An Economic and Pest Management Evaluation of the Insecticide Imidacloprid in California Agriculture

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

Rachael Goodhue[1], Brian Gress[1,2], Yanan Zheng[1], Sam Raburn[1], Ashley Spalding[1], Kevi Mace[1,2]

[1] Department of Agricultural and Resource Economics, University of California, Davis, CA 95616
[2]California Department of Food and Agriculture, Office of Pesticide Consultation and Analysis, Office of Environmental Farming and Innovation, Sacramento, CA 95814

Executive Summary

A formal review of the insecticide imidacloprid was initiated by the California Department of Pesticide Regulation (DPR) as required by the Pesticide Contamination Prevention Act (PCPA) due to its detection in groundwater. The purpose of this formal review is to determine whether imidacloprid can continue to be used and, if so, under what conditions. In this report we evaluate the potential economic and pest management impacts of a ban on the agricultural use of imidacloprid in designated Ground Water Protection Areas (GWPAs) for four focal crop groups: citrus, cole crops (*Brassica* genus), grape, and lettuce. These crops accounted for approximately 75% of statewide acres treated with imidacloprid in GWPAs from 2018-2020 and approximately 85% of use as measured by pounds of active ingredient (AI) applied. They also accounted for 32% of the value of California's field crop, fruit, nut, vegetable, and melon production in 2019 (CDFA 2020).

Table ES-1 reports losses within GWPAs by focal crop group based on historical use data. Over the three-year period, total annual losses averaged $4,393,906. Of this, grape (wine, table, and raisin) accounted for the largest share, roughly 61%. These values account only for losses that resulted from the material and application costs of switching to imidacloprid alternatives.

Table ES-1. Losses in $ in Statewide GWPAs by Focal Crop and Year

Year	Citrus	Cole Crops	Grape	Lettuce	Total
2018	1,435,546	154,651	2,975,263	158,596	**4,724,056**
2019	1,347,722	149,772	2,610,669	130,783	**4,238,946**
2020	1,459,466	136,845	2,489,791	132,614	**4,218,716**
Annual Average	**1,414,245**	**147,089**	**2,691,908**	**140,664**	**4,393,906**

Source: California Department of Food and Agriculture, California Agricultural Statistical Review 2019-2020

Citrus. Citrus – specifically grapefruit, lemon, orange, mandarin, and their hybrids – constitute one of California's top ten most economically important commodities by value, with $2.1 billion in gross revenues in 2019 (CDFA 2020). Within GWPAs, citrus is the number one and number two crop-user of imidacloprid as measured by pounds of active ingredient (AI) applied and acres treated, respectively. Between 2018 and 2020, GWPAs accounted for 34.9-37.3% of all imidacloprid pounds applied to citrus statewide and 34.9-36.7% of all citrus acres treated with imidacloprid. Imidacloprid is used to manage glassy-winged sharpshooter (GWSS), citricola scale, citrus leafminer, Fuller rose beetle, and Asian citrus psyllid (ACP). It is 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 devastating. In addition, imidacloprid is part of the area-wide programs for managing GWSS in citrus. Most importantly, imidacloprid is a vital component of ACP control programs for commercial and residential citrus. The loss of imidacloprid within GWPAs would increase the rate of spread of huanglongbing (HLB, or citrus greening disease), the deadly bacterial disease vectored by ACP, and jeopardize the entire industry. Economic losses from widespread HLB would be significant but are not estimated in this analysis. The annual pesticide material and application cost increase associated with switching to imidacloprid alternatives within GWPAs was estimated to be $1.348 million to $1.459 million.

Cole crops. Cole crops included in this study were those within the *Brassica* genus, most notably broccoli, cabbages, and cauliflower. In 2019, this crop group generated more than $1.4 billion in gross revenues (CDFA 2020). Within GWPAs, cole crops together were the third-highest user of imidacloprid as measured by both pounds of AI applied and acres treated. Between 2018 and 2020, GWPAs accounted for 11.2-11.9% of all imidacloprid pounds applied to cole crops statewide and 10.2-11.6% of all acres treated with imidacloprid. Imidacloprid is primarily used to manage aphids, garden symphylans, and springtails. Alternatives are available for each of these pests but are more expensive. The associated annual cost increase of using imidacloprid alternatives within GWPAs was estimated to be $0.137 million to $0.155 million.

Grape. Grape is California's third largest agricultural commodity by value of production, with gross revenues of $5.4 billion in 2019 (CDFA 2020). There are three categories of grape production in California: wine, raisin, and table. Together, these crops ranked second in terms of pounds of imidacloprid applied in GWPAs and first as measured by acres treated. Between 2018 and 2020, GWPAs accounted for 15.7-18.3% of all imidacloprid pounds applied to grape statewide and 20.9-21.4% of all grape acres treated with imidacloprid. Imidacloprid is primarily used to manage mealybugs, sharpshooters, leafhoppers, and grape phylloxera. Alternatives are available for vine mealybug, sharpshooters, and leafhoppers but are more expensive; however, no good alternatives are available for grape phylloxera. The associated annual cost increase of using imidacloprid alternatives in GWPAs was estimated to range from $2.490 million to $2.975 million.

Lettuce. Lettuce is the eighth-most valued crop produced in California, with $1.3 billion in gross revenues in 2019 (CDFA 2020). There are three categories of lettuce production in California: head, leaf, and romaine. Within GWPAs, lettuce is the fourth-highest user of imidacloprid as measured by pounds applied and the fifth-highest user by acres treated. Between 2018 and 2020, GWPAs accounted 5.1-6.5% of all imidacloprid pounds applied to lettuce statewide and 6.3-6.8% of all lettuce acres treated with imidacloprid. Imidacloprid is primarily used to manage aphids, garden symphylans, and springtails. Alternatives are available for each of these pests but are more expensive. The associated annual cost increase of using imidacloprid alternatives within GWPAs was estimated to be $0.131 million to $0.159 million.

There are a number of caveats regarding the estimates in this report. First, the net revenue loss estimates are not comprehensive estimates for California agriculture; the crops examined account for 32% of California's field crop, fruit, nut, vegetable and melon production and 75% of acreage treated with imidacloprid in GWPAs. Second, the analysis uses historical data from 2018-2020, the three most recent years of data available. There may have been notable changes in pesticide use since then that altered the use of imidacloprid or alternative AIs. Third, growers' land allocation decisions could change the use of specific AIs by altering the acreage planted in different crops. Fourth, new regulations may change the availability of alternative AIs, or new AIs (or new uses for existing AIs) could be registered in California. Fifth, invasive species may increase the cost of banning imidacloprid in GWPAs. Finally, the development of pest resistance to AIs can increase the cost of the ban by reducing the available set of modes of action. Using alternatives that are efficacious for target pests currently managed with imidacloprid may limit their availability for controlling other pests. This could reduce yields, increase pest management costs, or both.

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Introduction

A formal review of imidacloprid has been initiated by the Department of Pesticide Regulation (DPR) as required by the Pesticide Prevention Contamination Act (PCPA) due to its detection in groundwater from legal agricultural use. The purpose of the formal review process is to determine whether imidacloprid can continue to be used and, if so, under what conditions. In this report we evaluate the potential economic and pest management impacts of a ban on the agricultural use of imidacloprid in designated Groundwater Protection Areas (GWPAs). This report is part of the interagency consultation between DPR and the Office of Pesticide Consultation and Analysis (OPCA) in the California Department of Food and Agriculture (CDFA). Accordingly, the analysis is limited to OPCA's mandate, which is to evaluate the economic effects of regulations regarding pesticides being considered by DPR (California Food & Agricultural Code, Section 11454.2).

The report focuses on four crops/crop groups that are significant users of imidacloprid in GWPAs: grape, citrus, cole (specifically those in the *Brassica* genus), and lettuce crop groups. Together, they accounted for the majority of imidacloprid use in GWPAs from 2018-2020, as defined by either acres treated or pounds applied. Grape production alone accounts for 42% of acres treated with imidacloprid and 39% of pounds applied during this period.

The report is organized as follows. Background information on imidacloprid and its detection in California groundwater is provided prior to an overview of the PCPA regulatory process. Study methodology and an analysis of imidacloprid use in GWPAs from 2018-2020 follow. The report then provides crop-specific information on the role that imidacloprid plays in integrated pest management (IPM) programs and possible alternative insecticides that would be available in its absence, followed by the economic analysis for that crop.

Background

Imidacloprid is a nitroguanidine-substituted neonicotinoid (NGN) insecticide that attacks the central nervous system of insects by blocking acetylcholine receptors (Le Goff and Giraudo 2019). Its systemic properties make it effective for controlling a wide range of piercing-sucking insect pests including lygus bug, mealybugs, psyllids, sharpshooters, aphids and whiteflies as well as some chewing pests such as caterpillars and soil-dwelling arthropods (Elbert et al. 2008; Jeschke et al. 2010). In California, imidacloprid is registered for use on many agricultural crop groups, though grape, tomato, cotton, lettuce, citrus, and cole crops (*Brassica* genus) account for nearly three-quarters of all acres treated with this material from 2018-2020 (Figure 1). Imidacloprid is also widely used for residential purposes including in backyard gardens and to control indoor pests, though these uses are not subject to the PCPA review process. Over the past decade, agricultural use of imidacloprid steadily increased from 2010 until 2018, after which both pounds applied and acres treated with this active ingredient (AI) began to decline (Figure 2). Imidacloprid is commonly applied both as a foliar spray and directly to the soil via chemigation or sprays. It is also used as a seed treatment product, but information regarding its use for this purpose is not available, and these applications are not under review in the current PCPA process. DPR is conducting a separate re-evaluation of imidacloprid and three other NGNs – clothianidin, dinotefuran, and thiamethoxam – concurrent with this regulatory process (CDPR 2020a). Revised regulations focused on mitigating harm to managed pollinators may alter the potential for imidacloprid to be detected in groundwater if they impact use substantially.

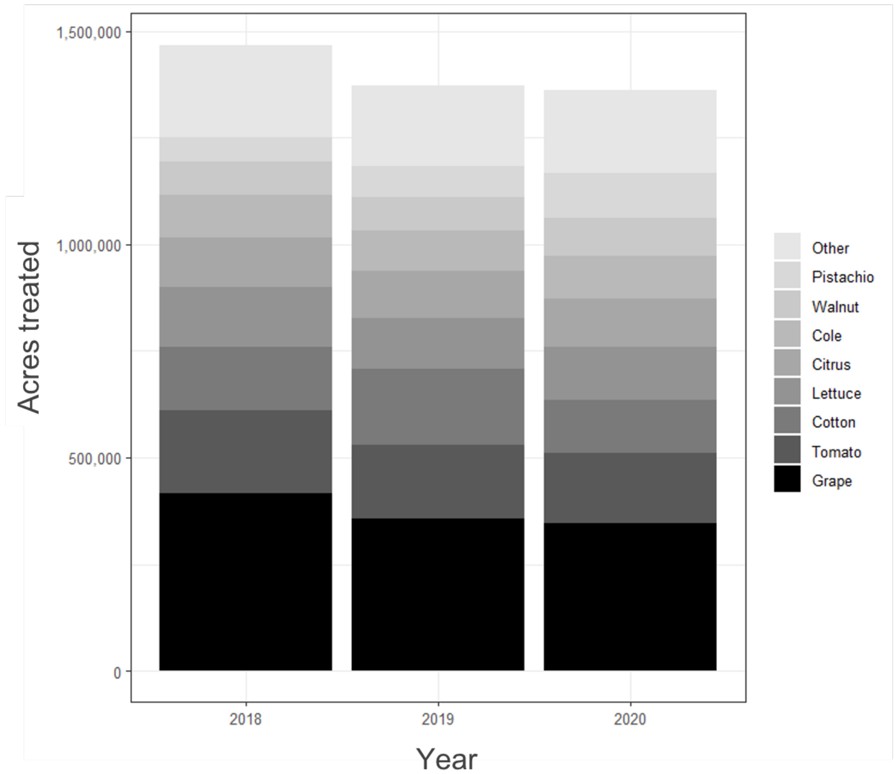

Figure 1. Acres treated statewide with imidacloprid by crop: 2018-2020

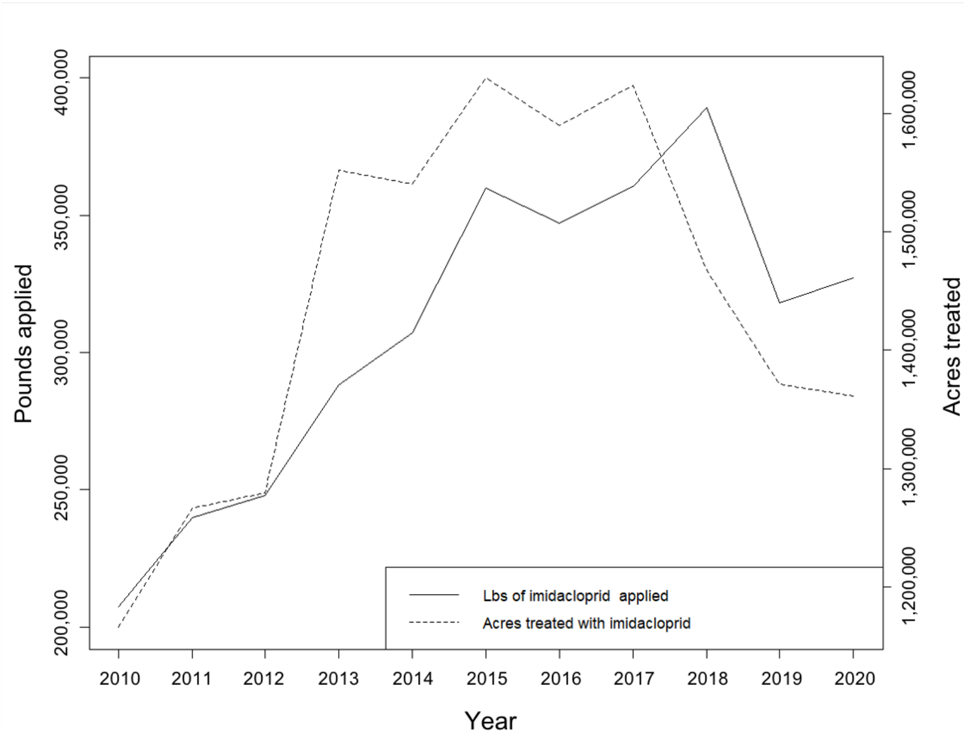

Figure 2. Statewide imidacloprid use: 2010-2020

There are alternatives for most uses of imidacloprid in the focal crops addressed here. Alternatives often include other neonicotinoids such as acetamiprid, clothianidin, dinotefuran, and thiamethoxam; however an ongoing NGN re-evaluation process at DPR will lead to additional restrictions on the use of clothianidin, dinotefuran, and thiamethoxam. Sulfoxaflor, another common alternative of imidacloprid, is the subject of two lawsuits, one stemming from the EPA registration processes and another from the DPR registration process. Accordingly, sulfoxaflor may also be unavailable for future use. For some pests, pyrethroid insecticides are alternatives; however, pyrethroids are one class of pesticides targeted for more stringent controls in Ag Order 4.0 (Central Coast RWQCB 2021). As monitoring and other aspects of Ag Order 4.0 go into effect, pyrethroid use is also likely to be curtailed in certain areas. There are several newer insecticides that can be alternatives to imidacloprid depending on the pest, including spirotetramat and chlorantraniliprole. Alternatives are covered in detail in the crop sections below.

One critical use of imidacloprid that does not have viable alternatives is its use against Asian citrus psyllid (ACP). ACP 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 70% and is threatening the California citrus industry. Imidacloprid is used for ACP control for multiple reasons: 1) 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 by nurseries to provide long-term protection of nursery stock going to retail nurseries, and 3) as a foliar spray, 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. Outside of agriculture, it is one of only two tools available for treating ACP in residential citrus trees. It is commonly used in the HLB quarantine areas where treatments of residential and commercial citrus with systemic insecticides are mandatory. Without imidacloprid, it is likely that HLB will spread at a much faster rate in the state, putting into jeopardy the $2 billion/year citrus industry, as well as jeopardizing backyard citrus, which in L.A. County alone is present in ~ 70% of residential properties.

Imidacloprid is included on DPR's Ground Water Protection List due to its mobility and persistence in soil, and because it can be applied directly to the soil via sprays or chemigation. Imidacloprid's ability to move through soil is due to its high water solubility ($\bar{x}$ = 514 mg/L) and low tendency for absorption to soil particles (mean K_{oc} = 262 cm^3/g) (CDPR 2020b). It is classified as persistent in the environment due to a mean hydrolysis half-life of greater than 30 days, mean aerobic soil metabolism half-life of 997 days, and mean anaerobic soil metabolism half-life of 27 days (CDPR 2020b). However, field studies have shown that numerous factors including product formulation and soil type, as well as the use of cover crops and organic fertilizers, can affect imidacloprid's ability to persist and move through soil. For example, Sarkar et al (1999) found that wettable powder formulations increased the hydrolysis half-life by three to six days versus liquid formulations, while Gupta et al (2002) similarly found that wettable powder formulations had the greatest leaching potential. Additionally, Scholz and Spiteller (1992) demonstrated that the use of cover crops reduced imidacloprid's soil half-life from 190 days to 40 days, while Sarkar et al. (2001) found that persistence increased with soil pH. Nevertheless, these studies demonstrate the potential for imidacloprid to contaminate groundwater and have led to its inclusion in DPR's groundwater monitoring program.

Groundwater Protection Areas

GWPAs place restrictions on the use of certain labile and persistent pesticides that have previously been detected in California's groundwater. These pesticides are found on the 6800(a) list and are considered restricted materials in GWPAs. High-risk areas for contamination are identified based on previous pesticide detections, soil type, and the depth to groundwater. GWPAs are further subdivided into areas that are prone to contamination either through leaching or runoff. Growers located in these areas are required to obtain a permit and file a Notice of Intent prior to using a 6800(a) listed material, in addition to implementing a DPR-approved mitigation option. The mitigation options available to growers differ between leaching and runoff areas. Figure 3 maps the location of GWPAs and imidacloprid groundwater exceedances throughout the state.

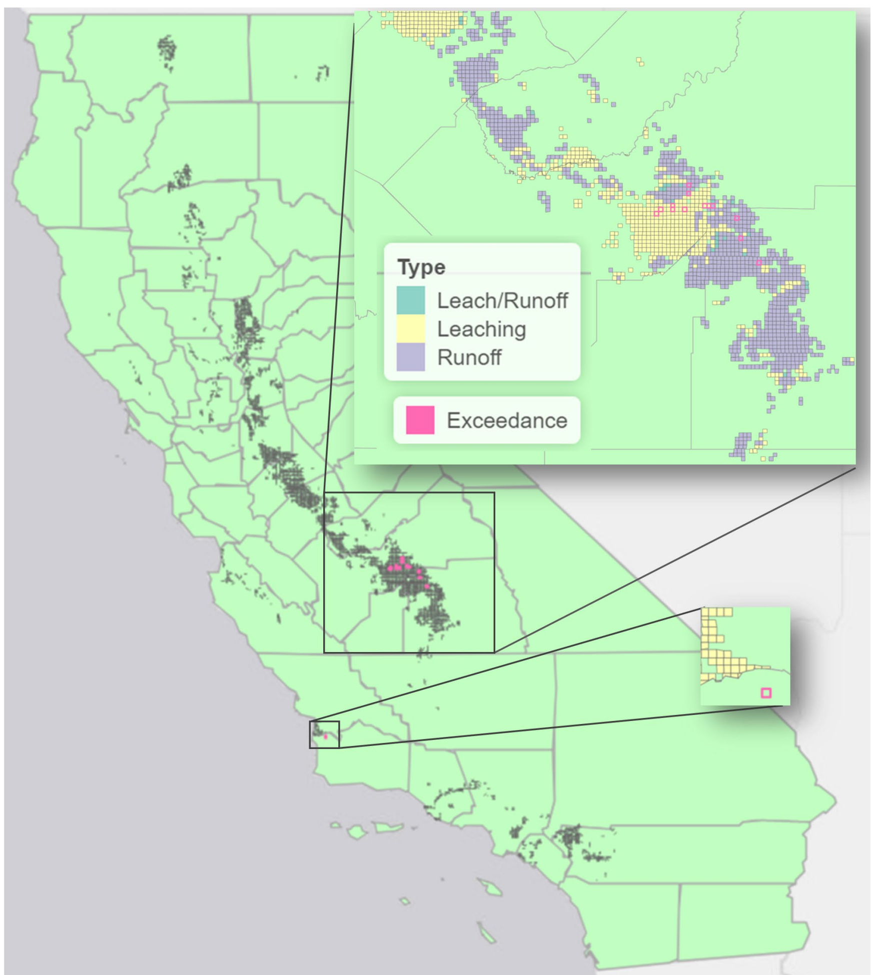

Figure 3. Location of Ground Water Protection Areas and imidacloprid exceedances in California. Squares represent 1 mi x 1 mi sections that contain a GWPA and/or an exceedance.

Regulatory Process

DPR detected imidacloprid residues in excess of the 0.05 parts per billion limit in fourteen groundwater wells in Fresno and Tulare counties and one well in Santa Barbara county (Figure 3). Exceedances ranged from 0.051 to 5.97 ppb. Of these detections, only the Santa Barbara well was located outside of a GWPA (Figure 3). DPR concluded that all detections were the result of legal agricultural use (CDPR 2021a). Under the Pesticide Contamination Prevention Act, the confirmed detection of a pesticide active ingredient or degradation product in groundwater from legal agricultural use triggers a formal review process. The formal review process determines whether or not the pesticide can continue to be used and, if so, under what conditions.

The formal review process has three steps. First, DPR provides the product registrant with a formal notice. The product's registration will be cancelled unless the registrant requests a public hearing and provides the mandated report and documentation detailed in Food and Agriculture Code (FAC) 13150 for public comment. Second, a public hearing before DPR's Pesticide Registration and Evaluation Committee subcommittee is conducted. The subcommittee includes one member each from DPR, Office of Environmental Health Hazard Assessment, and State Water Resources Control Board (SWRCB). Third, within 30 days after the public hearing, the subcommittee meets to deliberate on a recommendation to the DPR Director. As specified in FAC 13150(c), there are three possible recommendations:

(1) *That the ingredient found in the soil or groundwater has not polluted, and does not threaten to pollute, the groundwater of the state.*

(2) *That the agricultural use of the pesticide can be modified so that there is a high probability that the pesticide would not pollute the groundwater of the state.*

(3) *That modification of the agricultural use of the pesticide pursuant to paragraph (2) or cancellation of the pesticide will cause severe economic hardship on the state's agricultural industry, and that no alternative products or practices can be effectively used so that there is a high probability that pollution of the groundwater of the state will not occur. The subcommittee shall recommend a level of the pesticide that does not significantly diminish the margin of safety recognized by the subcommittee to not cause adverse health effects.*

When the subcommittee makes a finding pursuant to paragraph (2) or this paragraph (3), it shall determine whether the adverse health effects of the pesticide are carcinogenic, mutagenic, teratogenic, or neurotoxic.

Under FAC 13150(d), the DPR director can respond in four possible ways to the recommendation:

(1) *Concurs with the subcommittee finding pursuant to paragraph (1) of subdivision (c).*

(2) *Concurs with the subcommittee finding pursuant to paragraph (2) of subdivision (c), and adopts modifications that result in a high probability that the pesticide would not pollute the groundwaters of the state.*

(3) Concurs with the subcommittee findings pursuant to paragraph (3) of subdivision (c), or determines that the subcommittee finding pursuant to paragraph (2) of subdivision (c) will cause severe economic hardship on the state's agricultural industry. In either case, the director shall adopt the subcommittee's recommended level or shall establish a different level, provided the level does not significantly diminish the margin of safety to not cause adverse health effects.

(4) Determines that, contrary to the finding of the subcommittee, no pollution or threat to pollution exists. The director shall state the reasons for his or her decisions in writing at the time any action is taken, specifying any differences with the subcommittee's findings and recommendations. The written statement shall be transmitted to the appropriate committees of the Senate and Assembly, the State Department of Health Services, and the board.

When the director takes action pursuant to paragraph (2) or (3), he or she shall determine whether the adverse health effects of the pesticide are carcinogenic, mutagenic, teratogenic, or neurotoxic.

According to DPR's notice 2021-08, issued September 23, 2021, 125 of the 253 pesticide products registered in California (as of 9/10/21) containing imidacloprid were selected to be included in the current review process based on their potential for agricultural use (CDPR 2021b). On September 23, 2021, DPR notified these registrants of imidacloprid detections in groundwater and the legal agricultural use determination. Registrants had the opportunity to request a hearing with an October 25 deadline for making the request. On September 27, an imidacloprid registrant requested a hearing. Official notices, including the determination that legal agricultural use was the source of detections, and other materials are available on DPR's website.[1]

[1] See https://www.cdpr.ca.gov/docs/emon/grndwtr/imidacloprid.htm .

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.

Imidacloprid Use and Focal Crop Selection

Based on their economic importance and large share of imidacloprid use in GWPAs, we selected four focal crops/crop groups. Individual crops within groups are biologically similar and use imidacloprid to manage the same or virtually the same pests. The first focal crop is grape, which is separated into wine grape and grape in the Pesticide Use Reporting (PUR) database. The second focal crop group is citrus, which contains PUR-designated crop classifications including citrus, grapefruit, lemon, lime, orange, pomelo, tangelo, and tangerine. The third is cole crops from the genus *Brassica*, which includes bok choy, broccoli, Brussels sprout, cabbage, Chinese broccoli (gai lon), Chinese cabbage (nappa), cauliflower, collard, gai lon, kale, kohlrabi, mustard, mustard greens, rapini, and turnip. The fourth is lettuce, which includes head, leaf and romaine.

Of California's $37.38 billion in value of crop production in 2019, the four focal crops accounted for $10.19 billion, or 27.3%. Grape (raisin, table and wine) was the largest of the four, totaling $5.412 billion. Citrus accounted for an additional $2.124 billion.

Each of the four focal crop groups are top users of imidacloprid statewide and together account for approximately half of all acreage treated with this AI, ranging from 50% to 53% depending on the year (Figure 1). These same crop groups also account for a majority of pounds of imidacloprid applied statewide, ranging from 59 to 63% annually. The focal crops are similarly significant users of imidacloprid within GWPAs. Table 1 reports acreage treated and pounds of imidacloprid applied to each crop group both within and outside of GWPAs as well as use not accounted for by our focal crops. Together, these crop groups accounted for 84% to 87% of pounds applied and 72% to 77% of acres treated with imidacloprid in GWPAs depending on the year. Of the focal crops, citrus had the greatest share of its statewide imidacloprid use applied within GWPAs (34.9% to 37.3% of pounds applied and 34.9% to 36.7% of acres treated), while lettuce had the least (5.1% to 6.5% of pounds applied and 6.3% to 6.8% of acres treated; Table 1).

Table 1. Imidacloprid Use within and outside Ground Water Protection Areas by Crop: 2018-2020

	Year	GWPAs		Outside GWPAs		Total		% within GWPAs	
		lbs	acres	lbs	acres	lbs	acres	lbs	acres
Citrus	2018	18,988	41,495	34,033	74,344	53,021	115,839	35.8	35.8
	2019	18,324	38,957	34,120	72,530	52,444	111,486	34.9	34.9
	2020	19,652	42,187	33,023	72,688	52,675	114,875	37.3	36.7
Cole	2018	2,532	11,555	18,850	90,458	21,381	102,013	11.8	11.3
	2019	2,686	11,014	19,853	83,932	22,539	94,947	11.9	11.6
	2020	2,546	10,188	20,087	89,653	22,633	99,841	11.2	10.2
Grape	2018	18,994	87,123	102,175	330,006	121,169	417,129	15.7	20.9
	2019	18,003	76,463	85,322	281,270	103,325	357,733	17.4	21.4
	2020	19,524	72,752	87,273	272,363	106,797	345,116	18.3	21.1
Lettuce	2018	1,323	9,524	19,019	131,553	20,342	141,077	6.5	6.8
	2019	1,183	7,774	21,965	111,149	23,148	118,923	5.1	6.5
	2020	1,198	7,779	20,798	115,679	21,996	123,458	5.4	6.3
Other	2018	7,982	50,652	140,238	640,539	148,220	691,191	5.4	7.3
	2019	7,304	50,987	111,713	637,209	119,017	688,196	6.1	7.4
	2020	6,192	40,667	116,773	637,442	122,965	678,109	5.0	6.0
All	**2018**	**49,819**	**200,349**	**314,314**	**1,266,900**	**364,133**	**1,467,250**	**13.7**	**13.7**
	2019	**47,500**	**185,194**	**272,972**	**1,186,090**	**320,473**	**1,371,285**	**14.8**	**13.5**
	2020	**49,112**	**173,574**	**277,955**	**1,187,825**	**327,067**	**1,361,399**	**15.0**	**12.7**

Citrus: Citrus, Grapefruit, Lemon, Lime, Orange, Pomelo, Tangelo, and Tangerine
Cole: Bok Choy, Broccoli, Brussels Sprout, Cabbage, Chinese Broccoli (Gai Lon), Chinese Cabbage (Nappa), Cauliflower, Cole Crop, Collard, Gai Lon, Kale, Kohlrabi, Mustard, Mustard Greens, Rapini, and Turnip
Grape: Grape, Wine and Grape
Lettuce: Lettuce, Leaf and Lettuce, Head

Pesticide Use Data

Following Steggall et al. (2018), we obtained the amount of active ingredient and treated acreage from the PUR database for imidacloprid and alternative active ingredients. All agricultural imidacloprid use was included in our analysis since the PCPA process is focused on all imidacloprid products with the potential for agricultural use. Because the PUR does not include the target pest(s) for an application, identifying alternatives requires knowing what growers are generally targeting with imidacloprid and alternative AIs for a given crop, along with reasons imidacloprid use varies temporally within a year or across years. Using consultations with pest control advisors, growers, industry members, University of California Cooperate Extension personnel, and our own knowledge of pest management for the focal crops, we identify target pests and alternative AIs for managing those pests for each focal crop.

Economic Analysis

In order to estimate the cost of the ban, we compare the cost of managing the target pests with and without imidacloprid being available. We assume that no imidacloprid products will be available for agricultural use. We then construct a composite alternative of what growers would apply if imidacloprid was banned. The composite alternative is a weighted average of the use of each alternative AI within GWPAs, where the weights are shares of total acreage treated with any alternative AI over the 2018-2020 period. For each crop we identified a representative pesticide product for each AI to use when determining the cost of the ban. In most instances, the representative product was the one applied to the most acres of that crop in the 2018-2020 study period. Product prices were collected from online retailers or from agricultural product vendors, manufacturers, or growers with the agreement that they would remain anonymous.

The economic analysis uses a partial budgeting approach, meaning we consider only changes in costs and revenues due to using an alternative to imidacloprid. Using application rates and the representative product prices we calculate the cost per acre of each AI. We then construct the cost of the composite alternative per acre. We identify the affected acreage as all acreage treated with imidacloprid within GWPAs during the study period and compare the cost of treating with imidacloprid to the counterfactual of treating with alternatives. 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 2). The annual cost of the imidacloprid ban in GWPAs is calculated by subtracting the total cost of using imidacloprid from what the total cost of using alternative AIs on the acreage treated with imidacloprid would have been in 2018-2020.

Table 2. 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

Caveats

There are several caveats regarding the estimates presented here. They can be grouped into three broad groups: methodology, external factors not included in the analysis, and biological changes. Methodologically, one consideration is that we use historical data. To the extent that there have been significant changes in pesticide use patterns since then, there is the possibility that affected acreage is significantly different from the historical record. Another is that we do not analyze all applications of imidacloprid, instead limiting consideration to crops that are major users. Hence, the estimates are not the full cost to California agriculture as a complete sector. Steggall et al. (2018) documents the development of the methodology and the factors underlying each major modeling decision.

There are a number of external factors that could materially alter the results. Growers may change their land allocation choices across crops, which could change pesticide use patterns. This is a particularly important possibility when not all acreage would be subject to the ban. New pesticide use regulations may alter the availability of AIs that are substitutes for imidacloprid. Cancellations of specific uses or restrictions on use, such as permitted application methods or rates could affect the availability of alternative AIs. On the other hand, it is possible that new uses of existing AIs or new AIs could be approved for use in California.

An important biological change to consider is the development of resistance. Resistance management includes rotating AIs with different modes of action. If an alternative AI is necessary to manage a target pest currently treated with imidacloprid, it may not be available to use for other target pests. Invasive species are another biological consideration. The approach rate of new hemipterous pest species is increasing, and imidacloprid is the primary treatment for these insects. There is growing concern about how new threats such as spotted lanternfly will be managed going forward. The loss of imidacloprid could increase both management costs and yield losses that will result from their arrival.

Citrus

Grapefruit, lemon, orange, and tangerine, referred to collectively as citrus, are one of California's most economically important crops. Orange alone is ranked ninth among all commodities, tangerine ranked eleventh, and lemon ranked seventeenth. In 2019, California generated $2.1 billion in gross receipts from 269,000 acres of citrus. Table 3 reports harvested acreage and value of production by citrus crop. Orange is the largest valued crop due to 44.1 percent of total citrus acreage being dedicated to growing orange. Lemon is valued the second-most, due to high value/unit, followed by tangerine as the third most-valued crop.

Table 3. Harvested Acreage and Value of Production for Citrus Crops in California: 2019

Year	Crop	Total acres	Yield (Cartons/)	Production (Cartons)	Price ($/Carton)	Total value ($1000)
2019	Orange	147,000	710	104,370,000	6.7	699,279
2019	Lemon	49,000	968	47,432,000	14.52	688,713
2019	Mandarin & Mandarin Hybrids	64,000	828	52,992,000	12.83	679,887
2019	Grapefruit	9,000	934	8,406,000	6.73	56,572
2019	**TOTAL**	**269,000**	**-**	**213,200,000**	**-**	**2,124,451**

Source: California Department of Food and Agriculture, California Agricultural Statistical Review 2019-2020

Orange production is concentrated in Tulare ($740 million), Kern ($299 million), and San Diego ($42 million), counties (CDFA 2020). Lemon production is concentrated in Ventura ($211 million), Tulare ($191 million), San Diego ($77 million), counties and is a top ten production value crop in only these counties plus Riverside County ($58 million). Grapefruit is not a top ten production value crop for any county. Production is concentrated in Riverside ($25.5 million), Tulare ($22.2 million), and San Diego ($15.5 million) counties. The top three tangerine producing counties, by value, were Tulare ($550 million), Kern ($487 million), and Fresno ($239 million).

Figure 4 maps the location of California citrus production and GWPAs. The large map of California depicts all sections in which any pesticide applications to citrus were reported in 2020. The two enlarged details plot regions where there is overlap between citrus production and GWPAs in the San Joaquin Valley and in Ventura County. Each orange block represents a section in which any pesticide applications to citrus were reported in 2020. Each block outlined in grey represents a section which belongs to a GWPA in whole or in part. Orange blocks outlined in grey are sections where GWPAs have citrus acreage and imidacloprid would be banned. Both locations are important citrus production regions. A significant number of sections would be affected in both production regions relative to the total number of sections producing citrus.

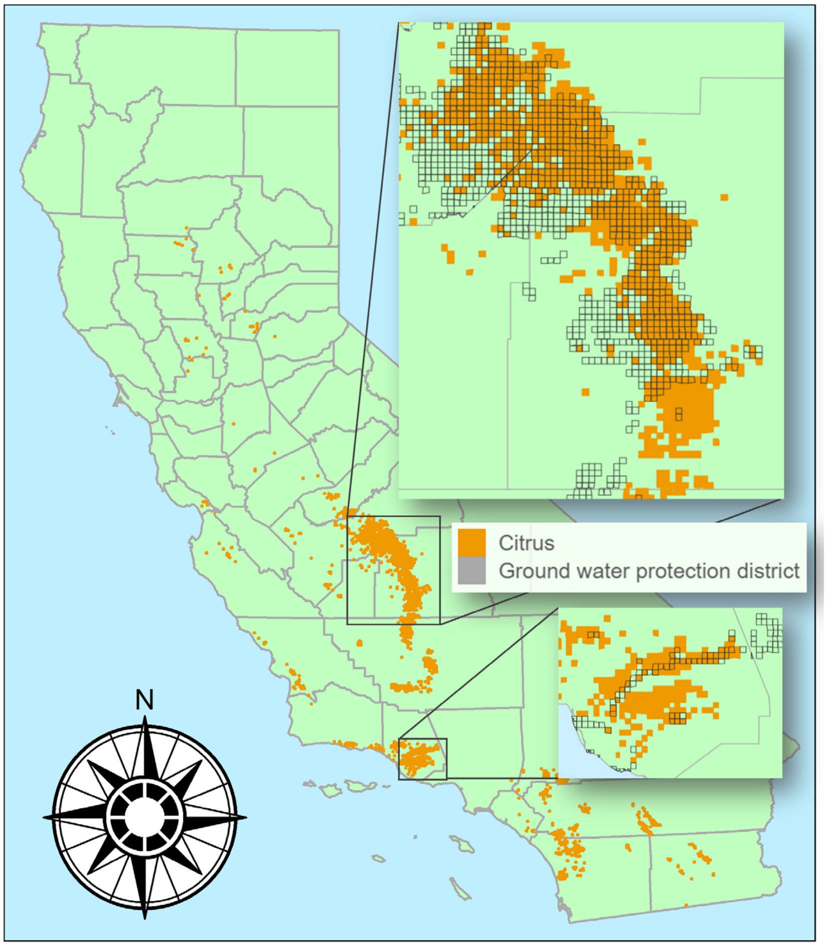

Figure 4. California citrus production and overlap with Ground Water Protection Areas: 2020

IPM Overview

Imidacloprid is used in citrus to manage glassy-winged sharpshooter (GWSS), citricola scale, citrus leafminer, export quarantine pests such as Fuller rose beetle (FRB), and invasive pests such as ACP. It can also be used to treat nursery citrus plants before shipping and citrus orchards prior to harvest in order to comply with rules meant to combat the geographic spread of insect pests. The four growing regions have different pest pressures. 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. Citrus production in ground water protection districts occurs mainly in the San Joaquin Valley with a small amount in the Coastal area. Restrictions in these areas would mainly affect orange, mandarin, and some lemon groves.

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. ACP is the vector HLB, a devastating, incurable bacterial disease of citrus that has reduced Florida citrus production by 70% 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.

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, ACP, 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 maximum residue limits and a short pre-harvest interval, making it convenient to use. It is also relatively inexpensive.

Glassy-winged sharpshooter. GWSS (*Homalodisca vitripennis*) overwinters in citrus, emerges in spring, and can spread Pierce's disease in neighboring grape vineyards. Funds are provided to reimburse citrus growers for pesticides applied to reduce GWSS in citrus in some regions of the state in order to keep populations from migrating into vineyards. Local eradication of GWSS has been achieved through the use of imidacloprid in commercial and residential areas throughout the state. Foliar (knockdown) and systemic (soil drench/injection) applications of imidacloprid are critical to providing long term protection from GWSS feeding and oviposition, thereby limiting the spread of Pierce's disease. 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. Citricola scale (*Coccus pseudomagnolarium*) 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 imidacloprid and thiamethoxam (Grafton-Cardwell and Scott 2011; Grafton-Cardwell and Reger 2019). Foliar formulations of imidacloprid or thiamethoxam are most commonly used for this pest.

Citrus leafminer. Citrus leafminer (*Phyllocnistis citrella*) 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. FRB (*Naupactus godmani*) 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. ACP (*Diaphorina citri*) is currently the most serious pest of citrus because it is the vector of *Candidatus* liberibacter asiaticus the bacterium that causes HLB. 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 two to four 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. Nymphs are critical to control, as this is 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.[2] Alternatives for this spray and move program include cyfluthrin, beta cyfluthrin, fenpropathrin, zeta cypermethrin, and thiamethoxam. The

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

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.

Imidacloprid Use: 2018-2020

More than 122,000 cumulative acres of citrus were treated with imidacloprid in GWPAs from 2018 to 2020, representing 36% of all statewide imidacloprid use in citrus. Fresno and Tulare counties account for more than 95% of this use as measured by both pounds applied and acres treated (Table 4). The potential restriction of imidacloprid use in GWPAs could be a significant problem for the management of ACP, which has been moving into the San Joaquin Valley. Imidacloprid is a key component of limiting the spread. HLB has not been detected in the San Joaquin Valley yet, but widespread ACP populations make the spread of HLB much more likely.

Table 4. County-level Imidacloprid Use on Citrus within Ground Water Protection Areas, 2018-2020: Three-year Total

County	Pounds applied	Acres treated	% GWPA pounds	% GWPA acres
Fresno	19,081	40,584	33.5	33.1
Kern	92	266	0.2	0.2
Kings	29	80	0.1	0.1
Merced	<1	<1	<0.1	<0.1
Monterey	220	595	0.4	0.5
Riverside	376	839	0.7	0.7
Tulare	36,121	76,408	63.4	62.3
Ventura	1,045	3,866	1.8	3.2

Monthly use in GWPAs is similar to statewide trends, with applications predominantly occurring from June through September, with a peak in August and September (Figure 5). Imidacloprid use during summer and fall months is thought to have low potential for runoff given the dry climatic conditions.

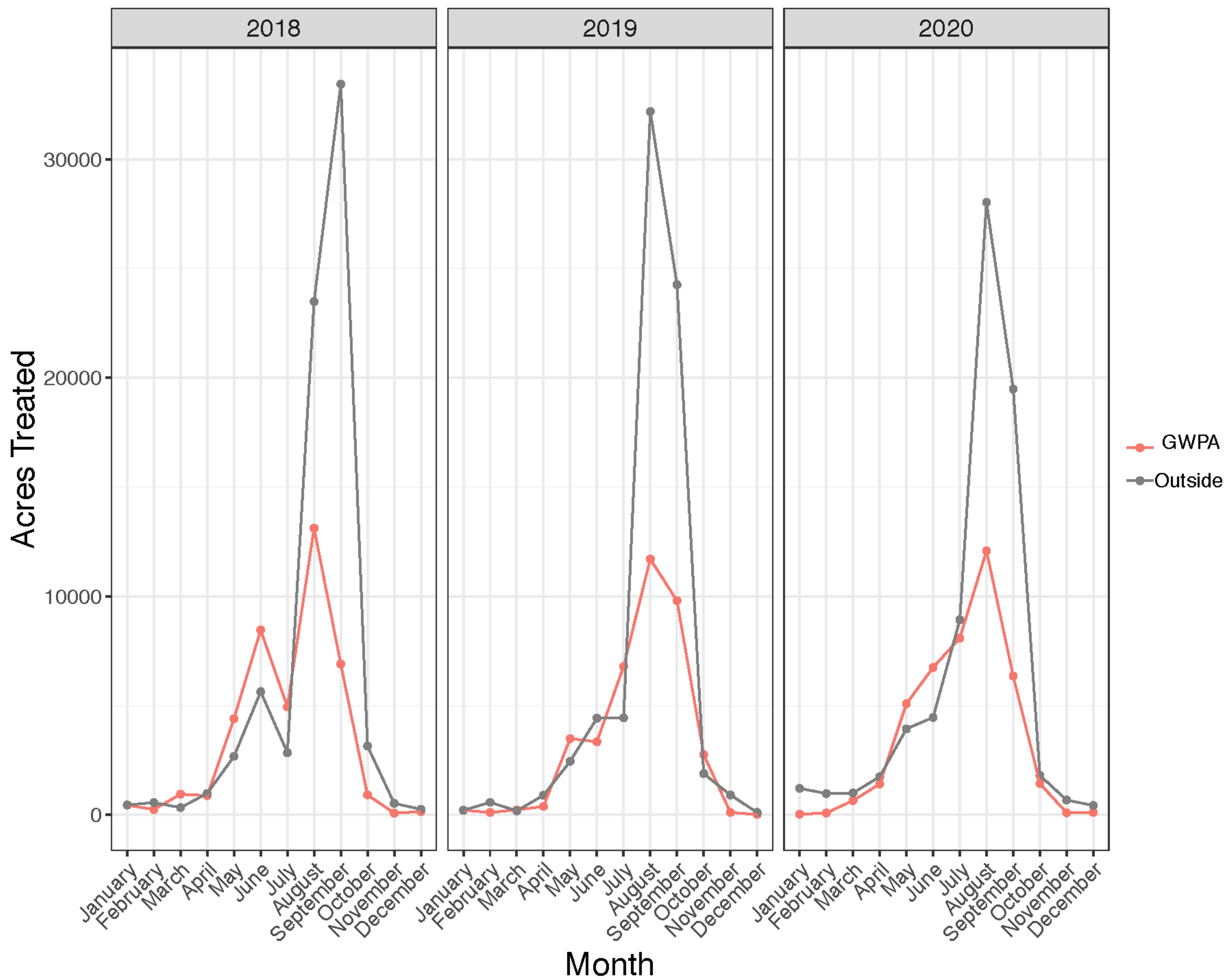

Figure 5. Monthly use of imidacloprid within and outside of GWPAs: Citrus, 2018-2020

Table 5 reports the annual use of imidacloprid and alternative AIs in GWPAs for the 2018-2020 period based on pounds applied and acres treated. It also includes the average use rate of each AI per acre, calculated by dividing the total pounds applied over the three-year period by the total number of acres treated. By acres treated, thiamethoxam was the most used AI, followed by spirotetramat and spinetoram.

Table 5. Annual Use of Imidacloprid and Alternative Active Ingredients in Ground Water Protection Districts: Citrus, 2018-2020

Active ingredient	----------Pounds applied---------				------------Acres treated------------				Use rate (lb/ac)
	2018	2019	2020	Total	2018	2019	2020	Total	
(s)-cypermethrin	859	430	96	1,384	18,398	9,017	2,087	29,501	0.05
acetamiprid	3,104	2,117	3,103	8,323	14,452	10,305	15,888	40,644	0.20
beta-cyfluthrin	1,596	1,903	1,566	5,064	38,714	43,363	41,869	123,945	0.04
bifenthrin	1,989	2,327	2,142	6,457	6,384	7,638	6,588	20,610	0.31
buprofezin	38,046	37,321	33,769	109,136	19,019	18,311	17,048	54,378	2.01
carbaryl	25,531	19,613	9,288	54,432	2,938	2,379	1,021	6,338	8.59
chlorantraniliprole	1,434	1,107	1,308	3,849	16,337	12,356	14,436	43,129	0.09
cyantraniliprole	614	367	419	1,400	4,617	3,327	3,263	11,208	0.12
cyantraniliprole/ abamectin	3,226	7,164	7,382	17,772	25,307	43,324	57,579	126,209	0.14
cyfluthrin	1,182	562	1,654	3,397	17,541	7,841	19,845	45,228	0.08
diflubenzuron	6,499	8,810	8,188	23,496	34,588	45,200	41,548	121,336	0.19
dimethoate	1,295	3,842	2,115	7,252	1,835	4,810	3,386	10,030	0.72
fenpropathrin	7,404	8,178	7,917	23,499	19,379	21,999	21,502	62,880	0.37
flupyradifurone	936	1,215	2,236	4,387	5,915	7,696	13,686	27,297	0.16
imidacloprid	18,988	18,324	19,652	56,964	41,495	38,957	42,187	122,638	0.46
malathion	12,445	13,905	13,770	40,120	4,242	6,049	7,299	17,589	2.28
spinetoram	6,363	4,824	2,525	13,712	72,005	54,028	28,434	154,467	0.09
spinosad	633	612	625	1,870	6,220	6,063	6,596	18,880	0.10
spirotetramat	12,551	12,117	12,639	37,307	81,084	78,491	81,828	241,403	0.15
thiamethoxam	8,198	7,451	7,231	22,880	96,378	87,770	84,747	268,895	0.09

Economic Analysis

This section presents the estimated change in pest management costs for citrus arising from an imidacloprid ban in GWPAs. The cost of this scenario is the difference in material costs and application costs, although the caveats discussed in the methods section apply.

Table 6. Representative Product Cost per Acre: Citrus

Active ingredient	Representative product	Material cost ($)	Application cost ($)	Total cost ($)
(s)-cypermethrin	Mustang	4.62	24.98	29.60
acetamiprid	Assail 70WP Insecticide	71.99	24.99	96.99
beta-cyfluthrin	Baythroid XL	17.81	24.98	42.79
bifenthrin	Brigade WSB Insecticide/Miticide	78.89	24.91	103.80
buprofezin	Centaur WDG Insect Growth Regulator	74.55	25.00	99.55
carbaryl	Sevin Brand XLR Plus Carbaryl Insecticide	128.42	24.91	153.33
chlorantraniliprole	Altacor	43.28	24.71	68.00
cyantraniliprole/abamectin	Minecto	30.18	24.98	55.16
cyfluthrin	Tombstone Helios Insecticide	10.27	25.00	35.27
diflubenzuron	Micromite 80WGS	58.57	25.00	83.57
dimethoate	Drexel Dimethoate 4EC	8.59	25.00	33.59
fenpropathrin	Danitol 2.4 EC Spray	32.85	24.94	57.79
flupyradifurone	Sivanto 200 SL	44.78	24.96	69.74
imidacloprid	Admire Pro	28.15	8.61	36.76
malathion	Malathion 8 Aquamul	13.93	25.00	38.93
spinetoram	Delegate WG	60.11	24.99	85.10
spinosad	Success	29.53	24.76	54.28
spirotetramat	Movento	87.87	24.97	112.84
thiamethoxam	Actara	21.78	24.97	46.75

Table 6 reports the representative products for each active ingredient used on citrus from 2018 to 2020 and the average cost per acre. Average cost per acre for each AI was calculated based on all applications. The average use rate was computed by dividing total pounds applied over the three-year period by the total acres treated. The pesticide material cost was obtained by multiplying the average use rate by the price per pound of AI, which was calculated based on the product formulation and product price. Application costs were calculated based on the different application methods mentioned previously. Including material and application costs, the cost per acre varied significantly for the different AIs, ranging from $29.60 for (s)-cypermethrin to $153.33 for carbaryl. Growers consider a wide variety of factors beyond cost per acre in determining which AI to use, as discussed above.

Table 7. Average Annual Acreage Shares of Alternative Insecticides for Imidacloprid and Shares of Composite Alternative: Citrus, 2018-2020

Active ingredient	Acreage share with imidacloprid available (% of imidacloprid and alternative use)	Share of composite alternative (%)
(s)-cypermethrin	1.9	2.1
acetamiprid	2.6	2.9
beta-cyfluthrin	8.1	8.8
bifenthrin	1.3	1.5
buprofezin	3.5	3.8
carbaryl	0.4	0.4
chlorantraniliprole	2.8	3.1
cyantraniliprole/abamectin	8.2	8.9
cyfluthrin	2.9	3.2
diflubenzuron	7.9	8.6
dimethoate	0.7	0.7
fenpropathrin	4.1	4.5
flupyradifurone	1.8	1.9
malathion	1.1	1.2
spinetoram	10.1	10.9
spinosad	1.2	1.3
spirotetramat	15.7	17.1
thiamethoxam	17.5	19.0
total	92.0	100.0

Note: Three-year average from 2018-2020.

Table 7 provides the acreage shares for the alternatives used on citrus from 2018 to 2020. The second column reports the acreage share treated with each alternative AI when imidacloprid is available. On average, 8% of treated citrus acreage was treated with imidacloprid each year. 92% was treated with an alternative. Prohibited applications of imidacloprid were replaced proportionately with alternatives AIs. The third column reports the share of each alternative in the composite alternative used to replace applications that would be prohibited under this scenario. The three most applied alternative AIs are thiamethoxam, spirotetramat, and spinetoram, which together would account for 47.0% of treated acreage under this scenario. Note that because use was scaled up based on all use, their shares in the overall use of alternatives may not represent their use as a substitute for imidacloprid for any specific pest. Note also that total acreage of citrus treated with imidacloprid or alternative AI may not correspond to total citrus acreage because some orchards may receive multiple applications.

Table 8. Costs Per Acre for Imidacloprid and the Composite Alternative: Citrus

Active ingredient	Material cost ($)	Application cost ($)	Total cost ($)	Cost increase of switching to composite alternative (%)
imidacloprid	28.15	8.61	36.76	94.1
composite alternative	46.39	24.97	71.36	-

Table 8 reports the average per acre costs for imidacloprid 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 $34.60 (94.1%) on imidacloprid-treated acreage.

Table 9. Change in Treatment Costs due to Restriction of Imidacloprid: Citrus, 2018-2020

Year	Cost with imidacloprid ($)	Cost without imidacloprid ($)	Change in cost ($)	Change in cost (%)	Share of change due to material costs (%)	Share of change due to application costs (%)
2018	1,525,518	2,961,064	1,435,546	94.1	52.7	47.3
2019	1,432,189	2,779,911	1,347,722	94.1	52.7	47.3
2020	1,550,938	3,010,404	1,459,466	94.1	52.7	47.3

Table 9 summarizes the annual change in total pesticide costs owing to restriction of imidacloprid for each of the three base years. The total increase in costs would have been between $1.35 million and $1.46 million. These estimates exclude the potential for long-term damage to the citrus industry due to ACP as a result of the loss of imidacloprid for treating citrus acreage in GWPAs.

Cole Crops

Broccoli, cabbage, and cauliflower, referred to collectively as cole crops, are another group of crops important to the Californian economy. Broccoli alone is ranked seventeenth most valuable among all commodities, cauliflower ranked twenty-seventh, and cabbage ranked forty-fourth. In 2019, California generated $1.4 billion in gross receipts from 153,000 acres of cole crops. Table 10 reports harvested acreage and value of production by cole crop. Broccoli is the highest-value cole crop due to a higher farmgate price and 65.2% of total cole acreage being dedicated to growing it.

Table 10. Harvested Acreage and Value of Production for Cole Crops in California: 2019

Year	Crop	Total acres	Yield (Cwt./acre)	Production (Cwt.)	Price ($/Cwt.)	Total value ($1000)
2019	Broccoli	99,700	160	15,952,000	49.3	786,434
2019	Cauliflower	38,800	230	8,915,100	41.1	366,360
2019	Cabbage	14,500	410	5,945,000	35.7	212,237
2019	**TOTAL**	**153,000**	**-**	**30,821,000**	**-**	**1,365,030**

Source: California Department of Food and Agriculture, California Agricultural Statical Review 2019-2020

Broccoli production is concentrated in Monterey ($458 million), Imperial ($105 million), and Santa Barbara ($80.6 million), counties (CDFA 2020). Cauliflower production is concentrated in Monterey ($212 million), Santa Barbara ($91 million), and Imperial ($37.4 million). Cabbage production is concentrated in Monterey ($64.7 million), Ventura ($34.4 million), and Santa Barbara ($22.1 million) counties.

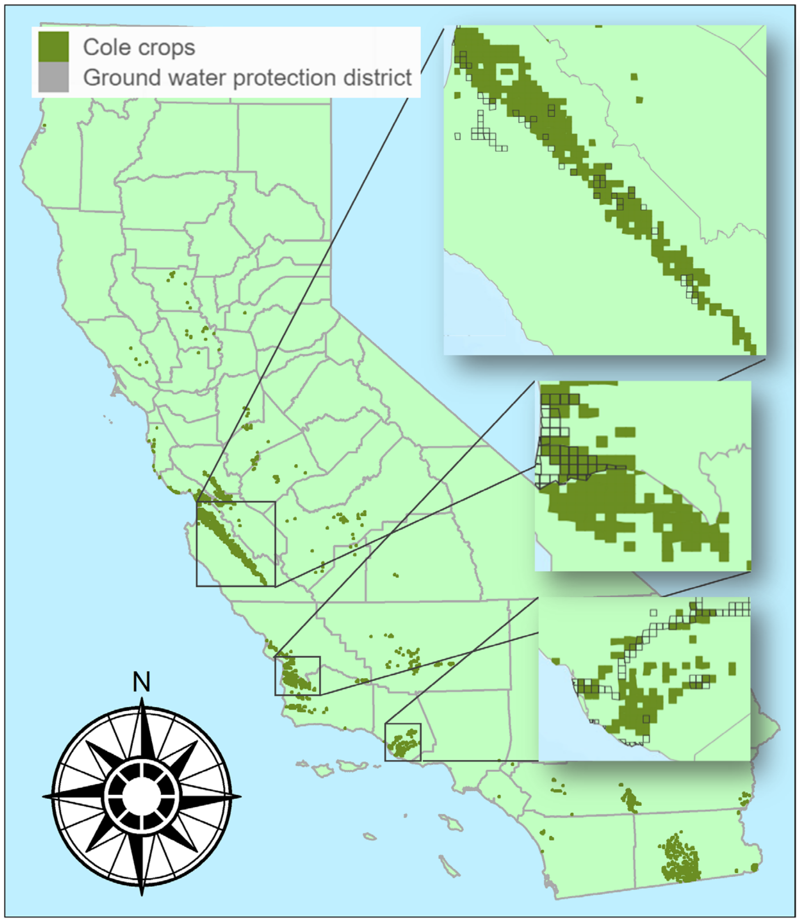

Figure 6. California cole crop production and overlap with Ground Water Protection Areas: 2020

Figure 6 maps California cole crop production and GWPAs. The map of California depicts all sections in which any pesticide applications to cole were reported in 2020. The three enlarged details plot regions where there is overlap between cole crop production and GWPAs in the Salinas Valley, Santa Maria (Santa Barbara and San Luis Obispo Countries) and in Ventura County. Each green block represents a section in which any pesticide applications to cole crops were reported in 2020. Each block outlined in grey represents a section which belongs to a GWPA in whole or in part. Green blocks outlined in grey are sections where GWPAs have cole crop acreage and imidacloprid would be banned. While the Imperial Valley, the wintertime supplier, would not be affected, the other two major production regions would be, as would Ventura County.

IPM Overview

In California, imidacloprid is primarily used to protect cole crops against aphids (cabbage aphid, green peach aphid, and turnip aphid) as well as soil-dwelling arthropods such as springtails and garden symphylans. As detailed in the target pest section below, alternative AIs are available for each of these pests.

Aphids. The aphid complex that attacks cole crops includes cabbage aphid (*Brevicoryne brassicae*), green peach aphid (*Myzus persicae*), and turnip aphid (*Lipaphis erysimi*). In general, aphids feed by piercing plants with specialized mouth parts which are used to suck out phloem sap. Aphid infestations have the ability to stunt or kill host plants depending on the intensity of the infestation and the stage of plant development. They are also capable of rapidly reproducing, making them difficult to control. However, species-specific patterns of feeding behavior, phenology and damage are found. Cabbage aphids preferentially feed on the youngest plant tissue, including leaves and flowers, and often move deep into heads of cabbage and Brussels sprout. Populations can begin to increase rapidly following thinning or transplant, and once large colonies are present, stunting or death can occur. The most serious impact caused by cabbage aphid, however, is contamination of the harvested crop. Neither green peach aphid or turnip aphid typically move into crop head, so their impacts are less severe. Green peach aphid is primarily found on older leaves which are more tolerant to aphid feeding, whereas turnip aphids feed on the roots of cole crops. When populations are high, both green peach aphid and turnip aphid are capable of stunting or killing host plants.

Aphids are attacked by many natural enemies including lady beetles, syrphid fly larvae, fungal diseases, and parasitic wasps including *Diaeretiella rapae*. However, the tendency of cabbage aphids to move deep within the crop head protects them from many natural enemies. Cultural practices such as destroying crop remnants post-harvest, removing alternate hosts (mustard weed) from the field borders, and roguing infested plants can also help slow population growth and delay or reduce the need for pesticide treatment.

Economic thresholds for cabbage aphid varies by crop and stage of plant development. Broccoli and cauliflower are capable of withstanding up to 100 aphids per plant prior to head formation. Once head formation begins, pesticide treatment is needed even if only a few cabbage aphids are present. Cabbage crops are far less tolerant of this pest during the preheading stage because of their overlapping leaves and require treatment if 1 to 2% of plants contain a single cabbage aphid. At least one or more pesticide application is required during this period for all cole crops. Green peach aphids and turnip aphids rarely require targeted pesticide treatments, as they are often controlled via applications made for cabbage aphids. However, if green peach aphids are present in high numbers during the seedling or transplant stage, an additional pesticide application is required. In addition to imidacloprid, aphids can be controlled using thiamethoxam, acetamiprid, spirotetramat, sulfoxaflor, flupyradifurone, flonicamid, and pymetrozine. The organophosphates dimethoate and acephate can also be used for aphids.

Garden symphylans and springtails. Garden symphylans (*Scutigerella immaculata*) and springtails (*Protaphorura fimata*) are soil-dwelling arthropod pests of cole crops. Both species attack plant roots or root hairs, causing the greatest damage to germinating seeds and seedlings. As plants get larger, their ability withstand feeding damage increases; however, damage to older roots can provide an entryway for pathogens. Sampling and management of these pests is notoriously difficult due to their ability to migrate deep in the soil and evade pesticide treatments.

Little research has been conducted to develop cultural or augmentative biological controls for garden symphylans or springtails. These pests are attacked by several natural enemies including centipedes, predatory mites, and predacious ground beetles, but their impact on soil pest populations is not known. In addition to imidacloprid, other neonicotinoids such as thiamethoxam and clothianidin, as well as pyrethroids like lambda-cyhalothrin, zeta-cypermethrin, permethrin, bifenthrin, and beta-cyfluthrin can be used as alternatives. Even with the current pesticide options, control of these pests is difficult to achieve.

Imidacloprid Use: 2018-2020

Nearly 33,000 cumulative acres of cole crops were treated with imidacloprid in GWPAs from 2018 to 2020, representing 11% of all statewide imidacloprid use in these crops. San Luis Obispo county alone accounts for 73% of acres treated in GWPAs, while Monterey and Ventura counties account for 14% and 5%, respectively (Table 11). Monthly use patterns within GWPAs are similar to trends in the rest of the state, with applications predominantly occurring from April through October (Figure 7). Outside of GWPAs, however, there is relatively greater use in late summer and early fall than within, with a prominent peak occurring in September. This timing corresponds to peak imidacloprid use in Monterey, Imperial, Santa Barbara and other counties, which together account for a large majority of statewide imidacloprid use in cole crops but relatively little use within GWPAs. In contrast, use in San Luis Obispo first peaks in May, followed by a second peak in July or August.

Table 11. County-level Imidacloprid Use on Cole Crops within Ground Water Protection Areas, 2018-2020: Three-year Total

County	Pounds applied	Acres treated	% GWPA pounds	% GWPA acres
Fresno	50	771	0.6	2.4
Monterey	394	4,690	5.1	14.3
Riverside	104	952	1.3	2.9
San Joaquin	27	70	0.3	0.2
San Luis Obispo	6,730	23,941	86.7	73.1
Stanislaus	77	393	1.0	1.2
Tulare	28	140	0.4	0.4
Ventura	355	1,801	4.6	5.5

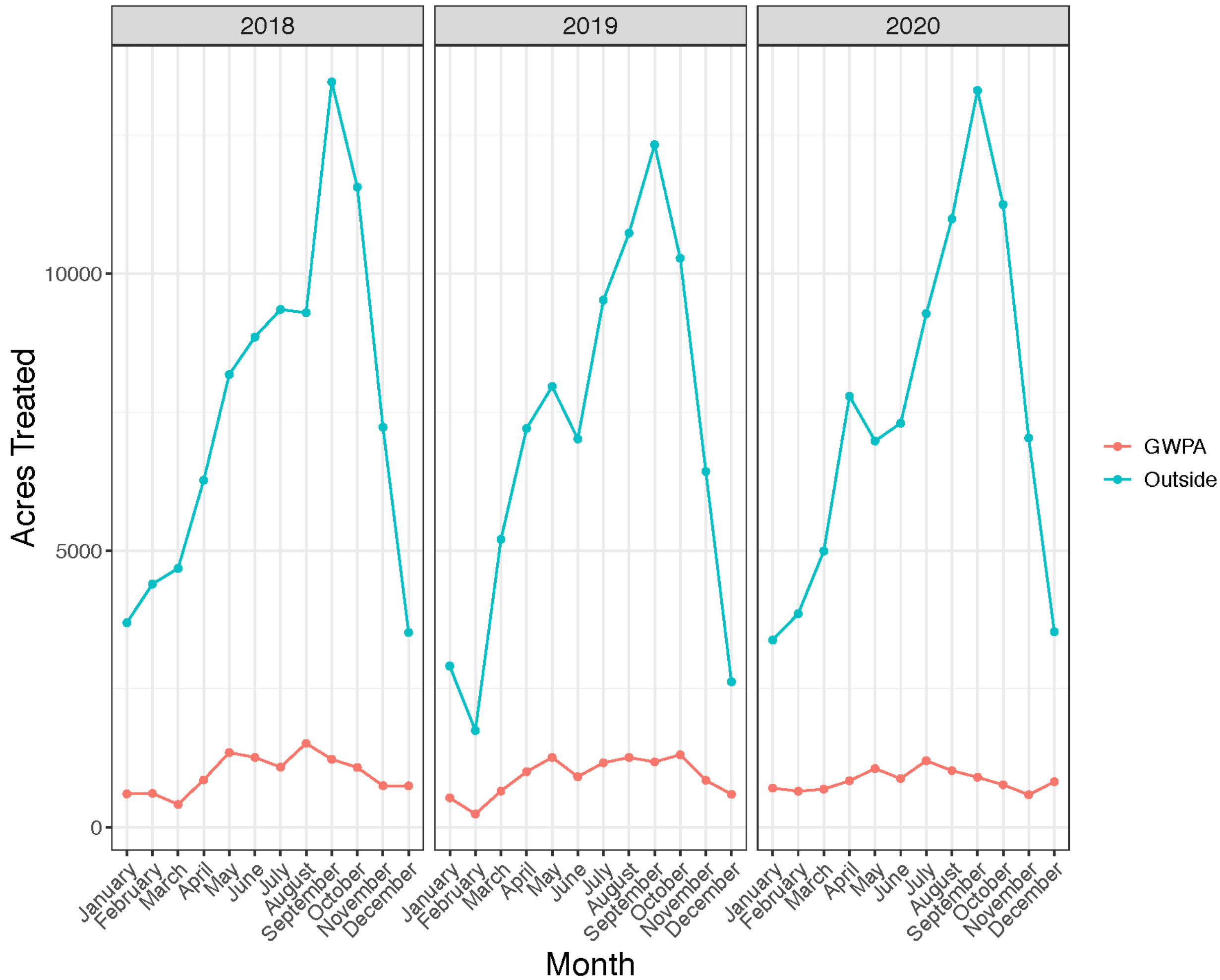

Figure 7. Monthly use of imidacloprid within and outside of Ground Water Protection Areas: Cole Crops, 2018-2020.

Table 12 reports the annual use of imidacloprid and alternative AIs in GWPAs for the 2018-2020 period based on pounds applied and acres treated. It also includes the average use rate of each AI per acre, calculated by dividing the total pounds applied over the three-year period by the total number of acres treated. By acres treated, spirotetramat was the most used AI, followed by imidacloprid and thiamethoxam.

Table 12. Annual Use of Imidacloprid and Alternative Active Ingredients in Ground Water Protection Districts: Cole Crops, 2018-2020

Active ingredient	----------Pounds applied---------				------------Acres treated------------				Use rate (lb/ac)
	2018	2019	2020	Total	2018	2019	2020	Total	
acephate	686	516	300	1,502	714	540	303	1,558	0.96
acetamiprid	153	163	144	459	2,189	2,294	2,023	6,506	0.07
beta-cyfluthrin	75	79	80	234	3,070	3,245	3,196	9,510	0.02
bifenthrin	105	73	209	387	1,200	703	1,849	3,752	0.10
clothianidin	239	268	198	705	1,863	1,825	1,386	5,074	0.14
dimethoate	279	148	223	650	629	301	449	1,379	0.47
flonicamid	104	78	89	271	1,210	895	1,025	3,129	0.09
flupyradifurone	177	194	191	563	1,058	1,205	1,219	3,482	0.16
imidacloprid	2,532	2,686	2,546	7,764	11,555	11,014	10,188	32,757	0.24
lambda-cyhalothrin	129	201	147	478	4,427	6,731	4,884	16,042	0.03
permethrin	247	228	373	849	1,980	1,690	2,282	5,952	0.14
pymetrozine	6	14	5	25	67	160	63	289	0.09
spirotetramat	1,100	1,086	1,016	3,202	14,603	14,211	13,480	42,294	0.08
sulfoxaflor	62	71	82	215	2,020	2,295	2,317	6,632	0.03
thiamethoxam	354	328	445	1,128	5,761	4,955	6,486	17,202	0.07
zeta-cypermethrin	119	97	40	256	2,460	2,014	933	5,407	0.05

Economic Analysis

This section presents the estimated change in costs to cole crops 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.

Table 13. Representative Products and Costs Per Acre: Cole Crops

Active ingredient	Representative product	Material cost ($)	Application cost ($)	Total cost ($)
(s)-cypermethrin	Mustang	3.70	23.40	27.10
acephate	Acephate 97UP Insecticide	14.86	25.00	39.86
acetamiprid	Assail 70WP Insecticide	24.82	23.72	48.54
beta-cyfluthrin	Baythroid XL	10.72	23.97	34.69
bifenthrin	Sniper	26.33	23.62	49.95
clothianidin	Belay Insecticide	20.14	24.36	44.50
dimethoate	Drexel Dimethoate 4EC	5.60	21.10	26.70
flonicamid	Beleaf 50 SG Insecticide	33.09	24.20	57.28
flupyradifurone	Sivanto Prime	45.16	23.04	68.19
imidacloprid	Admire Pro	14.52	20.55	35.07
lambda-cyhalothrin	Warrior II	6.10	22.28	28.38
permethrin	Perm-Up 3.2 EC Insecticide	5.97	21.91	27.88
pymetrozine	Fulfill	20.93	24.38	45.31
spirotetramat	Movento	43.06	23.39	66.45
sulfoxaflor	Sequoia	34.76	22.78	57.54
thiamethoxam	Actara	16.78	20.69	37.47

Table 13 presents representative products for each active ingredient used on cole crops in 2018-2020 and their costs per acre. The application cost per acre is the acre-weighted average application cost based on application method across all applications of the AI to the crops. 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. There was variation in the total cost per acre of AIs, ranging from $26.70 per acre for dimethoate to $68.19 for flupyradifurone in cole crops.

Table 14. Average Annual Acreage Shares of Alternative Insecticides for Imidacloprid and Shares of Composite Alternative: Cole crops, 2018-2020

Active ingredient	Imidacloprid available (% of imidacloprid and alternative use)	Share of composite alternative (%)
(s)-cypermethrin	3.4	4.2
acephate	1.0	1.2
acetamiprid	4.0	5.1
beta-cyfluthrin	5.9	7.4
bifenthrin	2.3	2.9
clothianidin	3.2	4.0
dimethoate	0.9	1.1
flonicamid	1.9	2.4
flupyradifurone	2.2	2.7
lambda-cyhalothrin	10.0	12.5
permethrin	3.7	4.6
pymetrozine	0.2	0.2
spirotetramat	26.3	33.0
sulfoxaflor	4.1	5.2
thiamethoxam	10.7	13.4
Total	79.6	100.0

Note: Three-year average from 2018-2020.

Table 14 provides the acreage shares for the alternatives used on cole crops from 2018 to 2020. The second column reports the acreage share treated with each alternative active ingredient when imidacloprid is available. Averaged over the three-year period 2018-2020, imidacloprid was used on 20.4% of total acres treated with imidacloprid or alternatives. The third column reports the share of each alternative AI in the composite alternative. To represent the situation if imidacloprid was restricted, the use of alternative AIs was scaled up in proportion to their acreage shares, as discussed in the methods section. The main alternative insecticides for cole crops were spirotetramat, thiamethoxam, and lambda-cyhalothrin, together accounting for 47.0% of total cole crop acres treated when imidacloprid is available, or 58.9% of acres treated without imidacloprid. Because use was scaled up based on all use, their shares in the overall use of alternatives may not represent their use as a substitute for imidacloprid for any specific pest.

Table 15. Costs per Acre for Imidacloprid and Composite Alternative: Cole crops

Active ingredient	Material cost ($)	Application cost ($)	Total cost ($)	Cost increase for switching to composite alternative (%)
imidacloprid	14.52	20.55	35.07	37.7
composite alternative	25.40	22.90	48.30	-

Table 15 reports the average per acre costs for imidacloprid as well as the cost of the composite alternative, used as a representative pesticide cost per acre if imidacloprid was restricted. For cole crops, switching to the alternative would lead to an increase in total cost per acre, owing to increases in both material and application costs. Imidacloprid users would incur an 37.7% cost increase.

Table 16. Change in Treatment Costs due to Restriction of Imidacloprid: Cole crops, 2018-2020

Year	Cost with imidacloprid ($)	Cost without imidacloprid ($)	Change in cost ($)	Change in cost (%)	Share of change due to material costs (%)	Share of change due to application costs (%)
2018	409,916	564,568	154,651	37.7	82.2	17.8
2019	396,984	546,756	149,772	37.7	82.2	17.8
2020	362,718	499,563	136,845	37.7	82.2	17.8

Table 16 reports the anticipated changes in cost due to the restriction of imidacloprid. For cole crops, the total annual change in costs from the 37.7% cost increase ranged from $136,845 in 2020 to $154,651 in 2018. 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.

Grape

Grapes are one of California's most economically important crops, ranking second among all agricultural commodities by value of production, only after shelled almonds. In 2019, California produced 6.48 million tons of grapes on 860,000 bearing acres (plus 58,000 non-bearing acres), corresponding to $5.4 billion in gross receipts (CDFA 2020).

Wine, raisin and table grapes are produced in California. Wine grapes were 68.6% of bearing acreage in 2019, raisin grapes 17.3%, and table grapes the remaining 14.1% (CDFA 2020). Wine grapes accounted for 70.3% of total value of production, table grapes 22.5%, and raisin grapes 7.1%. Wine grapes accounted for 77.6% of non-bearing acreage in 2019, table grapes 15.5%, and raisin grapes only 6.9%.

Table 17. Harvested Acreage and Value of Production for Grapes in California: 2019

Year	Crop	Total acres	Yield (tons/acre)	Production (tons)	Price ($/ton)	Total value ($1000)
2019	Grape, Wine	590,000	6.78	3,920,000	971	3,806,320
2019	Grape, Table	121,000	9.75	1,180,000	1030	1,219,996
2019	Grape, Raisin	149,000	8.72	1,300,000	296	385,372
2019	**TOTAL**	**860,000**	**-**	**6,400,000**	**-**	**5,411,688**

Source: California Department of Food and Agriculture, California Agricultural Statical Review 2019-2020

Grape production of all varieties occurs throughout the state of California. Figure 8 maps wine grape production, while Figure 9 shows table and raisin grape production. Table grape production is concentrated in Kern ($1,240 million), Tulare ($682 million), and Fresno ($416 million) counties, and is a top ten production value crop in five counties (the previous three plus Riverside and Madera) (CDFA 2020). Raisin grape production is concentrated in Fresno ($287 million), Kern ($112 million), and Madera ($109 million) and is a top ten production value crop in only these counties. Wine grapes were a top ten production value crop in 22 counties. The top three wine grape producing counties, by value, were Napa ($938 million), Sonoma ($654 million), and San Joaquin ($372 million). The former two counties were driven by relatively high gross revenues per acre rather than acreage.

Figure 8 maps California wine grape production and GWPAs. The map of California depicts all sections in which any pesticide applications to wine grape were reported in 2020. The two enlarged details plot regions where there is overlap between wine grape production and GWPAs: the Sacramento-San Joaquin Delta and the northern San Joaquin Valley. Each purple block represents a section in which any pesticide applications to wine grape were reported in 2020. Each block outlined in grey represents a section which belongs to a GWPA in whole or in part. Purple blocks outlined in grey are sections where GWPAs have wine grape acreage and imidacloprid would be banned.

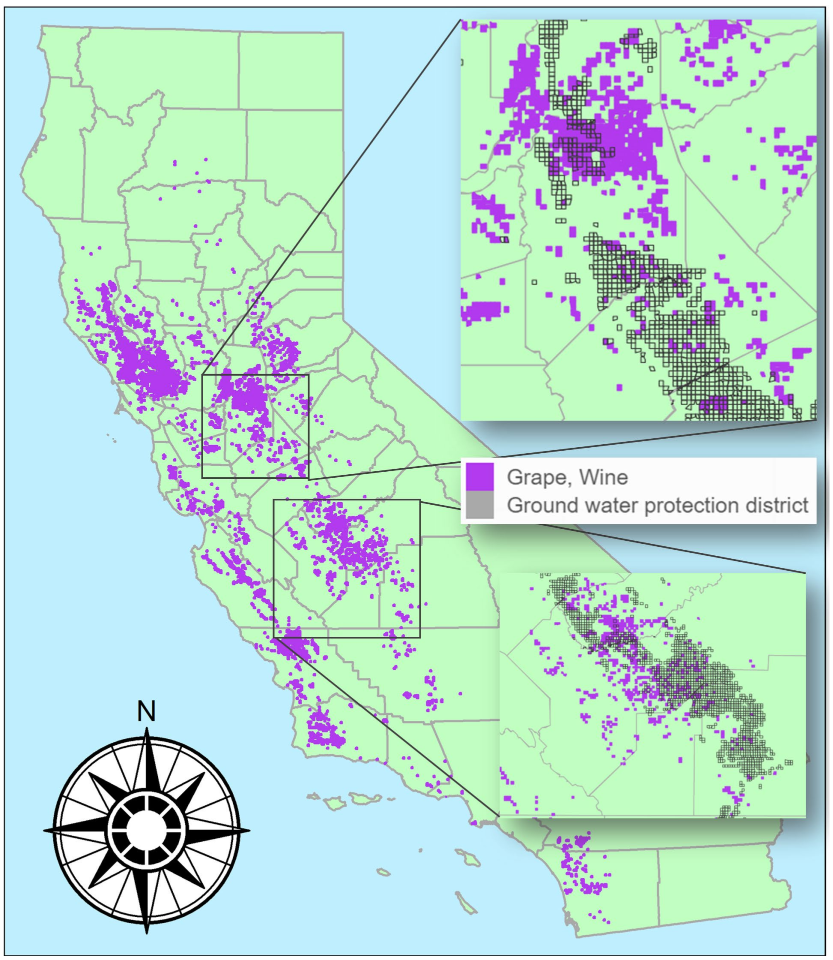

Figure 8. California wine grape production and overlap with Ground Water Protection Areas: 2020

Figure 9 maps California table and raisin grape production and GWPAs. The enlarged detail plots the northern San Joaquin Valley. Compared to wine grape, table and raisin grape has more sections in GWPAs, as well as having more sections with production.

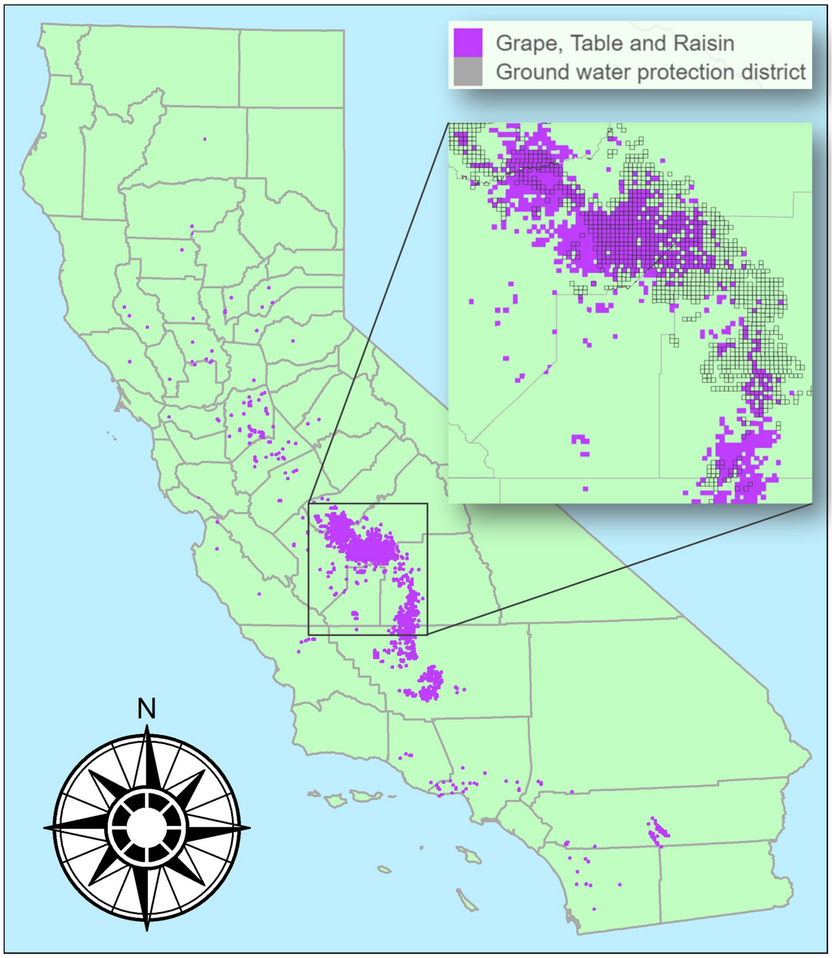

Figure 9. California table and raisin grape production and overlap with Ground Water Protection Areas: 2020

IPM Overview

In grapes, growers use imidacloprid products against leafhoppers (Western grape, variegated, Virginia creeper), sharpshooters, mealybugs (grape, obscure, long tail, pink hibiscus and vine) and grape phylloxera. Vine mealybug is a problem in all grape growing areas but can be especially bad in warmer areas, such as the southern San Joaquin Valley. Raisin grapes and table grapes are more concentrated in the warmer growing areas than wine grapes, and, as such, tend to have more problems with vine mealybug. As detailed below in the target pest section, there are alternatives for leafhoppers and mealybugs but phylloxera management does not have good alternatives for imidacloprid.

Leafhoppers. The leafhopper complex that attacks grapes 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 grapes is very similar. Grape leafhopper is found in the Sacramento, San Joaquin, and North Coast valleys as well as the warmer areas of the central coast. Varigated leafhopper is a pest mostly in the Central Valley and southern California but can go as far north as the San Joaquin Valley and Napa. Virginia Creeper leafhopper is found in the Sacramento Valley, the North Coast wine region, and the northern Sierra foothills.

Leafhopper nymphs and adults feed on the contents of plant cells in grape leaves, which causes light yellow spots. Very 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, which is a concern for table grapes.

Many vineyards will not reach damaging levels of leafhoppers in a given year even without chemical treatment. Several parasitoids as well as general predators often provide sufficient control and there are established treatment thresholds. 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.

When treatment is necessary, it is often done in the summer during the second generation of leafhoppers. In addition to imidacloprid, leafhoppers can be controlled with acetamiprid, beta-cyfluthrin, bifenthrin, buprofezin, *burkholderia*, clothianidin, dinotefuran, fenpropathrin, flupyradifuone, lambda-cyhalothrin, pyrethrin, sulfoxaflor, or thiamethozam. Upcoming regulations would limit the use of clothianidin and dinotefuran to some extent but one or the other could still be used in a vineyard.

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 that addresses GWSS. 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. Local eradication of GWSS has been achieved through the use of imidacloprid in commercial and residential areas throughout the state. Foliar (knockdown) and systemic (soil drench/injection) applications of imidacloprid are critical to providing long term protection from GWSS feeding and oviposition, thereby limiting the spread of Pierce's disease. 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.

Mealybugs. Grape (*Pseudococcus maritimus*), obscure (*Pseudococcus viburni*), long tail (*Pseudococcus longispinus*), pink hibiscus (*Maconellicoccus hirsutus*), and vine (*Planococcus ficus*) mealybugs all attack grapes 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 varietals of grape are differentially susceptible to mealybug damage from mold. All five mealybugs can transmit diseases.

The control of grape, obscure, long tail, and hibiscus mealybugs, collectively called *pseudococcus* mealybugs, is generally not as difficult to control as the vine mealybug. Vine mealybug is a more difficult to control because unlike the *pseudococcus* mealybugs, which only produce two generations per year, the vine mealybug can produce multiple generations per year. Thus, vine mealybug can develop very high and damaging populations late in the season as the grapes are maturing. Adding to the problem, vine mealybugs can then hide in the grape bunches, making them harder to kill with contact insecticide. This is especially an issue in warmer areas as the warm temperature allows for even more generations of vine mealybug.

Mealybugs are attacked by a variety of natural enemies, but they do not regularly provide sufficient control (Daane et al. 2012; Walton et al. 2012). The most useful one, *Anagyrus pseudococci*, can be added to vineyards to supplement control (Daane et al. 2012). However, the California supply of *A. pseudococci* has been unreliable, making it difficult for growers to use in pest control. Additionally, growers have access to mating disruption products. While they did not use to be widely used, adoption has been increasing, especially with the 2016 registration of a product with a more user-friendly formulation. Mating disruption decreases the need for chemical controls.

The threshold for mealybug treatment is dependent of the type of vineyard and target harvest date. Early season wine grapes might need only one treatment while late season table grapes in an infested field could require three treatments. For vine mealybug growers use a series of treatments that include imidaclorpid. Haviland et al. (2011) found that a combination of spirotetramat and buprofezin was the only treatment to significantly reduce vine mealybug damage while Van Steenwyk et al. (2016c) found that sequential use of spirotetramat and flupyradifuone was effective. Imidacloprid a part of that program but could be replaced with acetamiprid or extra applications of spirotetramat. However, heavier use of spirotetramat could lead to resistance; growers are already encouraged to rotate it with other active ingredients to prevent this. As spirotetramat is the primary effective active ingredient besides imidaclorpid, it would be hard to rotate it in order to manage resistance without incurring yield loss.

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

Resistant root stock is the best way to control phylloxera. However, imidacloprid is currently an important part of control phylloxera on non-resistant varieties. Clothianidin, dinotefuran, spirotetramat, and thiamethoxam are alternatives. As discussed earlier, more intensive use of spirotetramat is problematic due to the potential effect on the development of resistance. Upcoming regulations would limit the use of clothianidin, dinotefuran, and thiamethoxam to only one of those AIs in a vineyard per year. Although this possibility is not incorporated into this analysis, the continued development of grape root stock that is resistant to phylloxera would benefit California growers.

Imidacloprid Use: 2018-2020

More than 158,000 cumulative acres of table and raisin grape were treated with imidacloprid in GWPAs from 2018 to 2020, representing 39% of all statewide imidacloprid use in these crops. Nearly 78,000 cumulative acres of wine grape were treated in GWPAs during the same timeframe, representing 11% of its statewide acres treated with imidacloprid. Fresno, Madera, and Tulare counties were the top three counties by acres treated for table and raisin grape, while San Joaquin, Madera, and Fresno counties were the top users, respectively, for wine grape. When table, raisin, and wine grape use was combined, Fresno alone accounts for nearly half of the acres treated with imidacloprid in GWPAs (Table 18). Madera, San Joaquin, and Tulare account for nearly all of the remaining use. Monthly use patterns within GWPAs are similar to trends in the rest of the state, with most use occurring between April and July (Figure 10).

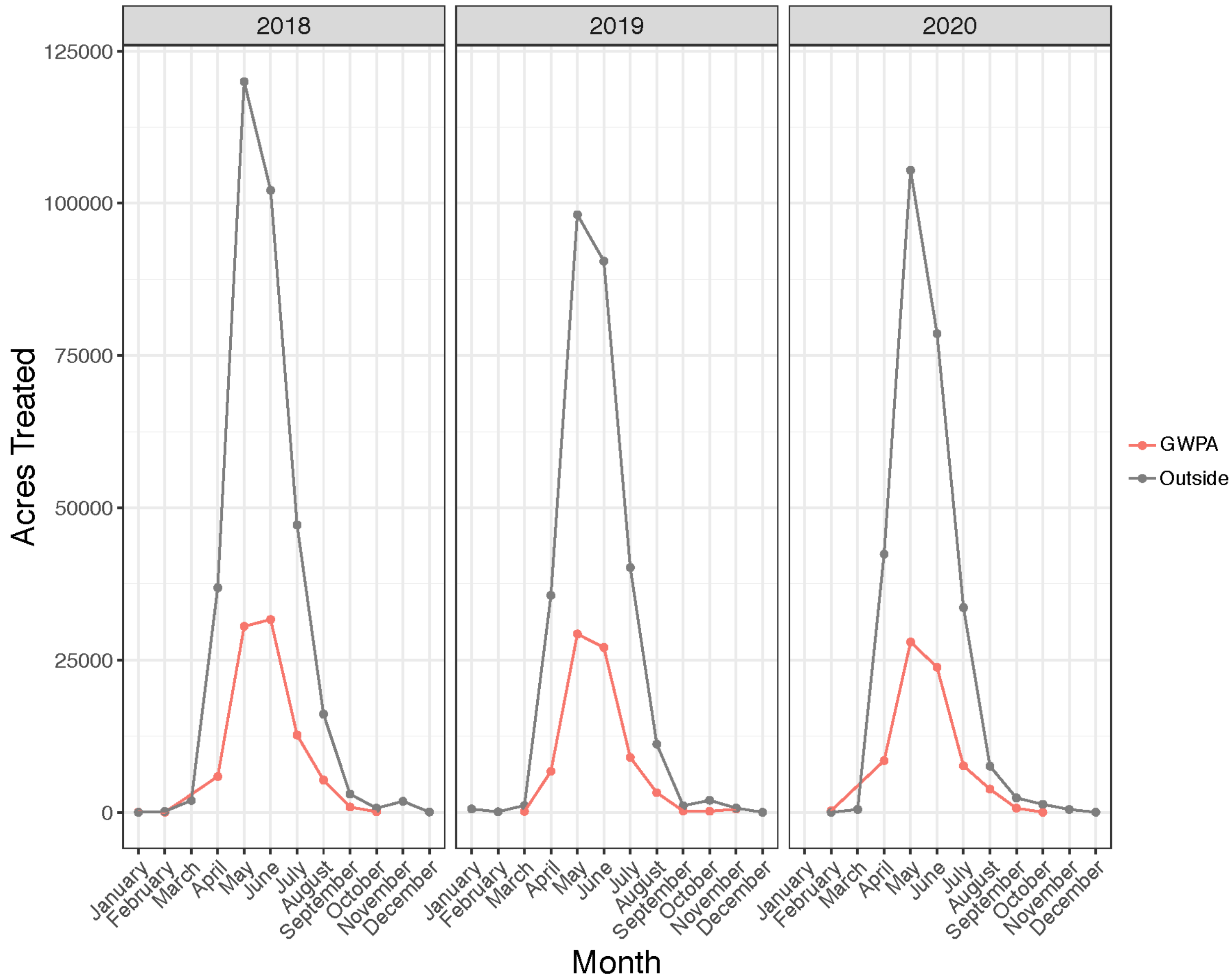

Figure 10. Monthly use of imidacloprid within and outside of GWPAs: Grape (combined), 2018-2020

Table 18. County-level Imidacloprid Use on Grape (Wine, Table, and Raisin) within Ground Water Protection Areas, 2018-2020: Three-year Total

County	Pounds applied	Acres treated	% GWPA pounds	% GWPA acres
Contra Costa	12	366	<0.1	0.2
Fresno	23,475	117,244	41.5	49.6
Kern	925	1,840	1.6	0.8
Kings	418	936	0.7	0.4
Madera	10,891	52,309	19.3	22.1
Mendocino	51	412	0.1	0.2
Merced	214	611	0.4	0.3
Monterey	2,218	4,303	3.9	1.8
Riverside	34	71	0.1	<0.1
Sacramento	625	2,759	1.1	1.2
San Joaquin	9,344	28,402	16.5	12.0
Sonoma	232	885	0.4	0.4
Stanislaus	586	2,114	1.0	0.9
Tehama	2	10	<0.1	<0.1
Tulare	7,493	24,078	13.3	10.2

Table 19 and Table 20 report the annual use of imidacloprid and alternative AIs in GWPAs for the 2018-2020 for raisin and table grape and wine grape, respectively. Pounds applied and acres treated are presented as well as the average use rate of each AI per acre, calculated by dividing the total pounds applied over the three-year period by the total number of acres treated. For table and raisin grape, imidacloprid was the most used AI by acres treated. Spirotetramat was the most used alternative, with over three times as many acres treated as the next most used AI, lavanduly senecioate. For wine grape, spirotetramat was the most used AI, followed by imidacloprid and thiamethoxam.

Table 19. Annual Use of Imidacloprid and Alternative Active Ingredients: Raisin and Table Grape, 2018-2020

Active ingredient	----------Pounds applied-----------				--------------Acres treated--------------				Use rate (lb/ac)
	2018	2019	2020	Total	2018	2019	2020	Total	
acetamiprid	432	261	441	1,135	4,674	3,014	4,841	12,529	0.09
beta-cyfluthrin	173	192	155	521	6,123	7,547	5,987	19,658	0.03
bifenthrin	28	26	58	112	283	258	549	1,090	0.10
buprofezin	4,436	5,952	5,938	16,326	7,942	10,021	9,372	27,335	0.60
Burkholderia sp	6,535	4,911	2,022	13,467	1,149	754	428	2,332	5.78
clothianidin	192	429	274	896	1,785	4,292	2,759	8,835	0.10
dinotefuran	30	NA	18	48	230	NA	137	367	0.13
fenpropathrin	1,307	868	430	2,605	4,515	3,177	1,534	9,226	0.28
flupyradifurone	564	466	193	1,223	3,690	2,456	1,068	7,214	0.17
imidacloprid	10,581	9,894	10,745	31,220	59,411	52,448	46,611	158,471	0.20
lavandulyl senecioate	105	181	159	444	7,251	14,788	12,862	34,901	0.01
spirotetramat	5,531	4,801	4,668	15,000	48,963	42,235	41,137	132,334	0.11
thiamethoxam	312	43	7	362	2,170	498	79	2,746	0.13

Table 20. Annual Use of Imidacloprid and Alternative Active Ingredients in Ground Water Protection Areas: Wine Grape, 2018-2020

Active ingredient	----------Pounds applied-----------				--------------Acres treated--------------				Use rate (lb/ac)
	2018	2019	2020	Total	2018	2019	2020	Total	
acetamiprid	69	116	135	321	921	1,425	1,559	3,905	0.08
beta-cyfluthrin	20	27	21	68	694	694	924	2,312	0.03
bifenthrin	5	9	3	17	54	39	30	123	0.14
buprofezin	697	131	2,549	3,376	1,306	184	2,866	4,356	0.78
Burkholderia sp	--	--	418	418	--	--	76	76	5.50
clothianidin	370	631	431	1,432	2,251	3,692	3,160	9,103	0.16
dinotefuran	56	14	57	128	391	254	436	1,082	0.12
fenpropathrin	111	116	51	278	326	514	217	1,057	0.26
flupyradifurone	219	57	37	312	1,298	342	237	1,877	0.17
imidacloprid	8,413	8,109	8,779	25,301	27,712	24,014	26,141	77,868	0.32
lavandulyl senecioate	45	58	62	165	3,945	4,678	5,347	13,970	0.01
spirotetramat	3,281	3,022	3,896	10,199	28,814	27,269	33,669	89,752	0.11
thiamethoxam	709	768	756	2,233	7,035	7,177	8,337	22,549	0.10

Economic Analysis

This section presents the estimated change in costs to grape production from a ban on imidacloprid use in GWPAs. 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 21 presents representative products for each active ingredient used on raisin and table grape in 2018-2020 and their costs per acre. Table 22 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.

Table 21. Representative Products and Costs Per Acre: Raisin and Table Grape

Active ingredient	Representative product	Material cost ($)	Application cost ($)	Total cost ($)
acetamiprid	Assail 70WP Insecticide	31.84	25.00	56.84
beta-cyfluthrin	Baythroid XL	11.55	25.00	36.55
bifenthrin	Bifenture Ec Agricultural Insecticide	5.07	25.00	30.07
buprofezin	Applaud 70 DF Insect Growth Regulator	38.39	24.99	63.38
burkholderia	Venerate	88.03	25.00	113.03
clothianidin	Belay Insecticide	14.76	25.00	39.76
dinotefuran	Venom Insecticide	27.74	25.00	52.74
fenpropathrin	Danitol 2.4 EC Spray	24.82	25.00	49.82
flupyradifurone	Sivanto 200 SL	47.24	24.99	72.23
imidacloprid	Macho 2.0 Fl	17.80	19.67	37.47
lavandulyl senecioate	Checkmate VMB-F	21.53	25.00	46.53
spirotetramat	Movento	64.45	24.98	89.43
thiamethoxam	Platinum 75 SG	20.20	19.07	39.27

Table 22. Representative Products and Costs Per Acre: Wine Grape

Active ingredient	Representative product	Material Cost ($)	Application cost ($)	Total cost ($)
acetamiprid	Assail 30sg Insecticide	21.68	24.92	46.60
beta-cyfluthrin	Baythroid XL	12.74	23.32	36.06
bifenthrin	Bifenture Ec Agricultural Insecticide	6.89	25.00	31.89
buprofezin	Applaud 70 DF Insect Growth Regulator	49.83	22.50	72.33
burkholderia	Venerate	83.75	25.00	108.75
clothianidin	Belay Insecticide	22.91	13.72	36.63
dinotefuran	Venom Insecticide	24.97	22.87	47.84
fenpropathrin	Danitol 2.4 EC Spray	23.15	25.00	48.15
flupyradifurone	Sivanto Prime	46.32	25.00	71.32
imidacloprid	Admire Pro	19.69	13.32	33.02
lavandulyl senecioate	Checkmate VMB-F	20.02	24.34	44.36
spirotetramat	Movento	64.61	24.81	89.42
thiamethoxam	Platinum 75 SG	15.18	4.85	20.03

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. There was substantial variation in the total cost per acre of AIs, ranging from $30.07 per acre for bifenthrin to $113.03 for burkholderia in table and raisin grape, and from $20.03 per acre for thiamethoxam to $108.75 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 imidacloprid being available was less than 1%, its high per-acre cost had a very small effect on the overall changes in material and total treatment costs.

Table 23. Average Annual Acreage Shares of Alternative Insecticides for Imidacloprid and Shares of Composite Alternative: Raisin and Table Grape, 2018-2020

Active ingredient	Imidacloprid available (% of imidacloprid and alternative use)	Share of composite alternative (%)
acetamiprid	3.0	4.8
beta-cyfluthrin	4.7	7.6
bifenthrin	0.3	0.4
buprofezin	6.6	10.6
burkholderia	0.6	0.9
clothianidin	2.1	3.4
dinotefuran	0.1	0.2
fenpropathrin	2.2	3.6
flupyradifurone	1.7	2.8
lavandulyl senecioate	8.4	13.5
spirotetramat	31.7	51.1
thiamethoxam	0.7	1.1
Total	62.0	100.0

Table 24. Average Annual Acreage Shares of Alternative Insecticides for Imidacloprid and Shares of Composite Alternative: Wine Grape, 2018-2020

Active ingredient	Imidacloprid available (% of imidacloprid and alternative use)	Share of composite alternative (%)
acetamiprid	1.7	2.6
beta-cyfluthrin	1	1.5
bifenthrin	0.1	0.1
buprofezin	1.9	2.9
burkholderia	0.1	0.2
clothianidin	4	6.1
dinotefuran	0.5	0.7
fenpropathrin	0.5	0.7
flupyradifurone	0.8	1.2
lavandulyl senecioate	6.1	9.3
spirotetramat	39.3	59.7
thiamethoxam	9.9	15
Total	65.9	100

Note: Three-year average from 2018-2020.

The second column of Table 23 shows the average acreage shares for each alternative used on raisin and table grape. Table 24 presents the same information for wine grape. Averaged over the three-year period 2018-2020, imidacloprid was used on 38.0% of total table/raisin grape acres treated with imidacloprid or alternatives and on 34.1% of total wine grape acres treated with imidacloprid or alternatives.

The third column reports the share of each alternative AI in the composite alternative. To represent the situation if imidacloprid was restricted, the use of alternative AIs was scaled up in proportion to their acreage shares, as discussed in the methods section. The main alternative insecticides for table/raisin grape were spirotetramat and lavandulyl senecioate, together accounting for 40.1% of total table/raisin grape acres treated with imidacloprid, or 64.6% of acres treated without imidacloprid. Spirotetramat and thiamethoxam were the main alternative insecticides for wine grape, accounting for 74.7% of acres treated without imidacloprid. Because use was scaled up based on all use, their shares in the overall use of alternatives may not represent their use as a substitute for imidacloprid for any specific pest.

Table 25. Costs per Acre for Imidacloprid and Composite Alternative: Raisin and Table Grape

Active ingredient	Material cost ($)	Application cost ($)	Total cost ($)	Cost increase for switching to composite alternative (%)
imidacloprid	17.8	19.67	37.47	89.6
composite alternative	46.13	24.93	71.06	-

Table 26. Costs per Acre for Imidacloprid and Composite Alternative: Wine Grape

Active ingredient	Material cost ($)	Application cost ($)	Total cost ($)	Cost increase for switching to composite alternative (%)
imidacloprid	19.69	13.32	33.02	107.1
composite alternative	47.36	21.00	68.37	-

Table 25 and Table 26 report the average per acre costs for imidacloprid as well as the cost of the composite alternative, used as a representative pesticide cost per acre if imidacloprid was 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, imidacloprid users would incur an 89.6% cost increase (Table 25). For wine grape, imidacloprid users would incur a 107.1% cost increase (Table 26).

Table 27. Change in Treatment Costs due to Restriction of Imidacloprid: Raisin and Table Grape, 2018-2020

Year	Cost with imidacloprid ($)	Cost without imidacloprid ($)	Change in cost ($)	Change in cost (%)	Share of change due to material costs (%)	Share of change due to application costs (%)
2018	2,226,128	4,221,738	1,995,610	89.6	84.4	15.6
2019	1,965,227	3,726,952	1,761,725	89.6	84.4	15.6
2020	1,746,513	3,312,172	1,565,659	89.6	84.4	15.6

Table 28. Change in Treatment Costs due to Restriction of Imidacloprid: Wine Grape, 2018-2020

Year	Cost with imidacloprid ($)	Cost without imidacloprid ($)	Change in cost ($)	Change in cost (%)	Share of change due to material costs (%)	Share of change due to application costs (%)
2018	914,931	1,894,584	979,653	107.1	78.3	21.7
2019	792,858	1,641,802	848,944	107.1	78.3	21.7
2020	863,078	1,787,209	924,132	107.1	78.3	21.7

Table 27 (raisin and table grape) and Table 28 (wine grape) report the anticipated changes in cost due to the restriction of imidacloprid. For table and raisin grape, the total annual change in costs from the 89.6% cost increase ranged from $1,565,659 in 2020 to $1,995,610 in 2018. For wine grape, the total annual change in costs from the 107.1% cost increase ranged from $848,944 in 2019 to $979,653 in 2018. 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.

Lettuce

Lettuce is the eighth-most valued crop produced in California. In 2019, California generated $1.3 billion in gross receipts from 124,700 acres of lettuce (head, leaf, and romaine). Lettuce production is concentrated in Monterey ($1,349 million), Imperial ($272 million), and Fresno ($161 million), counties (CDFA 2020). Lettuce production is in the top-ten crops by production value for these counties, in addition to San Benito, Santa Barbara, Santa Clara, and Santa Cruz counties.

Table 29. Harvested Acreage and Value of Production for Lettuce in California: 2019

Year	Crop	Total acres	Yield (Cwt./acre)	Production (Cwt.)	Price ($/Cwt.)	Total value ($1000)
2019	Lettuce, Head	77,200	375	28,950,000	30.2	874,290
2019	Lettuce, Leaf	47,500	215	10,215,500	41	418,713
2019	**TOTAL**	**124,700**	**-**	**39,162,500**	**-**	**1,293,303**

Source: California Department of Food and Agriculture, California Agricultural Statical Review 2019-2020

Figure 11 illustrates California lettuce production and GWPAs. The map of California depicts all sections in which any pesticide applications to lettuce were reported in 2020. The two enlarged insets detail plot regions where there is overlap between lettuce production and GWPAs: the Salinas Valley and the Santa Maria region. Each green block represents a section in which any pesticide applications to lettuce were reported in 2020. Each block outlined in grey represents a section which belongs to a GWPA in whole or in part. Green blocks outlined in grey are sections where GWPAs have lettuce acreage and imidacloprid would be banned.

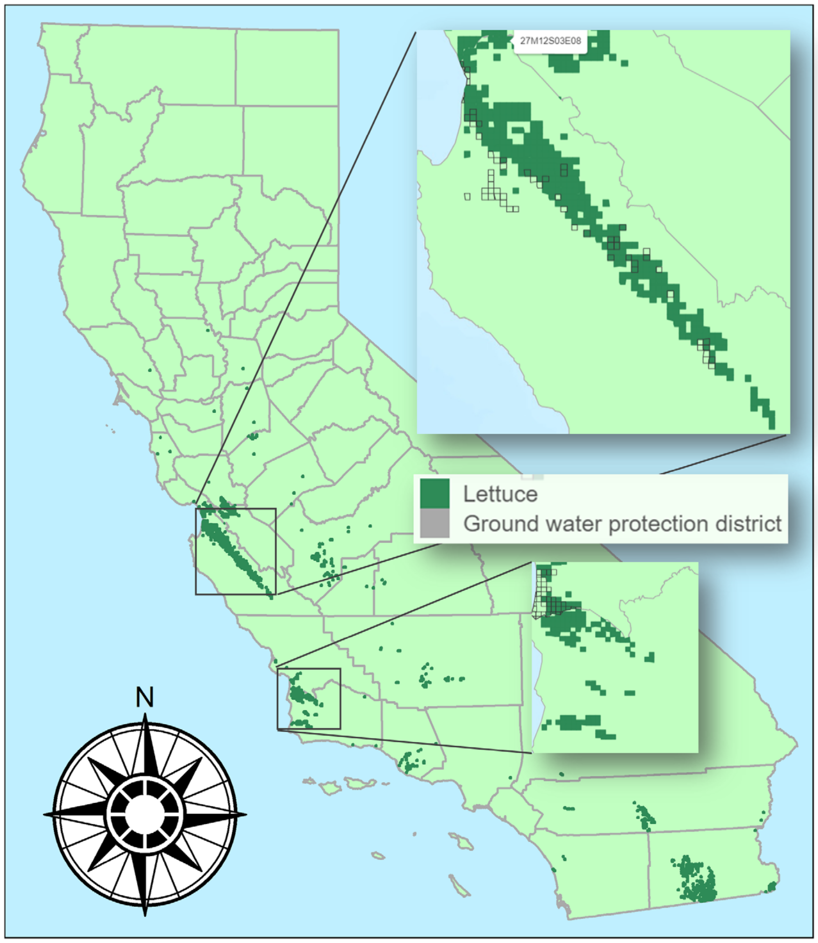

Figure 11. California lettuce production and overlap with Ground Water Protection Areas: 2020

IPM Overview

Imidacloprid is primarily used to protect lettuce against aphids (foxglove aphid, lettuce aphid, lettuce root aphid, green peach aphid, and potato aphid) and soil-dwelling arthropods such as springtails and garden symphylans. As detailed in the target pest section below, alternative AIs are available for each of these pests.

Aphids. The aphid complex that attacks lettuce includes foxglove aphid (*Aulacorthum solani*), lettuce aphid (*Nasonovia ribis-nigri*), green peach aphid (*Myzus persicae*), potato aphid (*Macrosiphum euphorbiae*), and lettuce root aphid (*Pemphigus bursarius*). In general, aphids feed by piercing plants with specialized mouth parts which are used to suck out sap. Aphid infestations have the ability to stunt or kill host plants depending on the intensity of the infestation and the stage of plant development. Contamination of harvested lettuce by aphids is the primary source of economic damage. Additionally, aphids are capable of rapidly reproducing parthogenetically, making them difficult to control, and can vector a variety of plant viruses. However, species-specific patterns of feeding behavior and damage are found. Foxglove aphid, lettuce aphid, green peach aphid, and potato aphid may feed on young leaves deep within the lettuce head which protects them from pesticide treatments and causes contamination of the harvested crop. Foxglove aphid and lettuce aphid in particular prefer to move into the inner parts of lettuce. Potato aphid and green peach aphid can be difficult to control with contact insecticides because they tend to occur on the undersides of leaves. Foxglove aphid and green peach aphid also vector numerous diseases including but not limited to Lettuce mosaic, alfalfa mosaic, beet western yellows, beet yellow stunt, and turnip mosaic viruses. Lettuce root aphid feeds on lettuce roots, which can stunt plant growth and cause wilting.

Aphids are attacked by many natural enemies including green lacewing larvae and syrphid fly larvae, as well as parasitoids such as *Lysiphlebus testaceipes*, *Aphidius matricariae* and *Aphelinus semiflavus*. However, the tendency of some aphids to move deep within the crop head protects them from natural enemies. Several cultural controls are available that may reduce the likelihood of lettuce root aphid infestations. One approach, which is now an established practice in several counties, is the removal of Lombardy poplars in the vicinity of lettuce fields as they serve as overwintering hosts. The planting of lettuce varieties with demonstrated resistance to root aphids is another available cultural practice.

Lettuce root aphid treatment often requires a banded application of imidacloprid at the time of planting to prevent infestation. Once root aphid infestations have occurred, insecticide applications do not effectively control this pest given their location within the soil. The presence of up to 20 green peach and potato aphid per plant can be tolerated prior to head formation. Once head formation begins, treatment is often needed to prevent aphids from moving into the head, where they are difficult to control. Similarly, careful monitoring of foxglove and lettuce aphids is needed to detect early infestations within lettuce. Aphid management with imidacloprid can be achieved through spray applications to the soil or through chemigation. Several insecticides other than imidacloprid are available for foxglove, lettuce, green peach and potato aphid control; these include thiamethoxam, acetamiprid, spirotetramat, sulfoxaflor, flupyradifurone, flonicamid, and pymetrozine. The organophosphates dimethoate and acephate can also be used for aphids.

Garden symphylans and springtails. Garden symphylans (*Scutigerella immaculata*) and springtails (*Protaphorura fimata*) are soil-dwelling pests of lettuce crops. Both species attack plant roots or root hairs, causing the greatest damage to germinating seeds and seedlings. As plants get larger, their ability to withstand feeding damage increases; however, damage to roots can provide an entryway for pathogens. Sampling and management of these pests is notoriously difficult due to their ability to migrate deep in the soil and evade pesticide treatments.

Little research has been conducted to develop cultural or augmentative biological controls for garden symphylans or springtails. These pests are attacked by several natural enemies including centipedes, predatory mites, and predacious ground beetles, but their impact on soil pest populations is not known. In addition to imidacloprid, other neonicotinoids such as thiamethoxam and clothianidin, as well as pyrethroids like zeta-cypermethrin, permethrin, bifenthrin, and beta-cyfluthrin can be used as alternatives. Even with the current pesticide options, control of these pests is difficult to achieve.

Imidacloprid Use: 2018-2020

More than 25,000 cumulative acres of lettuce crops were treated with imidacloprid in GWPAs from 2018 to 2020, representing approximately 7% of all statewide imidacloprid use in these crops. Monterey and San Luis Obispo counties together account for nearly all pounds applied and acres treated within GWPAs (Table 30). Monthly use trends are similar both within and outside of GWPAs, with use occurring throughout the year but declining sharply during winter months (Figure 12). An initial peak in April occurs in both areas; however, outside of GWPAs there is a second, more pronounced peak in September.

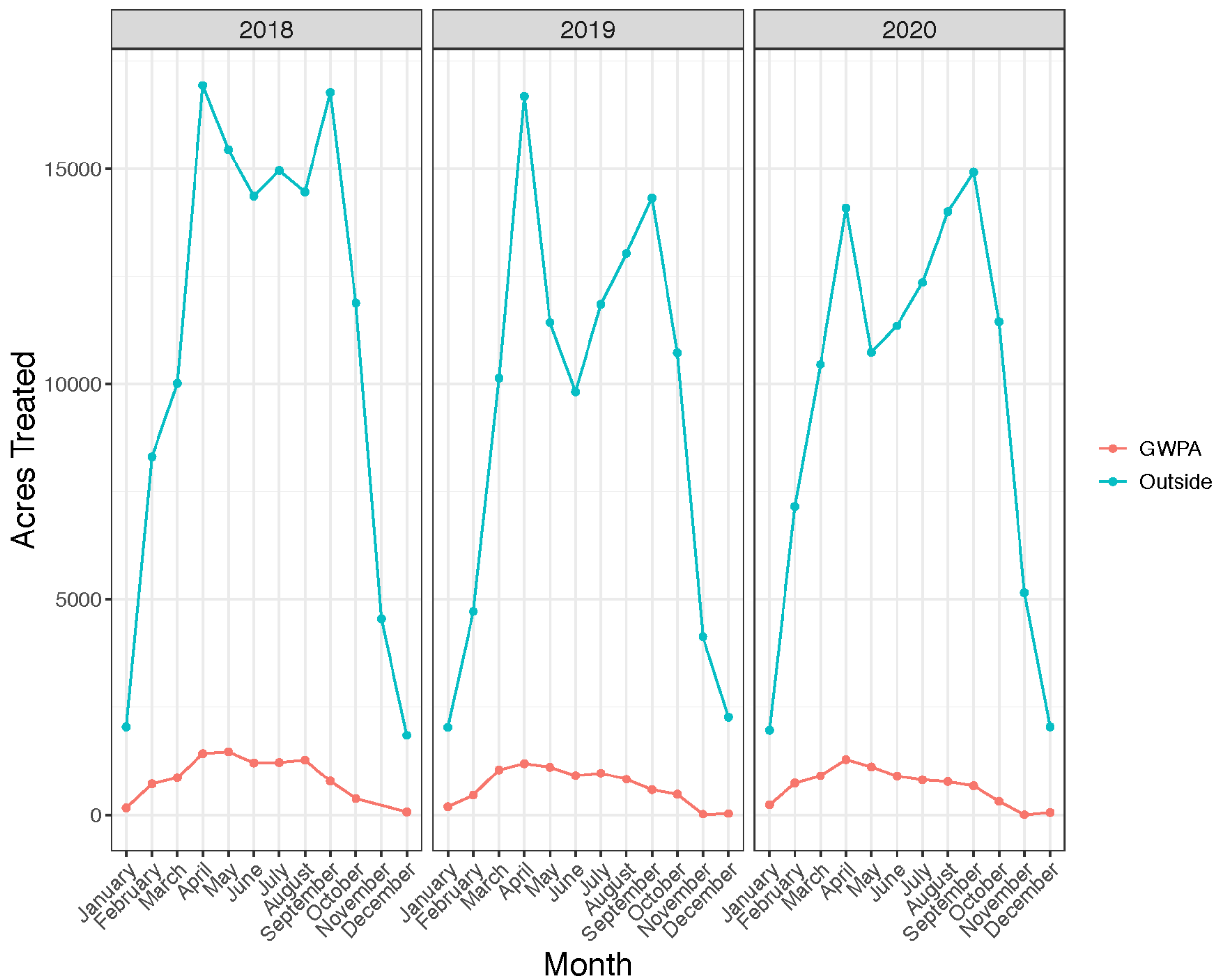

Figure 12. Monthly use of imidacloprid within and outside of GWPAs: Lettuce, 2018-2020

Table 30. County-level Imidacloprid Use on Lettuce within Ground Water Protection Areas, 2018-2020: Three-year Total

County	Pounds applied	Acres treated	% GWPA pounds	% GWPA acres
Fresno	31	108	0.8	0.4
Monterey	898	13,173	24.2	52.5
Riverside	10	24	0.3	0.1
San Luis Obispo	2,729	11,604	73.7	46.3
Stanislaus	37	169	1.0	0.7

Table 31 reports the annual use of imidacloprid and alternative AIs in GWPAs for the 2018-2020 period based on pounds applied and acres treated. It also includes the average use rate of each AI per acre, calculated by dividing the total pounds applied over the three-year period by the total number of acres treated. By acres treated, permethrin was the most used AI, followed by spirotetramat and sulfoxaflor.

Table 31. Annual Use of Imidacloprid and Alternative Active Ingredients in Ground Water Protection Districts: Lettuce, 2018-2020

Active ingredient	----------Pounds applied---------				------------Acres treated------------				Use rate (lb/ac)
	2018	2019	2020	Total	2018	2019	2020	Total	
acephate	3,969	2,613	3,497	10,078	4,090	2,703	3,785	10,578	0.95
acetamiprid	108	113	190	411	1,487	1,585	2,631	5,703	0.07
beta-cyfluthrin	46	35	58	139	1,899	1,456	2,353	5,709	0.02
bifenthrin	15	4	13	31	148	40	130	318	0.10
clothianidin	0	6	1	8	5	92	17	114	0.07
dimethoate	96	82	59	237	385	330	236	950	0.25
flonicamid	153	253	140	546	1,965	2,989	1,684	6,639	0.08
flupyradifurone	1,012	810	526	2,349	6,577	5,365	3,315	15,257	0.15
imidacloprid	1,323	1,183	1,198	3,704	9,524	7,774	7,779	25,077	0.15
permethrin	1,847	2,276	2,313	6,436	12,249	13,822	13,558	39,630	0.16
pymetrozine	34	90	10	134	401	1,045	115	1,561	0.09
spirotetramat	1,008	965	913	2,886	13,666	13,108	12,577	39,351	0.07
sulfoxaflor	216	282	403	901	6,991	9,019	12,149	28,159	0.03
thiamethoxam	480	512	413	1,405	8,492	9,417	7,397	25,306	0.06
zeta-cypermethrin	79	102	17	198	1,603	2,106	339	4,048	0.05

Economic Analysis

This section presents the estimated change in pest management costs for lettuce 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 32. Representative Product Cost per Acre: Lettuce

Active ingredient	Representative product	Material cost ($)	Application cost ($)	Total cost ($)
(s)-cypermethrin	Mustang	3.82	23.31	27.14
Acephate	Acephate 97UP Insecticide	14.70	24.92	39.62
Acetamiprid	Assail 70WP Insecticide	25.46	23.66	49.12
beta-cyfluthrin	Baythroid XL	10.61	24.58	35.19
Bifenthrin	Sniper	25.19	25.00	50.19
Clothianidin	Belay Insecticide	9.74	25.00	34.74
Dimethoate	Drexel Dimethoate 4EC	2.96	24.96	27.92
Flonicamid	Beleaf 50 SG Insecticide	31.48	22.2	53.68
Flupyradifurone	Sivanto Prime	43.02	22.89	65.91
Imidacloprid	Admire Pro	9.47	22.77	32.24
Permethrin	Perm-Up 3.2 EC Insecticide	6.86	23.31	30.17
Pymetrozine	Fulfill	20.98	24.95	45.93
Spirotetramat	Movento	41.83	24.00	65.83
Sulfoxaflor	Sequoia	34.25	23.58	57.83
Thiamethoxam	Actara	14.21	24.39	38.60

Table 32 reports the representative products for each active ingredient used on lettuce from 2018 to 2020 and the average cost per acre. Average cost per acre for each AI was calculated based on all applications. The average use rate was computed by dividing total pounds applied over the three-year period by the total acres treated. The pesticide material cost was obtained by multiplying the average use rate by the price per pound of AI, which was calculated based on the product formulation and product price. Application costs were calculated based on the different application methods mentioned previously. Including material and application costs, the cost per acre varied for the different AIs, ranging from $27.14 for (s)-cypermethrin to $65.91 for flupyradifurone.

Table 33. Average Annual Acreage Shares of Alternative Insecticides for Imidacloprid and Shares of Composite Alternative: Lettuce, 2018-2020

Active ingredient	Acreage share with imidacloprid available (% of imidacloprid and alternative use)	Share of composite alternative (%)
(s)-cypermethrin	1.9	2.2
Acephate	5.1	5.8
Acetamiprid	2.7	3.1
beta-cyfluthrin	2.7	3.1
Bifenthrin	0.2	0.2
Clothianidin	0.1	0.1
Dimethoate	0.5	0.5
Flonicamid	3.2	3.6
Flupyradifurone	7.3	8.3
Permethrin	19.0	21.6
Pymetrozine	0.7	0.9
Spirotetramat	18.9	21.5
Sulfoxaflor	13.5	15.4
Thiamethoxam	12.1	13.8
Total	88.0	100.0

Note: Three-year average from 2018-2020.

Table 33 provides the acreage shares for the alternatives used on lettuce from 2018 to 2020. The second column reports the acreage share treated with each alternative active ingredient when imidacloprid is available. On average, 12% of treated lettuce acreage was treated with imidacloprid each year. 88.0% was treated with an alternative. Prohibited applications of imidacloprid were replaced proportionately with alternatives AIs. The third column reports the share of each alternative in the composite alternative used to replace applications that would be prohibited under this scenario. The three most applied alternative AIs are permethrin, spirotetramat, and sulfoxaflor, which together would account for 58.5% of treated acreage without imidacloprid. Note that because use was scaled up based on all use, their shares in the overall use of alternatives may not represent their use as a substitute for imidacloprid for any specific pest.

Table 34. Costs Per Acre for Imidacloprid and the Composite Alternative: Lettuce

Active ingredient	Material cost ($)	Application cost ($)	Total cost ($)	Cost increase of switching to composite alternative (%)
Imidacloprid	9.47	22.77	32.24	50.3
composite alternative	24.70	23.74	48.45	-

Table 34 reports the average per acre costs for imidacloprid and the cost of the composite alternative. For lettuce, switching to alternatives would lead to increases in material cost and application cost. Total cost per acre would rise by $16.21 (50.3%) on imidacloprid-treated acreage.

Table 35. Change in Treatment Costs due to Restriction of Imidacloprid: Lettuce, 2018-2020

Year	Cost with imidacloprid ($)	Cost without imidacloprid ($)	Change in cost ($)	Change in cost (%)	Share of change due to material costs (%)	Share of change due to application costs (%)
2018	315,524	474,120	158,596	50.3	94.0	6.0
2019	260,192	390,976	130,783	50.3	94.0	6.0
2020	263,834	396,448	132,614	50.3	94.0	6.0

Table 35 summarizes the annual change in total pesticide costs owing to restriction of imidacloprid for each of the three base years. The total increase in costs would have been between $130,783 and $158,596.

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