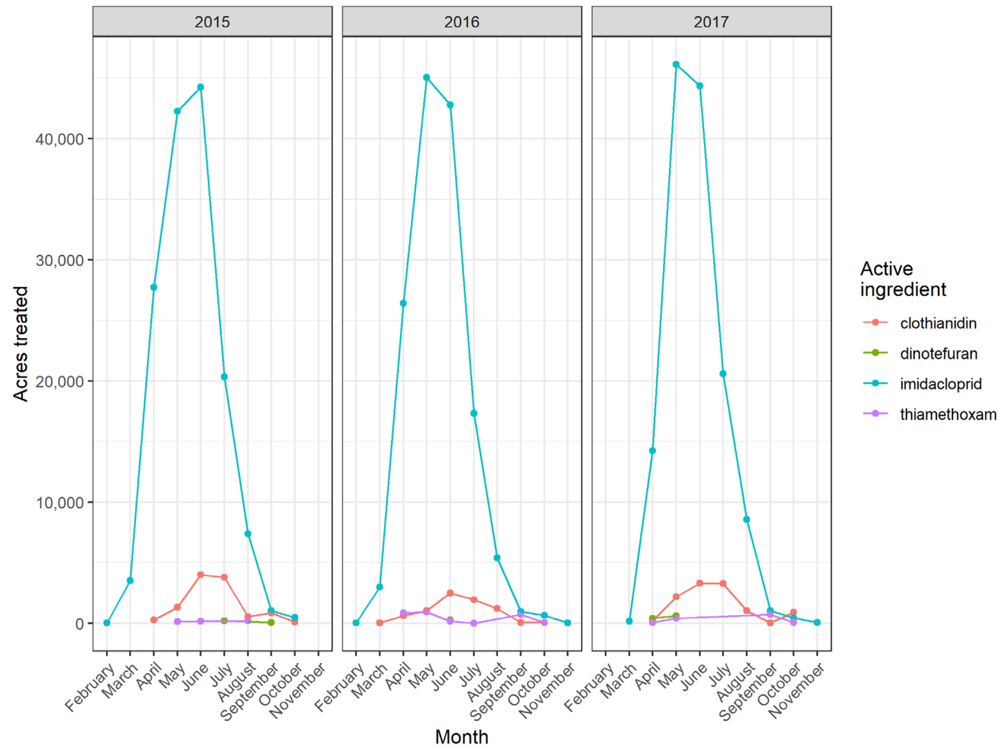
Proposed Restrictions

Grape is part of the berry crop group. Grapes do not use managed pollinators, thus only the three general restrictions would apply: use of clothianidin, dinotefuran, thiamethoxam, and imidacloprid would be restricted to only one AI per vineyard per year, only one application method, and no applications during bloom.[17]

All four NGNs are registered in grape. Imidacloprid is by far the most widely used (Figure 25) and is the most crucial for its role in managing vine mealybug. Under the general restrictions, in a given field any number of applications of one (and only one) NGN AI would be allowed (subject to label restrictions). Given its importance, if multiple NGNs were applied, we assume that under the proposed restrictions the grower would continue to use imidacloprid. Accordingly, if multiple NGNs were used, imidacloprid would be allowed while the other use would be prohibited and replaced with alternative AIs. If multiple application methods (soil and foliar) for imidacloprid were used, soil applications would be considered allowed while foliar applications would be replaced with alternatives. Chemigation, a soil application, is the most effective way to reach vine mealybug, a key pest. There are no known pest management reasons that applications could not be conducted pre- and post-bloom or even entirely post-bloom. Thus, we assume that grower would simply move those applications outside of bloom. With these restrictions 77-80% of acres and 76-86% of pounds applied would have been allowed on table and raisin grape, and 83-88% of acres and 87-91% of pounds applied would have been allowed on wine grape. Figure 26 shows acres and pounds that would have been allowed by month.

[17] Estimating a consistent bloom time in grape is not possible due to differences between varieties and weather variation from year to year.

(a) Raisin and Table grape



(b) Wine grape

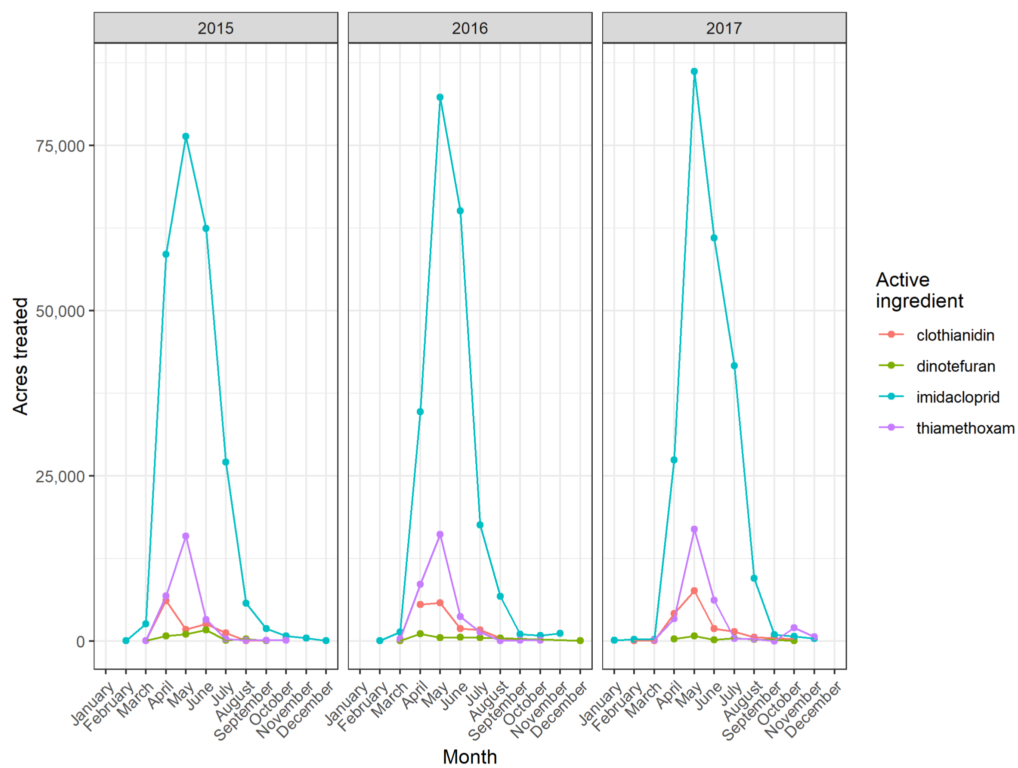


Figure 26. NGN use in grape that would have been allowed with the proposed restrictions: 2015-2017

Economic Analysis

This section presents the estimated change in costs to grape production from the proposed regulation. 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 practices and differentiated PUR data. No reduction in yield or quality is anticipated due to the use of alternatives, so gross revenues will not change as a result of the restrictions.

Table 29 presents representative products for each active ingredient used on raisin and table grape in 2015–2017 and their costs per acre. Table 30 presents the same information for wine grape. The material cost per acre is the product of the average use rate (lb/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. 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 acres treated with that AI that would have been prohibited (i.e., excluding allowed applications).

Table 29. 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	48.78
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	14.73	24.80	39.53
dinotefuran	Venom Insecticide	38.43	17.66	57.10
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	16.08	13.47	29.55
lambda-cyhalothrin	Warrior II	8.38	25.00	33.38
lavandulyl senecioate	Checkmate VMB-F	47.30	24.99	72.29
spirotetramat	Movento	63.09	25.00	88.08
thiamethoxam	Platinum 75 SG	17.66	13.38	31.04

Table 30. Representative Products and Costs Per Acre: Wine Grape

Active ingredient	Representative product	Material Cost ($)	Application cost ($)	Total cost ($)
acetamiprid	Assail 30sg Insecticide	19.91	24.65	44.56
beta-cyfluthrin	Baythroid XL	12.42	25.00	37.42
bifenthrin	Brigade WSB Insecticide/Miticide	21.24	25.28	45.52
buprofezin	Applaud 70 DF Insect Growth Regulator	43.73	25.02	68.75
burkholderia	Venerate	100.23	23.95	124.18
clothianidin	Belay Insecticide	19.41	16.82	36.24
dinotefuran	Venom Insecticide	36.09	15.74	51.77
fenpropathrin	Danitol 2.4 EC Spray	22.12	25.03	47.15
flupyradifurone	Sivanto 200 SL	42.64	23.44	66.08
imidacloprid	Admire Pro	18.13	12.12	30.25
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	13.38	7.47	20.84

Differences in the cost per acre for representative products between the two categories of grape are due to different average use rates and percentages of treatments using different 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 $29.55 per acre for imidacloprid to $92.17 for burkholderia in table and raisin grape, and from $20.84 per acre for thiamethoxam to $124.18 for burkholderia in wine grape. In both cases, *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 31. Average Annual Acreage Shares of Alternative Insecticides with and without Prohibited Applications of Target Nitroguanidine-substituted Neonicotinoids (NGNs): Raisin and Table Grape, 2015–2017

Active ingredient	Target NGNs available (%)	Target NGNs restricted(%)
acetamiprid	2.9	4.7
beta-cyfluthrin	5.6	9.2
bifenthrin	0.3	0.5
buprofezin	13.2	21.7
burkholderia	0.3	0.5
fenpropathrin	6.0	9.9
flupyradifurone	0.3	0.5
lambda-cyhalothrin	0.0	0.0
lavandulyl senecioate	2.7	4.5
spirotetramat	29.3	48.5
Total	60.5	100

Table 32. Average Annual Acreage Shares of Alternative Insecticides with and without Prohibited Applications of Target Nitroguanidine-substituted Neonicotinoids (NGNs): Wine Grape, 2015–2017

Active ingredient	Target NGNs available (%)	Target NGNs restricted (%)
acetamiprid	2.9	6.6
beta-cyfluthrin	0.6	1.3
bifenthrin	0.1	0.1
buprofezin	4.1	9.3
burkholderia	0.1	0.1
fenpropathrin	0.5	1.2
flupyradifurone	0.4	1.0
lambda-cyhalothrin	0.0	0.0
lavandulyl senecioate	3.1	7.0
spirotetramat	32.5	73.4
Total	44.3	100

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

Table 31 shows the average acreage shares for each non-NGN alternative used on raisin and table grape with and without NGNs being available. Table 32 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 restricted, 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 73.4% of acres treated with non-NGN insecticides. Because use is scaled up based on all use, their shares in the overall use of alternatives may not represent their use as a substitute for NGNs for any specific pest.

Table 33. 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	14.73	24.80	39.53	78.6
dinotefuran	38.43	17.66	57.10	23.7
imidacloprid	16.08	13.47	29.55	138.9
thiamethoxam	17.66	13.38	31.04	127.4
composite alternative	45.60	25.00	70.60	-

Table 34. 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	19.41	16.82	36.24	123.3
dinotefuran	36.03	15.74	51.77	56.3
imidacloprid	18.13	12.12	30.25	167.5
thiamethoxam	13.38	7.47	20.84	288.2
composite alternative	56.35	24.56	80.91	-

Table 33 and Table 34 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 restricted. 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 (23.7%) and imidacloprid users would incur the largest cost increase (138.9%) (Table 33). For wine grape, dinotefuran users would also incur the lowest cost increase (56.3%) and thiamethoxam users would incur the largest cost increase (288.2%) (Table 34).

Table 35. Change in Treatment Costs due to Restriction 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 (%)	Share of change due to material costs (%)	Share of change due to application costs (%)
2015	433,115	627,088	193,973	44.8	115.8	-15.8
2016	623,807	890,404	266,597	42.7	121.0	-21.0
2017	691,794	948,216	256,422	37.1	108.1	-8.1

Table 36. Change in Treatment Costs due to Restriction of Nitroguanidine-substituted Neonicotinoids: Wine Grape, 2015–2017

Year	Cost with target NGNs ($)	Cost without target NGNs ($)	Change in cost ($)	Change in cost (%)	Share of change due to material costs (%)	Share of change due to application costs (%)
2015	545,705	899,595	353,890	64.9	80.2	19.8
2016	541,034	922,335	381,891	70.5	74.9	25.1
2017	832,728	1,450,016	617,228	74.1	76.5	23.5

Table 35 (raisin and table grape) and Table 36 (wine grape) report the anticipated changes in cost due to the restriction of NGNs. For table and raisin grape, the percent change in costs ranges from 37.1% in 2017 to 44.8% in 2015 (Table 35). For wine grape, the percent change in costs ranges from 64.9% in 2015 to 74.1% in 2017 (Table 36). 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 table grape and raisin, the increase in total costs is due to the material costs of switching to more expensive pesticides. The material cost increases by over 100% each year, while application costs actually decline by 8.1% to 21%. For wine grape the majority of the increase is due to the increase in material costs.

Conclusions and Critical Uses

There is a small cost increase anticipated under the proposed restrictions, less than $1 million per year for all grape production combined. The relatively small magnitude of these changes is driven by the relatively small share of grape acreage treated with multiple NGNs and the predominance of imidacloprid use in total NGN use. Because growers will have the option of continuing to use imidacloprid, the impact is fairly small.

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 goes 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 was 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 highest agricultural commodity by value in 2017 for Orange County ($19 million produced). Figure 27 maps the distribution of California strawberry production.[18]

[18] 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.

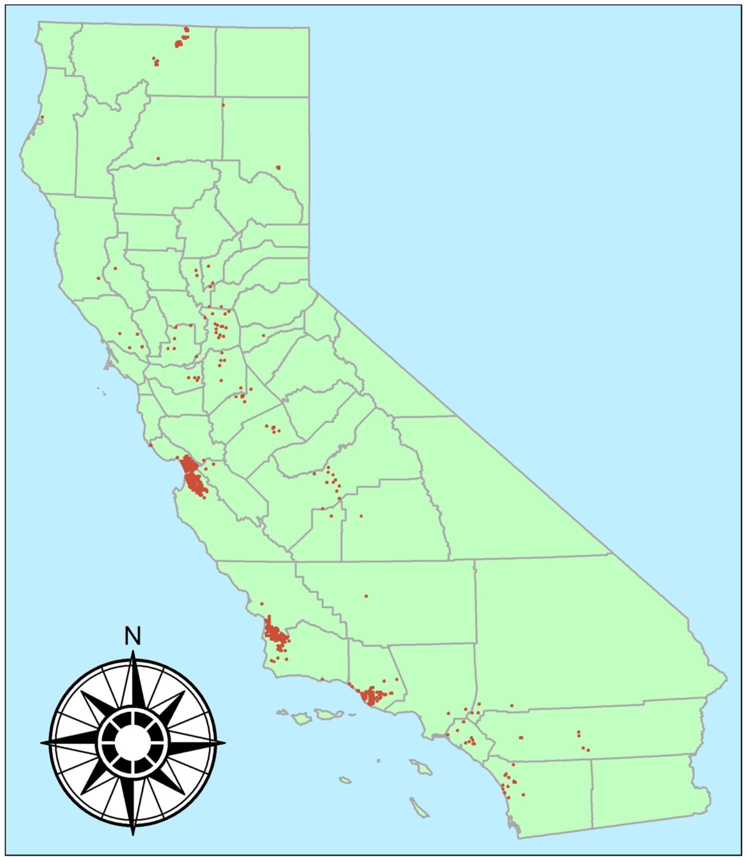


Figure 27. California strawberry production: 2017

Strawberry Production Systems

Strawberry production occurs in four designated 'districts' in California's Central Coast region: (from south to north): Orange-San Diego-Coachella district, Oxnard, Santa Maria, and Salinas-Watsonville. Production in these districts for calendar year 2018 are presented in Table 37. Until recently, the percentage of total California production in the Oxnard district was much greater than at present, and more similar to that of Santa Maria and Salinas-Watsonville. (Production has been shifting to Mexico, which has lower costs and fewer regulations.) 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 37. California Strawberry Acreage and Yield: 2018[19]

District	Acreage	Total production (Tons)
Orange-San Diego-Coachella	819	18.720
Oxnard	9,110	359,000
Santa Maria	11,750	536,000
Salinas-Watsonville	12,420,	650,500

The most important difference in production practices in these regions is best characterized by use of two distinctly different seasonal planting systems. In the "summer planting" system that is typical in 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 "fall planting" system of Santa Maria and Salinas-Watsonville districts, the annual strawberry crop is planted from late September to mid-November, depending on the location, and fruit harvest begins in the spring and continues through early fall. Table 38 presents typical planting periods, flowering periods, and harvest periods for California's production areas.

Table 38. 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

[19] https://www.nass.usda.gov/Statistics_by_State/California/Publications/AgComm/2018/2018cropyearcactb00.pdf

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 and continue into the fall after production has tapered off and ended for short-day cultivars. In California, short-day cultivars are 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 northern 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. Instead, growers tend to 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 berries (acceptable for processing) 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. 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 39.

Table 39. 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 a more serious pest problem 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 feed on developing fruit, resulting in distortion of the fruit that is referred to as “catfacing.” Such 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 became 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 October 2018 for use that began in 2019, there are no data available to use in this analysis. This means that though sulfoxaflor is 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 1,3-dichloropropene, 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, either 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. As a result, 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 28, 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 28 shows, imidacloprid use is essentially zero outside of planting season for three of the four production districts. The Santa Maria district is the only exception, with some summertime use.[20]

The proposed restrictions, discussed in detail below, are such that most to all of the use of imidacloprid would not be restricted because it is almost entirely used before the start of bloom. However, it is a target of the regulation. We have left imidacloprid historical use in Figure 28 but do not provide alternatives to its use or include imidacloprid in the economic analysis.

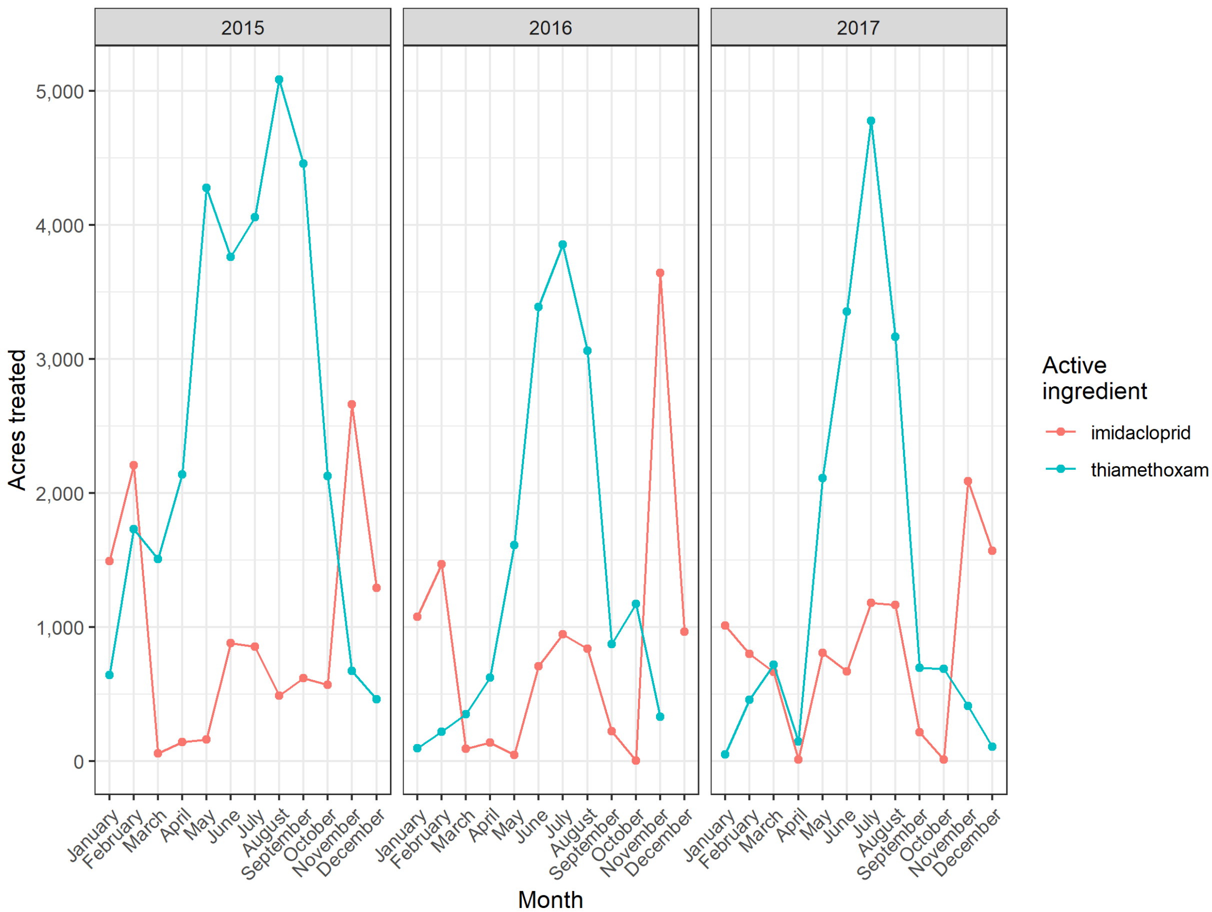


Figure 28. Nitroguanidine-substituted neonicotinoid use trends: Strawberry, 2015-2017

[20] There are at least three 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 previously had summertime use when there were active outbreaks in those locations as well. 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. Lastly, a small proportion of fields in the Santa Maria area are summer-planted, so this usage could represent pre-harvest applications to those fields.

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 pre-harvest 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. California's coastal strawberry growing regions typically feature lighter soils. Thiamethoxam use varied considerably for each region over the 2015-2017 period (Figure 28).

Table 40. Use Trends for Nitroguanidine-substituted Neonicotinoids and Alternative Active Ingredients: Strawberry Thiamethoxam, 2015-2017

Active ingredient (AI)	**----------Pounds applied-----------**				**-------------Acres treated------------**				**Use rate (lb/ 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 40 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, used on 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.

We have not included a similar table for imidacloprid because its use would not be affected by the proposed restrictions in strawberry.

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 restricted on strawberry.

Resistance management. Repeated applications of insecticides with similar modes of action create 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 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 pre-harvest 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.

Proposed Restrictions

Strawberry is in the berry crop group. Under the proposed regulations, the use of imidacloprid and thiamethoxam – the only two NGNs registered for the crop – would be restricted to only one AI per field per year and only one application method. No applications would be allowed once the plants have started blooming. If a grower uses managed pollinators, all use would be prohibited. However, this provision will not impact strawberries in California. Varieties grown in California are not self-incompatible and therefore no benefit to yield, quality or appearance is achieved through use of managed pollinators. In fact, the California Annual *Pollination Survey Results* from the California State Beekeepers Association from 2009 through 2018 (e.g., CSBA, 2018) show that there is no record of managed bees used in California strawberries. Accordingly, the analysis was conducted as if no strawberry grower used managed pollinators. Without the presence of managed pollinators, only the general restrictions discussed above still apply.

The bloom time restriction is the most consequential for strawberry. The use of thiamethoxam, occurs after bloom has started. All applications of thiamethoxam are considered prohibited and would be replaced with alternatives. In contrast almost all imidacloprid use already occurs before bloom because that is when the pest management benefits are greatest, as discussed in the Target NGN Use section above. As such, all imidacloprid applications are considered allowed and would not need to be replaced with alternatives. In other words, 100% of imidacloprid applications would have been allowed and 0% of thiamethoxam applications would have been allowed. Accordingly, 27.0-39.5% of treated acres and 73.2-80.7% of pounds applied would have been allowed per year. Because only imidacloprid use would be allowed, these percentages are equivalent to the percent of NGN use that was imidacloprid.

Economic Analysis

This section presents the expected change in costs for strawberry production owing to the restrictions that would be placed on the use of thiamethoxam. This cost includes the change in pesticide material costs and application method costs. 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 41 presents representative products for each active ingredient used on strawberry in 2015–2017 and their costs per acre. The material cost per acre is the product of the average use rate (lb/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 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 acres treated with that AI that would have been prohibited (i.e., excluding allowed applications). The total treatment cost per acre is the sum of the material and application cost per acre. Total cost per acre ranges from $32.93 for naled to $75.19 for flupyradifurone. Growers consider other factors in addition to price per acre when deciding which insecticides to use, as discussed above.

Table 41. Representative Products and Costs per Acre: Strawberry

Active ingredient	Representative product	Material Cost ($)	App Cost ($)	Total Cost ($)
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	24.92	24.83	49.75
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	12.09	24.91	37.00
naled	Dibrom 8 Emulsive	7.96	24.97	32.93
novaluron	Rimon 0.83 EC Insecticide	23.68	24.88	48.56
thiamethoxam	Actara	15.73	24.90	40.64

Table 42 shows the average acreage shares for each alternative AI used on strawberry, with and without thiamethoxam being available. Averaged over the three-year period 2015-2017 when thiamethoxam was available, it was used on 6.4% of total strawberry acres treated with insecticides, and alternative AIs were used on 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 thiamethoxam—novaluron, flonicamid, and bifenthrin—together accounted for 59.0% of strawberry acres treated, which is 63.0% of acres treated without thiamethoxam. Because use is scaled up based on all use, their shares in the overall use of alternatives may not represent their use as a substitute for NGNs for any specific pest.

Table 42. Average Annual Acreage Shares of Alternative Insecticides with and without Prohibited Applications of Target Nitroguanidine-substituted Neonicotinoids (NGNs): Strawberry, 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-year average from 2015-2017. Numbers may not add to 100% due to rounding

Table 43 reports the average per acre costs for the target NGN, thiamethoxam, as well as the cost of its composite alternatives, whose price we use as a representative pesticide cost if the NGNs were restricted. The composite alternative for thiamethoxam is $0.05 less expensive to apply, but its material costs are $12.50 per acre more expensive (Table 43). Overall, thiamethoxam users will incur an increased cost of 30.6%.

Table 43. Average Cost per Acre for Target Nitroguanidine-substituted Neonicotinoids and the Composite Alternative: Strawberry

Active ingredient	Material cost ($)	Application cost ($)	Total cost ($)	Cost increase for switching to composite alternative (%)
thiamethoxam	15.73	24.90	40.64	30.6
composite alternative	28.23	24.85	53.07	-

Table 44 reports the expected change in costs owing to the restrictions on thiamethoxam. The total change in costs from the 30.6% cost increase ranges from $193,893 in 2016 to $384,520 in 2015. At 760 cwt per acre and an average value of $63.80 per cwt, 2016 statewide average revenues were $48,488 per acre.[21] On a per acre basis, the cost of one application of the composite alternative to replace one application of thiamethoxam is $53.07 per acre, roughly one-tenth of a percent of average gross revenues.

Table 44. Change in Treatment Costs due to Restriction of Target Nitroguanidine-substituted Neonicotinoids (NGNs): Strawberry, 2015–2017

Year	Cost with target NGNs ($)	Cost without target NGNs ($)	Change in cost ($)	Change in cost (%)	Share of change due to material costs (%)	Share of change due to application costs (%)
2015	1,256,362	1,640,881	384,520	30.6	100.4	-0.4
2016	633,257	827,070	193,813	30.6	100.4	-0.4
2017	677,881	207,471	207,471	30.6	100.4	-0.4

Conclusions and Critical Uses

Prohibiting thiamethoxam in strawberry would result in an approximately $194,000 to $385,000 increase in insecticide material and application costs. In percentage terms these increases are moderate in terms of the increase in cost. On a per acre basis they amount to less than one-tenth of one percent of gross revenues.

[21] 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.

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. In California, 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 billion, 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 29 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 was the seventh most important agricultural export for California, with a value of $743 million. 72.0% of processing tomato were exported (CDFA 2017). Figure 30 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 varieties 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, and 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 are primarily 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.

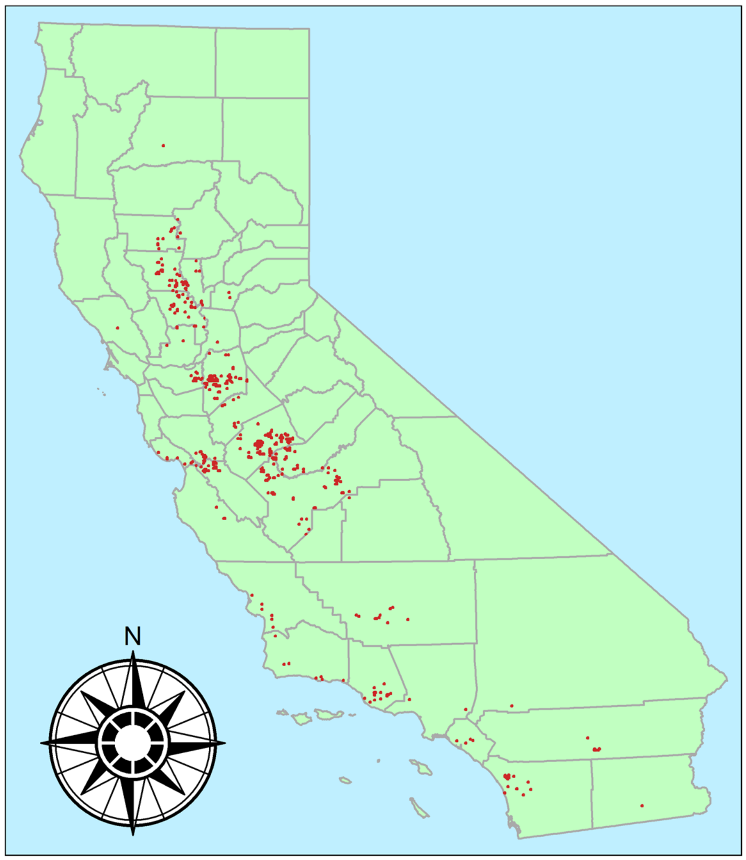


Figure 29. California fresh market tomato production: 2017

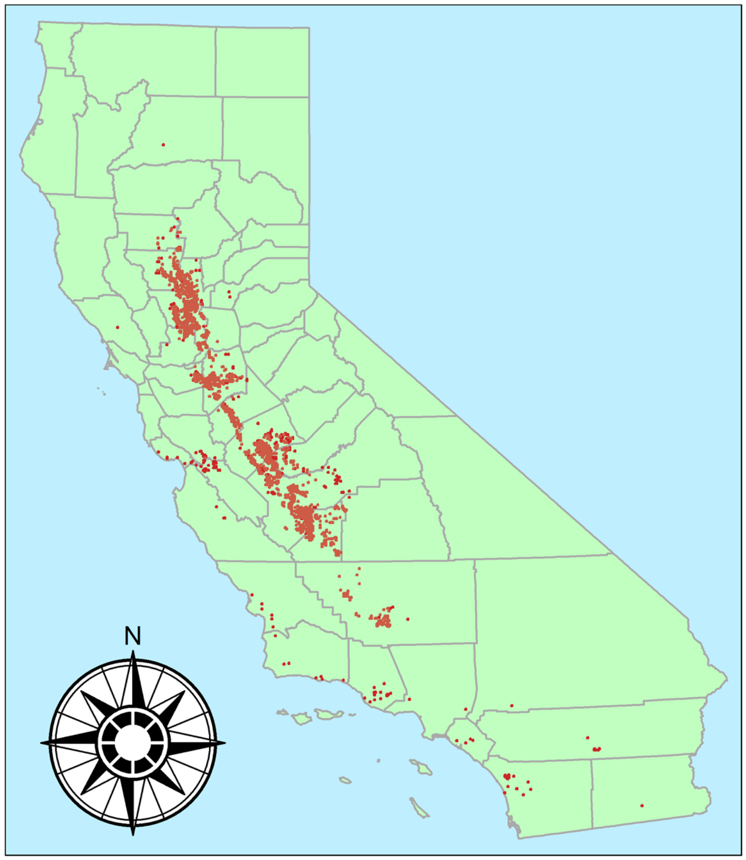


Figure 30. California processing tomato production: 2017

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, we define 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 AIs 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, or as a foliar spray either as a stand-alone product, a premix, 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 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. The target pest section includes information on pests targeted with any of the four NGNs to give a complete picture of their use even though most imidacloprid use would continue to be allowed under the proposed restrictions (see Proposed Restrictions section below).

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 viral 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 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 aphid is 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 aphid but provide control incidentally when they are used for other insects by chemigation or foliar sprays 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 and when beet leafhoppers are detected in fields. Alternatives for foliar applications include dimethoate and flupyradifurone. A newly registered insecticide, 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 with large acreages. Cyantraniliprole, when applied to the soil through chemigation at planting or soon thereafter, produces feeding cessation, which is useful in suppression of curly top transmission. Some growers have similarly applied chlorantraniliprole for leafhopper control, but this use has not been shown to be effective.

Flea beetles. Flea beetles are a pest of seedling processing tomato in the San Joaquin and Sacramento Valley regions (Zalom 2003). These beetles 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 when establishing tomato fields. Flea beetles occasionally become a late season pest when leaves are senescing, and they begin feeding on the fruit instead. Imidacloprid is effective as a pre-plant application 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. 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 regarded as effective when applied alone as a foliar spray as they are when applied in a premix or when tank mixed with a pyrethroid insecticide such as lambda–cyhalothrin, fenpropathrin and others (Cullen and Zalom 2007). These uses would likely be replaced directly with acetamiprid in the tank mix, which would otherwise remain the same.

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 abortion that results 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 the need for 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 tomato spotted wilt 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 has 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 considerably less effective than NGNs or the alternatives listed above. Cyantraniliprole 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. This is a newly registered AI, and no use data was available from 2015-2017. It is not included in the analysis. This is unlikely to affect the results significantly because it is mainly an alternative for imidacloprid, which will continue to be used (see Proposed Restrictions section below).

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 additional applications as well as increased 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 Southern 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 owing 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. Tomato yellow leaf curl is the most damaging whitefly-transmitted virus worldwide. It was not found in California until recently when it was 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 probable 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 and spider mites, 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 NGNs' residual efficacy when applied at this time.

Target NGN Use: 2015-2017

Most fresh market tomato acreage treated with NGNs is in the San Joaquin Valley, where most fresh market tomato production occurs. Imidacloprid is the primary NGN applied to tomato acreage and is substantially greater in most regions than the other NGNs except the South Coast and Central Coast regions, where thiamethoxam and dinotefuran are more widely used some years. Clothianidin has not been widely used in fresh market tomato with the exception of 2015 in the San Joaquin Valley. Dinotefuran was also applied to some extent in the San Joaquin Valley in 2016. Figure 31 reports monthly target NGN use for both fresh market and processing tomato. Table 46 reports annual use of target NGNs and alternative active ingredients on fresh market tomato for 2015-2017.

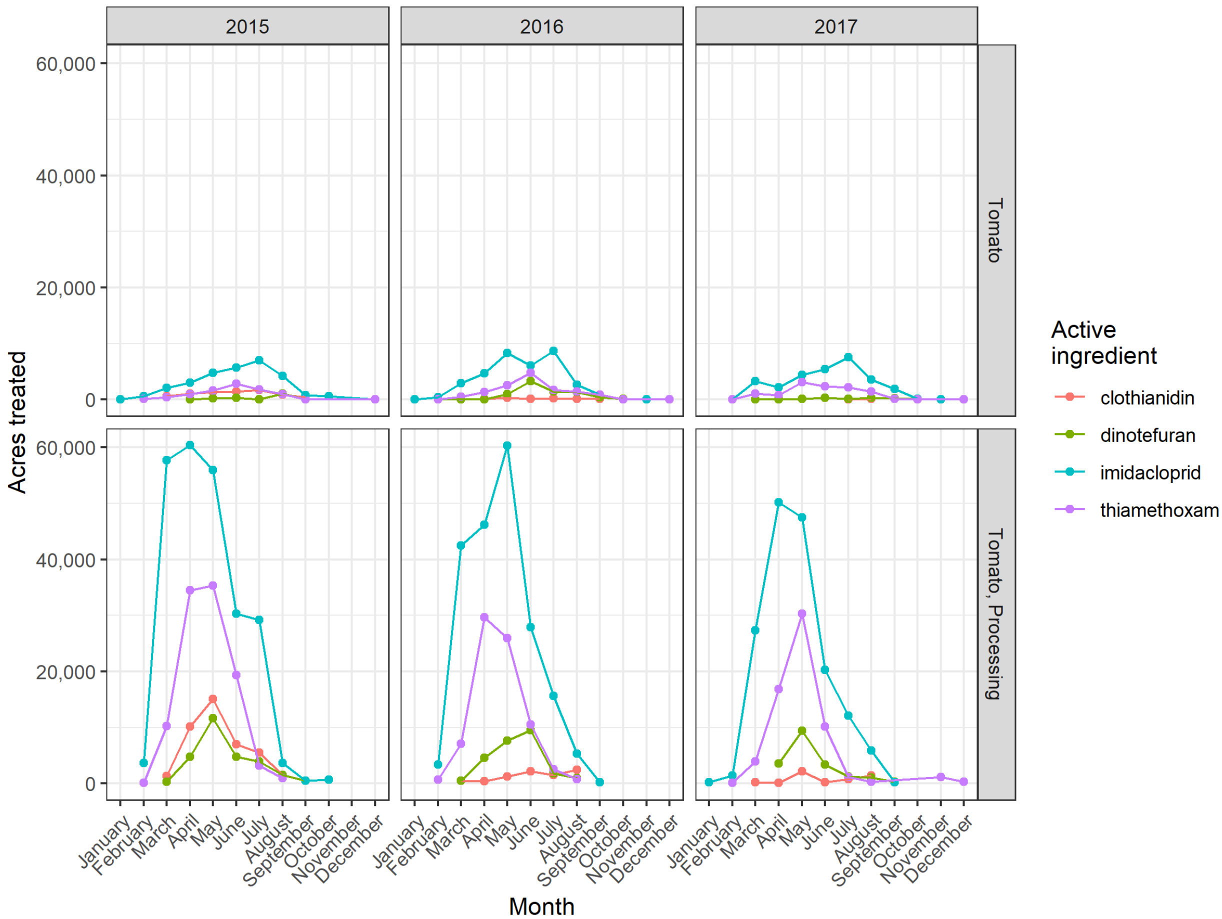


Figure 31. Monthly use of target nitroguanidine-substituted neonicotinoids: Fresh market and processing tomato, 2015-2017

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 was less used in the San Joaquin Valley. Clothianidin and dinotefuran were applied to proportionally more acres in the Sacramento Valley than in the San Joaquin region mid-season, possibly for stink bug control. Table 46 reports annual use of the target NGNs and alternative active ingredients on processing tomato for 2015-2017.

Table 45. Annual Use of Target Nitroguanidine-substituted Neonicotinoids and Alternative Active Ingredients: Fresh Market Tomato, 2015-2017

Active ingredient	**--------Pounds applied---------**				**-----------Acres treated-----------**				**Use rate (lb /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
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	120	247	63	429	628	1350	313	2291	0.19
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 NGNs

Table 46. Annual Use of Nitroguanidine-substituted Neonicotinoids and Alternative Active Ingredients: Processing Tomato, 2015-2017

Active ingredient	--------Pounds applied---------				-----------Acres treated-----------				Use rate (lb /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
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	702	180	57	938	3882	998	284	5,165	0.18
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	77,185	64,474	245,362	0.05

* Target NGNs

Proposed Restrictions

Tomato is in the Fruiting Vegetables crop group. Under the proposed regulations, the use of clothianidin, dinotefuran, thiamethoxam, and imidacloprid would be restricted to only one AI per field per year and only one application method. No applications would be allowed once plants have started blooming. All applications of imidacloprid would be prohibited if a grower used managed pollinators. Managed pollinators are not used in field-grown fresh market or processing tomato production; however, bumblebees may be used in greenhouse tomato production to improve fruit set. We assume for this analysis that growers will not use managed pollinators.

Imidacloprid is the most heavily used NGN (Figure 31) and the most critical as it protects transplants from several virus vectors. One particular use of imidacloprid and thiamethoxam is that either can be used in a tank mix or pre-mix to control stink bug.

This specific use has a drop-in alternative: acetamiprid. Applications where imidacloprid or thiamethoxam were used as a tank mix or pre-mix with a pyrethroid were replaced directly with acetamiprid.[22] Other imidacloprid use almost exclusively occurs before bloom and would continue to be allowed. The use of clothianidin, dinotefuran, and thiamethoxam, however, mostly occurs after bloom. Clothianidin and dinotefuran applications would be prohibited and replaced with alternatives. We estimate that roughly 10% of thiamethoxam use occurs before bloom; these applications would be allowed as long as imidacloprid had not already been used in the field. Acres receiving thiamethoxam applications once bloom begins would be replaced with roughly two applications of the composite alternative to achieve similar control as for each thiamethoxam application. In fields that applied imidacloprid using both soil and foliar application methods, we assume that growers would keep the soil applications because those are more critical for managing aphids, beet leafhoppers and whiteflies. Foliar applications after soil applications would be prohibited and redistributed to alternatives for this analysis. This is likely an overestimate of the impact because some growers would be able to use soil applications a second time, providing it was in compliance with the label rates and restrictions, instead of switching to alternatives. Additionally, new alternatives are coming onto the market that will provide growers with more options.

Economic Analysis

This section presents the estimated change in costs of pest management in tomato owing to the proposed restrictions of the four NGNs. This cost includes the change in pesticide material and application costs. 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 replace thiamethoxam sprays. To account for this, we calculate the cost of two 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.

[22] When mixing with pyrethroids, multiple-methods restriction is not considered in this analysis if the replacement would not contain an NGN.

Table 47. 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
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	4.98	22.39	27.37
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	Perm-Up 3.2 EC Insecticide	7.84	24.63	32.47
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 48. 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
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	5.81	22.34	29.14
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	Perm-Up 3.2 EC Insecticide	7.60	18.61	26.21
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 51 (fresh market) and Table 52 (processing). The material cost per acre is the product of the average use rate (lb/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 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 acres treated with that AI that would have been prohibited (i.e., excluding allowed applications). 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 (thiamethoxam, a target NGN) to $103.05 per acre for fresh market tomato (spinosad an alternative AI) and from $15.19 per acre (thiamethoxam) to $93.74 per acre (spinosad) for processing tomato.

Table 49. Average Annual Acreage Shares of Alternative Insecticides with and without Prohibited Applications of Target Nitroguanidine-substituted Neonicotinoids (NGNs): Fresh Market Tomato, 2015–2017

Active ingredient	Target NGNs available (%)	Target NGNs restricted (%)
abamectin	4.2	6.5
acetamiprid	3.0	4.6
buprofezin	1.3	2.1
dimethoate	3.5	5.5
esfenvalerate	4.9	7.5
fenpropathrin	3.0	4.6
flonicamid	0.8	1.2
flupyradifurone	4.1	6.3
lambda-cyhalothrin	10.9	16.8
methomyl	3.7	5.7
novaluron	0.6	1.0
permethrin	1.2	1.8
pymetrozine	0.3	0.5
pyriproxyfen	0.8	1.2
spinetoram	19.0	29.3
spinosad	1.7	2.7
spiromesifen	1.1	1.6
spirotetramat	0.8	1.2
Total	64.9	100

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

Because there is a specific alternative for the imidacloprid and thiamethoxam when tank mixed with pyrethroid, we exclude such applications when computing the cost per acre of the composite alternative. Table 49 reports the average acreage shares for each non-NGN alternative AI used on fresh market tomato with and without NGNs being available excluding application of a tank mix that also contains a pyrethroid. Averaged over the three-year period, 2015–2017, when NGNs were available, NGNs were used on 35.1% of total fresh market tomato acreage treated with insecticides and alternative AIs were used on 64.9% of fresh market tomato acreage treated with insecticides.

If NGNs were restricted, 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 spinetoram for fresh market tomato, together accounting for 29.9% of the acres treated when NGNs were available and scaling up to 46.1% of use if NGNs were restricted.

Table 50. Average Annual Acreage Shares of Alternative Insecticides with and without Prohibited Applications of Target Nitroguanidine-substituted Neonicotinoids (NGNs): Processing Tomato, 2015–2017

Active ingredient	Target NGNs available (%)	Target NGNs restricted (%)
abamectin	9.6	17.1
acetamiprid	2.1	3.8
buprofezin	0.1	0.1
carbaryl	8.1	14.5
dimethoate	10.7	19.0
esfenvalerate	4.2	7.5
fenpropathrin	0.2	0.3
flonicamid	0.0	0.0
flupyradifurone	0.3	0.5
lambda-cyhalothrin	12.0	21.3
methomyl	1.1	1.9
novaluron	0.5	0.9
permethrin	0.8	1.3
pyriproxyfen	0.2	0.3
spinetoram	4.6	8.2
spinosad	1.4	2.5
spiromesifen	0.1	0.1
spirotetramat	0.4	0.7
total	56.3	100

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

Table 50 reports the average acreage shares for each non-NGN alternative AI used on processing tomato, with and without NGNs being available, excluding tank mixes that also included a pyrethroid. Averaged over the three-year period, 2015–2017, when NGNs were available, NGNs were used on 43.7% of total acres treated with insecticides and alternative AIs were used on 56.3% of acreage treated with insecticides. Note that total acres treated with insecticides does not correspond to total acres of tomato grown because some growers may have used multiple AIs on the same field.

The two most common alternative AIs were dimethoate and lambda-cyhalothrin for processing tomato, together accounting for 22.7% of the acres treated without NGNs when NGNs were available, scaling up to 40.3% if NGNs were restricted.

Table 51. 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	61%
dinotefuran	40.70	17.41	58.11	-8%
imidacloprid	4.98	22.39	27.37	83%
thiamethoxam	8.37	8.20	16.56	546%
composite alternative*	31.48	22.00	53.48	-

*Cost per application of the composite alternative. Two applications required when substituting for thiamethoxam.

Table 51 reports average per acre costs for the NGNs and the composite alternative for fresh market tomato. Switching to the alternative would lead to a 61% increase in cost on acres using clothianidin, an 8% decrease for dinotefuran, an 83% increase for imidacloprid (excluding pre-bloom use, which is unaffected), and a 546% increase for thiamethoxam. The percentage changes are large for thiamethoxam because each application is replaced by two applications of the composite alternative. For tank mixes of imidacloprid or thiamethoxam with a pyrethroid, the increase in the cost per acre for imidacloprid is $11.06, a 90% increase and for thiamethoxam is $1.31, an 8% increase.

Table 52. 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	34.16	25%
dinotefuran	46.44	11.61	58.05	-26%
imidacloprid	5.81	23.34	29.14	32%
thiamethoxam	8.06	7.13	15.19	463%
composite alternative*	20.12	22.64	42.76	-

*Cost per application of the composite alternative. Two applications required when substituting for thiamethoxam.

Table 52 reports average per acre costs for the target NGNs and the composite alternative. Switching to the alternative would lead to a 25% increase in cost on acres using clothianidin, a 26% decrease for dinotefuran, a 32% increase for imidacloprid (excluding prebloom use), and a 463% increase for thiamethoxam. As mentioned previously, the composite alternative is applied twice to replace thiamethoxam applications. For tank mixes, the increase in the cost per acre for imidacloprid is $29.94, a 34% increase and for thiamethoxam is $23.78, a 157% increase.

Table 53. Change in Treatment Costs due to Restriction 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	916,844	2,184,162	1,267,318	138.2	76.1	23.9
2016	1,164,373	2,680,465	1,516,092	130.2	67.6	32.4
2017	671,847	1,901,203	1,229,356	183.0	70.6	29.4

*Of the total increase in costs, the cost increase from directly substituting acetamiprid into mixes with pyrethroids is $271,021 in 2015, $304,370 in 2016, and $337,152 in 2017.

Table 54. Change in Treatment Costs due to Restriction 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	6,936,056	14,712,397	7,776,341	112.1	49.2	50.8
2016	4,736,123	10,438,668	5,702,545	120.4	45.7	54.3
2017	3,678,426	8,459,611	4,781,185	130.0	45.8	54.2

*Of the total increase in costs, the cost increase from directly substituting acetamiprid in mixes with pyrethroids is $715,180 in 2015, $417,835 in 2016, and $382,079 in 2017.

Table 53 (fresh market tomato) and Table 54 (processing tomato) report the change in insecticide material and application costs due to the restriction of NGNs. Costs increase for both. Substituting for the restricted NGNs would result in a 130.2% to 183% increase in total treatment costs for fresh market tomato acreage treated with the NGNs, with an total cost increase between $1.3 million and $1.5 million. For processing tomato, the increase would be 112.1% to 130%, with a total cost increase of $4.8 million to $7.8 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 23,265 annual acres treated with NGNs from 2015-2017, compared to 152,304 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.

Conclusions and Critical Uses

In the case of tomato, the most critical uses of NGNs – imidacloprid prior to bloom – would still be allowed, and other NGN uses would be changed to alternatives. Utilizing alternative pesticides for the target pests due to the proposed regulation increases costs for both fresh market and processing tomato. The two types face different impacts from the proposed restrictions. Fresh market tomato has a larger percentage increase in costs per acre than processing tomato, but due to the larger acreage treated with NGNs, processing tomato has a higher total cost.

Walnut

California accounts for nearly 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% 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 commodity in two of these counties (Glenn and Sutter), and the top agricultural commodity in four (Butte, Tehama, Solano, and Yuba). In 2017, 70% of walnuts were sold shelled, the remainder marketable in-shell.

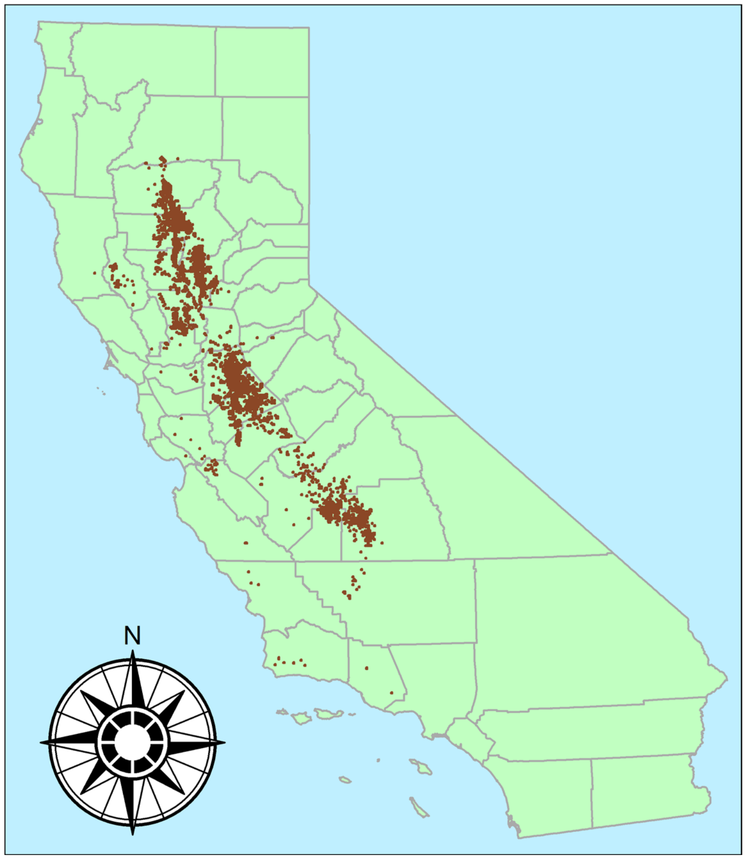


Figure 32. California walnut production: 2017

IPM Overview

California walnut is 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, 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's proposed regulation restricts use to only one of the two each year and prohibits applications during bud and bloom. For this analysis, we consider this time period to be February – early May depending on location. However, there is not a pest management reason to use either NGN before the end of bloom. The applicatinons in April and May likely occur after bloom for a particular orchard. As such, that use is considered to be allowed.

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, aphids produce honey dew, which encourages 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. Although both clothianidin and imidacloprid are effective, it is more common for growers to use imidacloprid. Either could serve as an alternative for the other without changing pest management outcomes.

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 remove (an issue primarily for in-shell sales). For walnut husk fly, both imidacloprid and clothianidin are effective. It is more common for growers to use imidacloprid. Either could serve as an alternative for the other without changing pest management outcomes.

Target NGN Use: 2015-2017

Figure 33 illustrates the treated acreage of NGNs on walnut for 2015-2017 by year, month, and AI. The majority of imidacloprid is applied in June-August (Figure 33) 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.

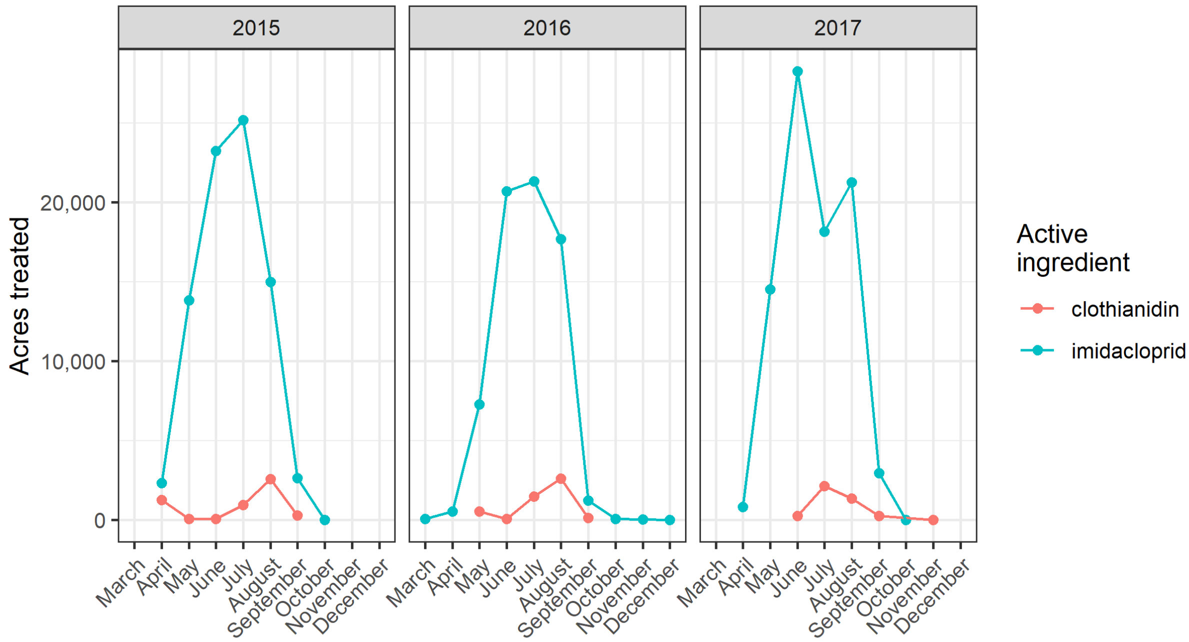


Figure 33. Monthly use of target nitroguanidine-substituted neonicotinoids: Walnut, 2015-2017

As discussed in the IPM Overview section above, imidacloprid is a drop-in replacement for clothianidin in fields that used both AIs.

Table 55. Annual Use of Target Nitroguanidine-substituted Neonicotinoids and Alternative Active Ingredients: Walnut, 2015-2017

Active ingredient	**--------Pounds applied---------**				**-----------Acres treated-----------**				**Use rate (lb /ac)**
	2015	2016	2017	Total	2015	2016	2017	Total	
clothianidin*	446	398	398	1,242	5,242	4,841	4,075	14,158	0.09
imidacloprid*	6,625	5,771	7,259	19,655	82,216	68,864	85,965	237,1145	0.08

*Target NGNs

Proposed Restrictions

Walnut is in the tree nut crop group. Only imidacloprid and clothianidin are regularly used. Under the proposed regulations, any number of applications of one (and only one) NGN AI would be allowed (subject to label restrictions) and only one application method – soil or foliar – would be allowed in a given orchard each year. No applications would be allowed during bloom.

Imidacloprid is more widely used than clothianidin (Figure 33). Applications in fields that had only one of the NGN AIs in a year would be allowed. For fields that used more than one AI, we assumed that the imidacloprid applications would be kept and clothianidin applications would be replaced with an imidacloprid application because imidacloprid use is more common. This only affected roughly 2% of acres treated (Figure 34), as walnut growers rarely used more than one NGN AI per year.

Figure 34 shows what the use in 2015-2017 would have been if the new restrictions had been in place. Under the proposed restrictions 98% of treated acres and lb applied would still have been allowed.

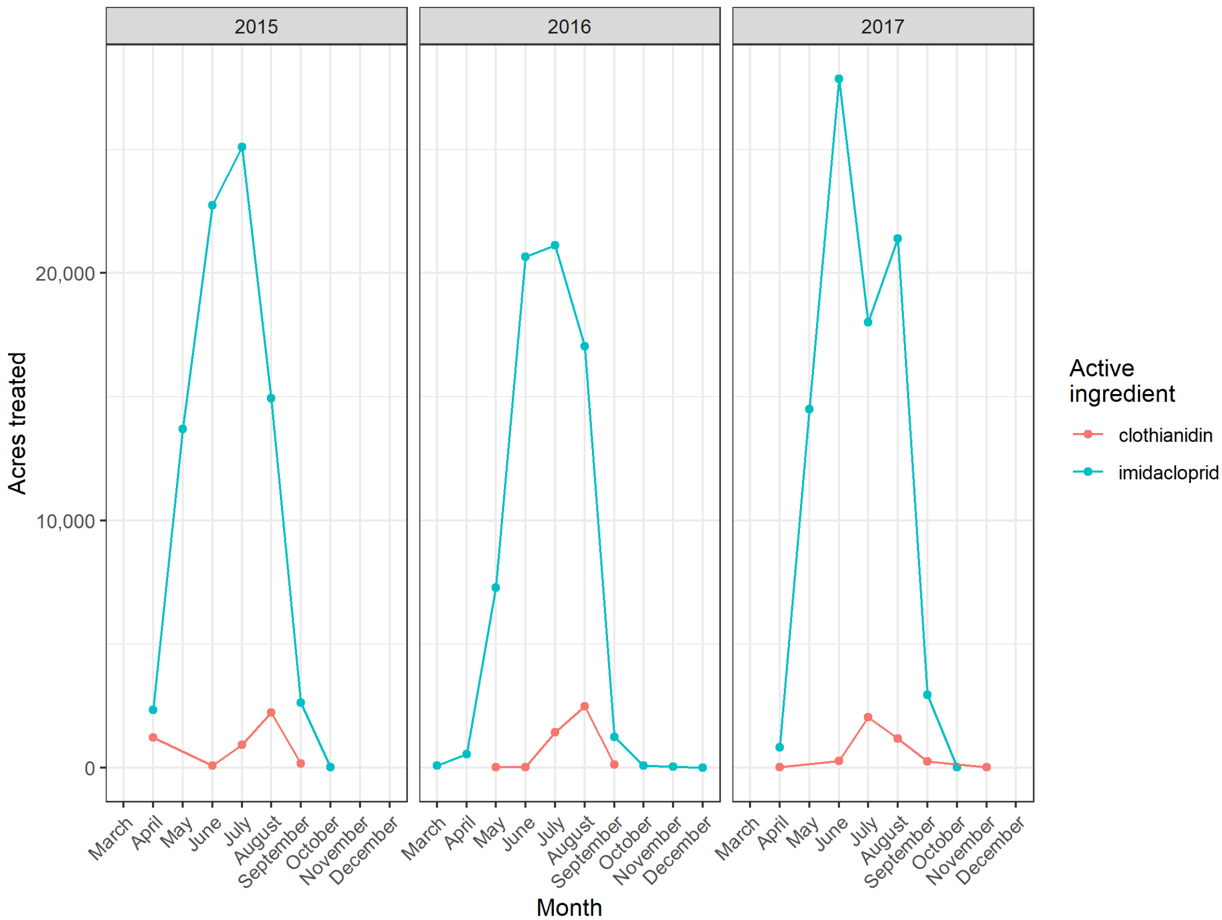


Figure 34. Monthly use of target nitroguanidine-substituted neonicotinoids that would have been allowed under the proposed restrictions: Walnut, 2015-2017

Economic Analysis

This section presents the estimated change in costs to walnut if only one NGN were available for use after bloom. Imidacloprid is as effective if not more effective than clothianidin, so using it as a replacement for clothianidin would have no negative yield consequences. Imidacloprid would only be used as an alternative in fields where both imidacloprid and clothianidin had been applied within one year. 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 56. Representative Products Cost per Acre in 2018: Walnut

Active ingredient	Representative product	Material Cost per acre($)	App Cost per acre($)	Total Cost per acre($)
clothianidin	Belay	13.40	25.17	38.57
imidacloprid	Leverage	14.40	24.67	39.07

Table 56 reports the representative products for clothianidin and imidacloprid on walnut for 2015-2017. The material cost per acre is the product of the average use rate (lb/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. 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 acres treated with that AI that would have been prohibited (i.e., excluding allowed applications). At $39.07 per acre, imidacloprid is 1.3% more expensive than clothianidin at $38.57 per acre. Growers consider a number of factors including cost per acre in determining which pesticide to apply.

When imidacloprid and clothianidin are used on the same field, meaning one would be prohibited under the proposed regulation, the imidacloprid is scaled up to compensate for clothianidin – this only occurred on 2% of acres.

Table 57. Change in Treatment Costs due to Restriction of Nitroguanidine-substituted Neonicotinoids (NGNs): Walnut Pre-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	23,911	24,224	313	1.3	199.5	-99.5
2016	28,626	29,000	375	1.3	199.5	-99.5
2017	12,245	12,405	160	1.3	199.5	-99.5

Table 57 reports the change in treatment costs due to restricting applications to one AI per field per growing season. For walnut, insecticide material and application costs increase by a little over 1% under the proposed policy. The magnitude of the total change in net returns is likely to be small.

Conclusions and Critical Uses

For walnut, the proposed restrictions have little impact on use. As such, pest management costs are only estimated to increase by 1.3%, which would be only a very small change in net returns.

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Appendix A: Draft Text of Proposed Regulation

This draft text of the proposed regulation was provided by DPR to CDFA on 6/5/2020.

TEXT OF PROPOSED REGULATIONS
FOR PURPOSES OF PRE-REGULATORY WEBINARS

TITLE 3. CALIFORNIA CODE OF REGULATIONS
DIVISION 6. PESTICIDES AND PEST CONTROL OPERATIONS
CHAPTER 4. ENVIRONMENTAL PROTECTION
SUBCHAPTER 6. POLLINATOR PROTECTION
ARTICLE 2. PESTICIDE EXPOSURE PREVENTION

Section YYYY. Scope and Definitions

(a) For the purposes of this article, the following definitions apply:
(1) "Bloom" means from bud break until complete petal fall (all petals have fallen).
(2) "Crop group" means the groupings of agricultural commodities specified in Title 40 Code of Federal Regulations section 180.41(c) (May 3, 2016).
(3) "Growing season" means the time period from planting until harvest is completed for a particular annual crop or biennial crop, and is not more than one year (365 days) for perennial crops.
(4) "Managed pollinators" means any bees that are used by growers to provide pollination services.

(b) The provisions of this article apply to foliar, soil, or both foliar and soil applications of pesticides containing one or more of the active ingredients clothianidin, dinotefuran, imidacloprid, and thiamethoxam, when used for the production of the following agricultural commodities:
(1) Berries and small fruits (Crop Group 13 and 13-07)
(2) Bulb vegetables (Crop Group 3 and 3-7)
(3) Cereal grains (Crop Group 15 and 16)
(4) Citrus fruit (Crop Group 10 and 10-10)
(5) Cucurbit vegetables (Crop Group 9)
(6) Fruiting vegetables (Crop Group 8 and 8-10)
(7) Herbs and spices (Crop Group 19)
(8) Leafy vegetables including brassica (cole) (Crop Group 4, 4-16, 5, 5-16 and 22)
(9) Legume vegetables (Crop Group 6 and 7)
(10) Oilseed (Crop Group 20)
(11) Pome fruits (Crop Group 11 and 11-10)
(12) Root and tuber vegetables (Crop Group 1 and 2)

(13) Stone fruits (Crop Group 12 and 12-12)
(14) Tree nuts (Crop Group 14 and 14-12)
(15) Tropical and subtropical fruit, edible and inedible peel (Crop Group 23 and 24)
(16) Coffee, peanuts, globe artichoke, mint, hops (female plants only), and tobacco
(c) An application made to address an emergency declared by the U.S. Department of Agriculture or the California Department of Food and Agriculture pursuant to Government Code section 8630 is not subject to the provisions of this article for the duration of the declared emergency.

(d) For purposes of this article, if the operator of the property uses managed pollinators at the application site, then the operator of the property is presumed to have intended to use managed pollinators at the time of application for that growing season.

Section YYYY.1. General Application Restrictions for Clothianidin, Dinotefuran, Imidacloprid, and Thiamethoxam

(a) Applications of clothianidin, dinotefuran, imidacloprid, and thiamethoxam are prohibited during bloom when used on a crop subject to the provisions of this article.
(b) The application of more than one of the following active ingredients to a crop subject to the provisions of this article within the same growing season is prohibited: clothianidin, dinotefuran imidacloprid, thiamethoxam.

(c) The use of more than one application type (soil or foliar) on a crop subject to provisions of this article within the same growing season is prohibited, except as specified in sections YYYY.12 (pome fruits crop group) and YYYY.14 (stone fruits crop group).

Section YYYY.2. Berries and Small Fruits Crop Groups (Crop Groups 13 and 13-07)
(a) If managed pollinators will not be used to pollinate crops in the berries crop groups during the growing season, then the provisions of this section do not apply. However, the general application restrictions in section YYYY.1 must be followed.

(b) Except as provided in subsections (c) and (d), if managed pollinators will be used to pollinate crops in the berries crop groups, applications are prohibited.

(c) Applications to mulberries are not subject to the provisions of this article.

(d) If managed pollinators will be used for grapes during the growing season, the application rate and timing restrictions listed in the following table are required:

Application Rate and Timing Restrictions for Grapes				
Active Ingredient	Soil Application		Foliar Application	
	Maximum Application	Allowed Timing	Maximum Application	Allowed Timing

	Rate		Rate	
Clothianidin	0.2 lbs. ai/A/season	Apply up until bud break	0.1 lbs. ai/A/season	Apply between post-bloom (all flower hoods fallen) and harvest
Dinotefuran	0.2 lbs. ai/A/season	Apply up until bud break	0.1 lbs. ai/A/season	Apply between post-bloom (all flower hoods fallen) and harvest
Imidacloprid	Prohibited		0.1 lbs. ai/A/season	Apply between post-bloom (all flower hoods fallen) and harvest
Thiamethoxam	0.2 lbs. ai/A/season	Apply up until bud break	0.1 lbs. ai/A/season	Apply between post-bloom (all flower hoods fallen) and harvest

The specified application rates are in units of pounds of active ingredient (ai) per acre (A) per growing season. The growing season for grapes is one year.

Section YYYY.3. Bulb Vegetables Crop Groups (Crop Groups 3 and 3-7)
If harvested before bloom, applications to crops in the bulb vegetables crop groups are not subject to the provisions of this article. Otherwise, applications of clothianidin, dinotefuran, imidacloprid, and thiamethoxam to these crops are prohibited.

Section YYYY.4. Cereal Grains Crop Groups (Crop Groups 15 and 16)
(a) If managed pollinators will not be used to pollinate crops in the cereal grains crop groups during the growing season, then the provisions of this section do not apply. However, the general application restrictions in section YYYY.1 must be followed.

(b) Applications to barley, oats, rice, rye, triticale, and wheat are not subject to the provisions of this article.

(c) Except as provided in subsection (b), if managed pollinators will be used to pollinate crops in the cereal grain crop groups during the growing season, the application rate and timing restrictions listed in the following table are required:

Application Rate and Timing Restrictions for Crops in the Cereal Grains Crop Group				
Active Ingredient	Soil Application		Foliar Application	
	Maximum Application Rate	Allowed Timing	Maximum Application Rate	Allowed Timing

Clothianidin	0.18 lbs. ai/A/season	Apply at seed planting	0.126 lbs. ai/A/season	Apply up until heading (inflorescence or tassel emergence)
Dinotefuran	0.18 lbs. ai/A/season	Apply at seed planting	0.126 lbs. ai/A/season	Apply up until heading (inflorescence or tassel emergence)
Imidacloprid	0.18 lbs. ai/A/season	Apply at seed planting	0.126 lbs. ai/A/season	Apply up until heading (inflorescence or tassel emergence)
Thiamethoxam	0.18 lbs. ai/A/season	Apply at seed planting	0.126 lbs. ai/A/season	Apply up until heading (inflorescence or tassel emergence)

The specified application rates are in units of pounds of active ingredient (ai) per acre (A) per growing season. The growing season for cereal grain crops is from planting until harvest.

Section YYYY.5. Citrus Fruit Crop Groups (Crop Groups 10 and 10-10)
(a) Except as provided in subsection (b), for citrus fruit crop groups, the application rate and timing restrictions listed in the following table are required:

Application Rate and Timing Restrictions for Crops in the Citrus Fruit Crop Group				
Active Ingredient	Soil Application		Foliar Application	
	Maximum Application Rate	Allowed Timing	Maximum Application Rate	Allowed Timing
Clothianidin	0.172 lbs. ai/A/season	Apply between petal fall and December 15	0.172 lbs. ai/A/season	Apply after petal fall with the second application no later than December 1
Dinotefuran	0.172 lbs. ai/A/season	Apply between petal fall and January 31	0.172 lbs. ai/A/season	Apply after petal fall with the second application no later than December 1
Imidacloprid	0.086 lbs. ai/A/season	Apply between petal fall and January 31	0.172 lbs. ai/A/season	Apply after petal fall with the second application no later than December 1
Thiamethoxam	0.172 lbs. ai/A/season	Apply between petal fall and January 31	0.172 lbs. ai/A/season	Apply after petal fall with the second application no later than December 1

The specified application rates are in units of pounds of active ingredient (ai) per acre (A) per growing season. The growing season for citrus fruit crops is one year.

(b) Exceptions: All applications are prohibited to indeterminate blooming citrus crops.

Section YYYY.6. Cucurbit Vegetables Crop Group (Crop Group 9)
(a) If managed pollinators will not be used to pollinate crops in the cucurbit vegetables crop group during the growing season, then the provisions of this section do not apply. However, the general application restrictions in section YYYY.1 must be followed.

(b) Except as provided in subsection (c), if managed pollinators will be used to pollinate crops in the cucurbit vegetables crop group during the growing season, the application rate and timing restrictions listed in the following table are required:

Application Rate and Timing Restrictions for Crops in the Cucurbit Vegetables Crop Group				
Active Ingredient	Soil Application		Foliar Application	
	Maximum Application Rate	Allowed Timing	Maximum Application Rate	Allowed Timing
Clothianidin	0.2 lbs. ai/A/season	Apply up until primary side shoot formation	0.2 lbs. ai/A/season	Apply up until bloom
Dinotefuran	0.536 lbs. ai/A/season	Apply up until first flower open on main stem	0.172 lbs. ai/A/season	Apply up until bloom
Imidacloprid	0.2 lbs. ai/A/season	Apply up until primary side shoot formation	0.172 lbs. ai/A/season	Apply up until bloom
Thiamethoxam	0.172 lbs. ai/A/season	Apply up until fifth true leaf on main stem unfolded	0.172 lbs. ai/A/season	Apply up until bloom

The specified application rates are in units of pounds of active ingredient (ai) per acre (A) per growing season. The growing season for cucurbit vegetable crops is from planting until harvest.

(c) Exceptions: If managed pollinators will be used for cucumbers during the growing season, then foliar applications of either dinotefuran, imidacloprid, or thiamethoxam are prohibited.

Section YYYY.7. Fruiting Vegetables Crop Groups (Crop Groups 8 and 8-10)
(a) If managed pollinators will not be used to pollinate crops in the fruiting vegetables crop groups during the growing season, then the provisions of this section do not apply. However, the general application restrictions in section YYYY.1 must be followed.

(b) Except as provided in subsection (c), if managed pollinators will be used to pollinate crops in the fruiting vegetables crop groups during the growing season, the application rate and timing restrictions listed in the following table are required:

Application Rate and Timing Restrictions for Crops in the Fruiting Vegetables Crop Group				
Active Ingredient	Soil Application		Foliar Application	
	Maximum Application Rate	Allowed Timing	Maximum Application Rate	Allowed Timing
Clothianidin	0.172 lbs. ai/A/season	Apply up until third leaf on main shoot unfolded	Prohibited	
Dinotefuran	0.172 lbs. ai/A/season	Apply up until third leaf on main shoot unfolded	Prohibited	
Imidacloprid	Prohibited		Prohibited	
Thiamethoxam	0.172 lbs. ai/A/season	Apply up until third leaf on main shoot unfolded	Prohibited	

The specified application rates are in units of pounds of active ingredient (ai) per acre (A) per growing season. The growing season for fruiting vegetable crops is from planting until harvest.

(c) Exceptions: If managed pollinators will be used for peppers, goji berry, ground cherry, martynia, okra, roselle, or tomatillo during the growing season, then soil applications are prohibited.

Section YYYY.8. Herbs and Spices Crop Group (Crop Group 19)
If harvested before bloom, applications to crops in the herbs and spices crop group are not subject to the provisions of this article. Otherwise, applications of clothianidin, dinotefuran, imidacloprid, and thiamethoxam to these crops are prohibited.

Section YYYY.9. Leafy Vegetables Including Brassica (Cole) Crop Groups (Crop Groups 4, 4-16, 5, 5-16 and 22)

If harvested before bloom, applications to crops in the leafy vegetables, brassica (cole), stalk, and stem crop groups are not subject to the provisions of this article. Otherwise, applications of clothianidin, dinotefuran, imidacloprid, and thiamethoxam to these crops are prohibited.

Section YYYY.10. Legume Vegetables Crop Groups (Crop Groups 6 and 7)
(a) If managed pollinators will not be used to pollinate crops in the legume vegetables crop groups during the growing season, then the provisions of this section do not apply. However, the general application restrictions in section YYYY.1 must be followed.

(b) If managed pollinators will be used to pollinate crops in the legume vegetables crop group during the growing season, then applications of clothianidin, dinotefuran, imidacloprid, and thiamethoxam are prohibited.

Section YYYY.11. Oilseed Crop Group (Crop Group 20)
(a) If managed pollinators will not be used to pollinate crops in the oilseed crop group during the growing season, then the provisions of this section do not apply. However, the general application restrictions in section YYYY.1 must be followed.

(b) If managed pollinators will be used to pollinate crops in the oilseed crop group during the growing season, the application rate and timing restrictions listed in the following table are required:

Application Rate and Timing Restrictions for Crops in the Oilseed Crop Group				
Active Ingredient	Soil Application		Foliar Application	
	Maximum Application Rate	Allowed Timing	Maximum Application Rate	Allowed Timing
Clothianidin	Prohibited		Prohibited	
Dinotefuran	Prohibited		Prohibited	
Imidacloprid	Prohibited		0.25 lbs. ai/A/season	Apply before the beginning of main stem elongation
Thiamethoxam	Prohibited		Prohibited	

The specified application rates are in units of pounds of active ingredient (ai) per acre (A) per growing season. The growing season for oilseed crops is from planting until harvest.

Section YYYY.12. Pome Fruits Crop Groups (Crop Groups 11 and 11-10)
(a) Except as provided in subsection (b), for crops in the pome fruit crop groups, the application rate and timing restrictions listed in the following table are required:

Application Rate and Timing Restrictions for Crops in the Pome Fruit Crop Groups				
Active Ingredient	Soil Application		Foliar Application	
	Maximum Application Rate	Allowed Timing	Maximum Application Rate	Allowed Timing
Clothianidin	0.38 lbs. ai/A/season	Between post bloom and harvest	0.2 lbs. ai/A/season	Between post-bloom and harvest
Dinotefuran	0.38 lbs. ai/A/season	Between post-bloom and harvest	0.2 lbs. ai/A/season	Between post-bloom and harvest
Imidacloprid	0.38 lbs. ai/A/season	Between post-bloom and harvest	0.2 lbs. ai/A/season	Between post-bloom and harvest
Thiamethoxam	0.38 lbs. ai/A/season	Between post-bloom and harvest	0.2 lbs. ai/A/season	Between post-bloom and harvest

The specified application rates are in units of pounds of active ingredient (ai) per acre (A) per growing season. The growing season for pome fruit crops is one year.

(b) If soil and foliar applications are used on the same crop in the same growing season:
(1) A maximum amount of 0.5 lbs. ai/A/season can be applied;
(2) Foliar application rates cannot exceed 0.12 lbs. ai/A/season; and
(3) Foliar and soil applications may only be made between post-bloom and harvest.

Section YYYY.13. Root and Tuber Vegetables Crop Groups (Crop Groups 1 and 2)
(a) If managed pollinators will not be used to pollinate crops in the root and tuber vegetables crop groups during the growing season, then the provisions of this section do not apply. However, the general application restrictions in section YYYY.1 must be followed.

(b) Applications to cassava are not subject to the provisions of this article.
(c) If any of the following crops will be harvested before bloom, then the provisions of this article do not apply: artichokes, carrots, chicory roots, sugar beets, turnip, turnip-rooted chervil, turnip-rooted parsley, parsnip, radish, rutabaga, and skirret.
(d) Except as provided in subsections (b) and (c), if managed pollinators will be used to pollinate crops in the root and tuber vegetables crop groups during the growing season, the application rate and timing restrictions listed in the following table are required:

Application Rate and Timing Restrictions for Crops in the Root and Tuber Vegetables Groups				
Active Ingredient	Soil Application		Foliar Application	
	Maximum Application Rate	Allowed Timing	Maximum Application Rate	Allowed Timing
Clothianidin	0.2 lbs. ai/A/season	One application at seed or tuber planting	0.05 lbs. ai/A/season	One application before the beginning of main stem elongation or crop cover
Dinotefuran	0.2 lbs. ai/A/season	One application at seed or tuber planting	0.05 lbs. ai/A/season	One application before the beginning of main stem elongation or crop cover
Imidacloprid	Prohibited		0.05 lbs. ai/A/season	One application before the beginning of main stem elongation or crop cover
Thiamethoxam	0.2 lbs. ai/A/season	One application at seed or tuber planting	0.05 lbs. ai/A/season	One application before the beginning of main stem elongation or crop cover

The specified application rates are in units of pounds of active ingredient (ai) per acre (A) per growing season. The growing season for root and tuber vegetable crops is from planting until harvest.

Section YYYY.14. Stone Fruits Crop Groups (Crop Groups 12 and 12-12)
(a) Except as provided in subsections (b) and (c), for crops in the stone fruit crop groups, the application rate and timing restrictions listed in the following table are required:

Application Rate and Timing Restrictions for Crops in the Stone Fruits Crop Groups

Active Ingredient	Soil Application		Foliar Application	
	Maximum Application Rate	Allowed Timing	Maximum Application Rate	Allowed Timing
Clothianidin	0.38 lbs. ai/A/season	Between post-bloom and harvest	0.2 lbs. ai/A/season	Between post-bloom and harvest
Dinotefuran	0.38 lbs. ai/A/season	Between post-bloom and harvest	0.54 lbs. ai/A/season	Between post-bloom and harvest
Imidacloprid	0.38 lbs. ai/A/season	Between post-bloom and harvest	0.5 lbs. ai/A/season	Between post-bloom and harvest
Thiamethoxam	0.38 lbs. ai/A/season	Between post-bloom and harvest	0.172 lbs. ai/A/season	Between post-bloom and harvest

The specified application rates are in units of pounds of active ingredient (ai) per acre (A) per growing season. The growing season for stone fruit crops is for 1 year.

(b) If soil and foliar applications are used on the same crop in the same growing season:
(1) A maximum amount of 0.5 lbs. ai/A/season can be applied;
(2) Foliar application rates cannot exceed 0.12 lbs. ai/A/season; and
(3) Foliar and soil applications may only be made between post-bloom and harvest.

(c) Exceptions: Soil applications of either clothianidin or imidacloprid are prohibited on peaches.

Section YYYY.15. Tree Nuts Crop Groups (Crop Groups 14 and 14-12)
(a) Except for almonds, if managed pollinators will not be used to pollinate crops in the tree nuts crop groups during the growing season, then the provisions of this section do not apply. However, the general application restrictions in section YYYY.1 must be followed.

(b) Applications to pistachio, beechnut, gingko and pecans are not subject to the provisions of this article.

(c) For almonds, and if managed pollinators will be used to pollinate other crops in the tree nuts crop groups during the growing season, the application rate and timing restrictions listed in the following table are required:

Application Rate and Timing Restrictions for Crops in the Tree Nuts Crop Groups				
Active Ingredient	Soil Application		Foliar Application	
	Maximum Application Rate	Allowed Timing	Maximum Application Rate	Allowed Timing
Clothianidin	Prohibited		0.2 lbs. ai/A/season	Apply between post-bloom and harvest
Dinotefuran	Prohibited		0.2 lbs. ai/A/season	Apply between post-bloom and harvest
Imidacloprid	Prohibited		0.2 lbs. ai/A/season	Apply between post-bloom and harvest
Thiamethoxam	Prohibited		0.2 lbs. ai/A/season	Apply between post-bloom and harvest

The specified application rates are in units of pounds of active ingredient (ai) per acre (A) per growing season. The growing season for tree nut crops is for one year.

Section YYYY.16. Tropical and Subtropical Fruit, Edible and Inedible Peel Crop Groups (Crop Groups 23 and 24)
(a) If managed pollinators will not be used to pollinate crops in the tropical and subtropical fruit (edible and inedible peel) crop groups during the growing season, then the provisions of this section do not apply. However, the general application restrictions in section YYYY.1 must be followed.

(b) If managed pollinators will be used to pollinate crops in the tropical and subtropical fruit (edible and inedible peel) crop groups during the growing season, then applications of clothianidin, dinotefuran, imidacloprid, and thiamethoxam are prohibited.
Section YYYY.17. Miscellaneous Crops
(a) *Coffee and peanuts.*
(1) If managed pollinators will not be used to pollinate coffee or peanuts during the growing season, then the provisions of this section do not apply. However, the general application restrictions in section YYYY.1 must be followed.

(2) If managed pollinators will be used during the growing season to pollinate coffee or peanuts, then applications of clothianidin, dinotefuran, imidacloprid, and thiamethoxam are prohibited.

(b) *Globe artichoke, hops, mint, and tobacco.* If the following crops will be harvested before bloom, then the provisions of this article do not apply: globe artichoke, hops (female plants only), mint, and tobacco. Otherwise, applications of clothianidin, dinotefuran, imidacloprid, and thiamethoxam are prohibited.