Organic Pesticide Use in Almond: 2015-2019

Houston Wilson, Asst. Cooperative Extension Specialist
Dept. Entomology, UC Riverside
Brian Gress, Senior Environmental Scientist, Office of Pesticide Consultation and Analysis, California Department of Food and Agriculture

11/18/2022

Introduction

Almonds are a leading crop in California and in 2020 generated $5,619,930 in annual farm-gate sales. This alone accounts for 11% of the total annual value of California agriculture ($49,081,688), making it the second most valuable commodity in the state (the first is milk and cream, valued at $7,466,612 annually). In terms of acreage, almond orchards account for approximately 17% of total cropland in the state (as of 2017, total estimated cropland is 9,333,400 acres). Almonds are planted throughout the Central Valley, from the northern Sacramento Valley to the southern San Joaquin Valley. Such extensive production makes this crop highly visible, and as such it can easily become the focus of public concerns about pesticide use and, more generally, environmental impacts of crop production.

The primary arthropod pest of almonds is the navel orangeworm (Pyralidae: *Amyelois transitella*) (NOW). This insect overwinters as larvae or pupae in the remnant "mummy" nuts left behind in the orchard after harvest. In the summer, adults deposit their eggs directly onto the nuts, and the larvae feed on the developing almond kernel. Infestation by NOW not only reduces crop yield and quality, but is also associated with incidence of *Aspergillus* spp., which can lead to the production of aflatoxin, a known human carcinogen that is heavily regulated in key markets. As such, almond growers have a very low tolerance for NOW damage, and typically aim to achieve no more than 1-2% infestation annually.

Large plant bugs are another major pest of almonds. This includes the leaffooted plant bug (Coreidae: *Leptoglossus zonatus*) (LFB) and green stink bug (Pentatomidae: *Acrosternum hilare*) (GSB), and to a lesser extent the red-shouldered stink bug (Pentatomidae: *Thyanta custator accerra*). These are pierce-suck feeders with strong mouthparts that can penetrate the almond hull. Feeding from plant bugs early in the season (typically LFB) can cause the developing almond kernel embryo to wither and abort. Feeding later in the season (typically GSB) can cause the kernel to become wrinkled, misshapen and/or have a dark stain.

Webspinning spider mites (Tetranychidae: *Tetranychus* spp.) also pose a significant threat to almonds. These acarid pests feed on the leaves, which causes stippling and can lead to premature leaf drop. This damage reduces crop production and tree vigor, the impacts of which are typically seen in the following year.

There are also a variety of minor and sporadic pests that can be problematic at times, including peach twig borer (Gelechiidae: *Anarsia lineatella*), San Jose scale (Diaspididae: *Diaspidiotus [=Quadraspidiotus] perniciosus*), Tenlined June Beetle (Scarabaeidae: *Polyphylla* spp.) and ants (Formicidae: *Tetramorium caespitum, Solenopsis xyloni*).

Methods and Data

This analysis is a review of all material applied to California almond over a 5-year period (2015-2019) that was approved for certified organic production by (1) the Organic Materials Review Institute (OMRI), (2) the Washington State Department of Agriculture (WSDA) Organic Program, or (3) the United States Department of Agriculture (USDA) National List of Allowed and Prohibited Substances. A total of 71 organic-allowed products were applied to almond during this time frame according to data from California's Pesticide Use Reporting (PUR) database. Within the dataset, fields were classified as 'organic' if only organic-allowed products were applied throughout the study period. Fields that included a mixture of allowed and prohibited products were classified as 'conventional'. After identifying organic and conventional fields based on spray history, total annual field acreage for each production type was then estimated. Information on the target pests associated with the different pesticide use timings, as well as utilization of cultural and biological controls, were obtained from personal communications with growers, pest control professionals and UC Cooperative Extension personnel.

Almond Production Trends

According to estimates based on PUR data, organic almond acreage in California increased from 7,296 acres in 2015 to 16,190 acres in 2019 (122% increase), while conventional acreage increased from 1,135,600 to 1,432,578 (26% increase) during the same time period. These values include all land dedicated to almond production, including bearing and non-bearing fields that received at least one pesticide treatment. These numbers differ slightly from the official estimates published by CDFA, which in 2019 reported 15,206 acres of organic almonds and a total acreage (bearing and non-bearing) of 1,530,000 acres. In both cases, organic almonds represent about 1% of total almond acreage in the state.

While almonds are grown throughout the entirety of the Central Valley, the top five counties with the largest share of total acreage are Fresno (22% of all almond acres), Kern (19%), Stanislaus (18%), Madera (13%) and San Joaquin (9%) counties. Organic acreage has a slightly different geographic distribution. Fresno County still leads with 43% of all organic almond acres, but this is followed by Merced (13%), Tulare (11%), Madera (9%) and Stanislaus (6%) counties. This distinct geography could suggest that certain almond production regions may be better suited for organic production, although there may be other factors driving this trend.

Use of Organic Products in Both Conventional and Organic Almond Orchards

The most commonly used organic products include horticultural mineral and petroleum oils, which account for 67% of the total acres treated with organic products. This is followed by various forms of copper, especially copper hydroxide. Next is sulfur and *Bacillus thuringiensis* subsp. kurstaki, which in combination with oils and coppers account for 90% of total acres treated with organic products). Most of these products were frequently reported from both conventional and organic orchards, although it is important to note that total share of conventional acreage was relatively small compared to total share of organic acreage. That is, with the exception of oils, a relatively small proportion of conventional growers appear to use any of these organic-allowed products (Figure 1), whereas organic growers heavily rely upon them (Figure 2). Evidence of this can be seen not only in terms of total treated acres, but also by total number of applications per field, with organic growers typically applying these products more frequently on any given field compared to conventional. As such, the few conventional growers that utilized organic products are likely using them as a part of a larger rotation with non-organic products.

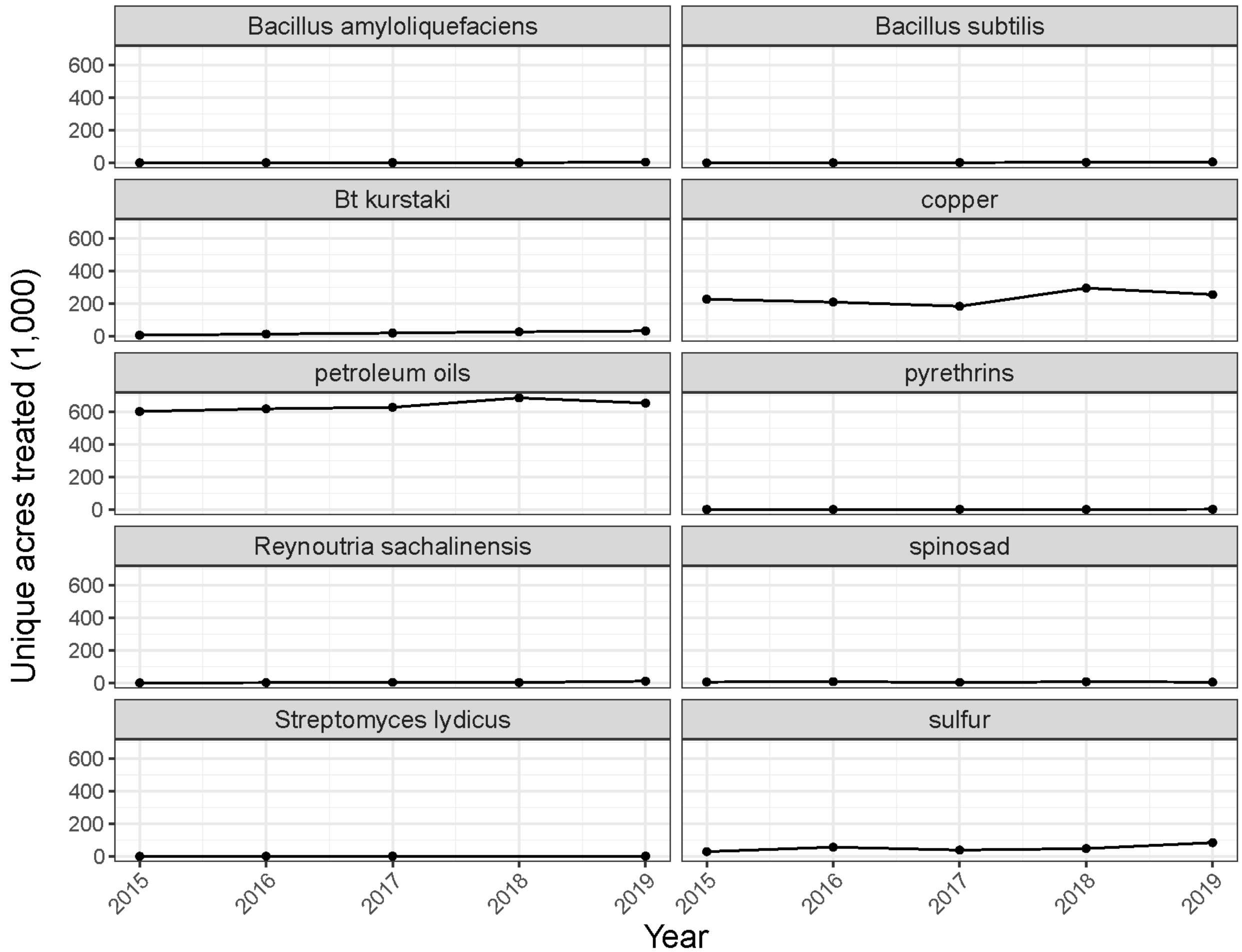

Figure 1. Unique conventional field acres treated per year with top organic active ingredients: almonds, 2015-2019. Total conventional production increaed from 1.1 million to 1.4 million acres during this timeframe.

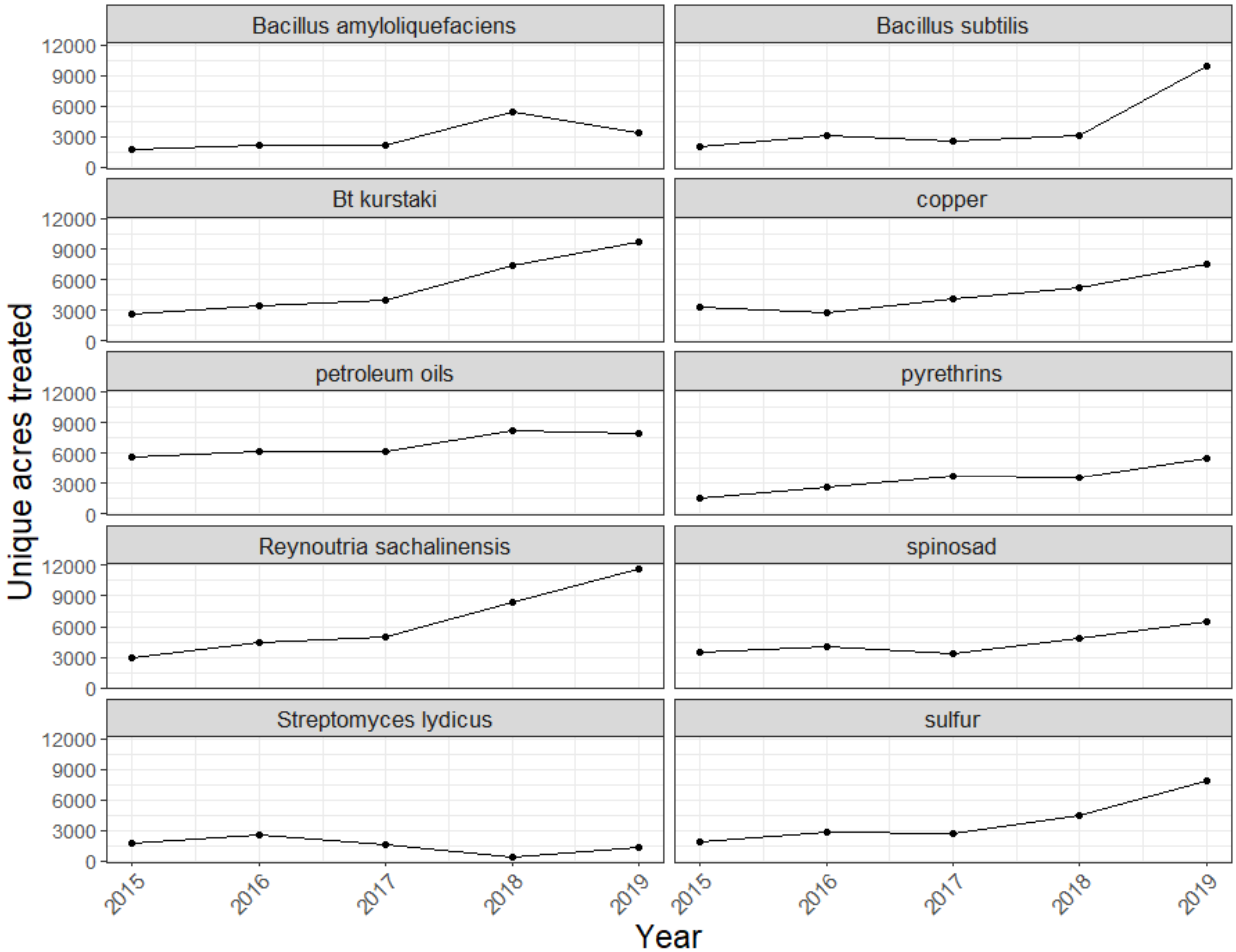

Figure 2. Unique organic field acres treated per year with top organic active ingredients: almond, 2015-2019. Total organic production increased from 7,296 to 16,190 acres during this timeframe.

Primary Products Used in Organic Almond

When data were compared between 'organic' and 'conventional' fields, unique use trends emerged for organic almond production. In organic orchards, the most commonly used products (as a proportion of total treated acreage) were *Bacillus thuringiensis* (*Bt*), *Reynoutria sachalinensis*, and petroleum/mineral oils, followed by sulfur, spinosad, *Bacillus subtilis* strain QST 713, pyrethrins, copper hydroxide, *Bacillus amyloliquefaciens* strain D747, *Streptomyces lydicus* and *Paecilomyces fumosoroseus apopka* strain 97 (Figure 2). In combination, these products account for 80% of total treated acreage in organic almond orchards. Within this group, *Bt*, *R. sachalinensis*, petroleum/mineral oils, sulfur and spinosad alone account for just over half (53%) of the total treated acres. More details on each of these active ingredients can be found below in the Description and Use Trends for Specific Active Ingredients section.

Description and Use Trends for Specific Active Ingredients

Arthropod Management

Navel Orangeworm and Other Lepidoptera

Navel orangeworm (Pyralidae: *Amyelois transitella*) (NOW) is arguably the most important arthropod pest of almonds. The main products used by organic growers for control of NOW include *Bacillus thuringiensis* (*Bt*) (most common products include DiPel®, Valent; Deliver®, Certis; Xentari®, Valent) and spinosad (Entrust®, Corteva; Seduce®, Certis). Applications of both AIs start in the early spring (March/April) and then ramp up in July during almond hull-split when the crop becomes vulnerable to attack by NOW (Figure 3 and Figure 4). Total annual use averaged approximately 49,500 acres treated with *Bt* and 16,800 acres treated with spinosad. While *B. thuringiensis* subsp. kurstaki is the most commonly applied form of *Bt*, records also include *B. thuringiensis* subsp. aizawai and *B. thuringiensis* subsp. israelensis. While it is evident that *Bt* is mostly used for control of NOW, it can also impact other Lepidoptera pests of almonds such as peach twig borer (Gelechiidae: *Anarsia lineatella*). In conventional fields, use of *Bt* was highest in the early spring period (Figure 3), which is likely for control of peach twig borer and/or a spring spray for NOW.

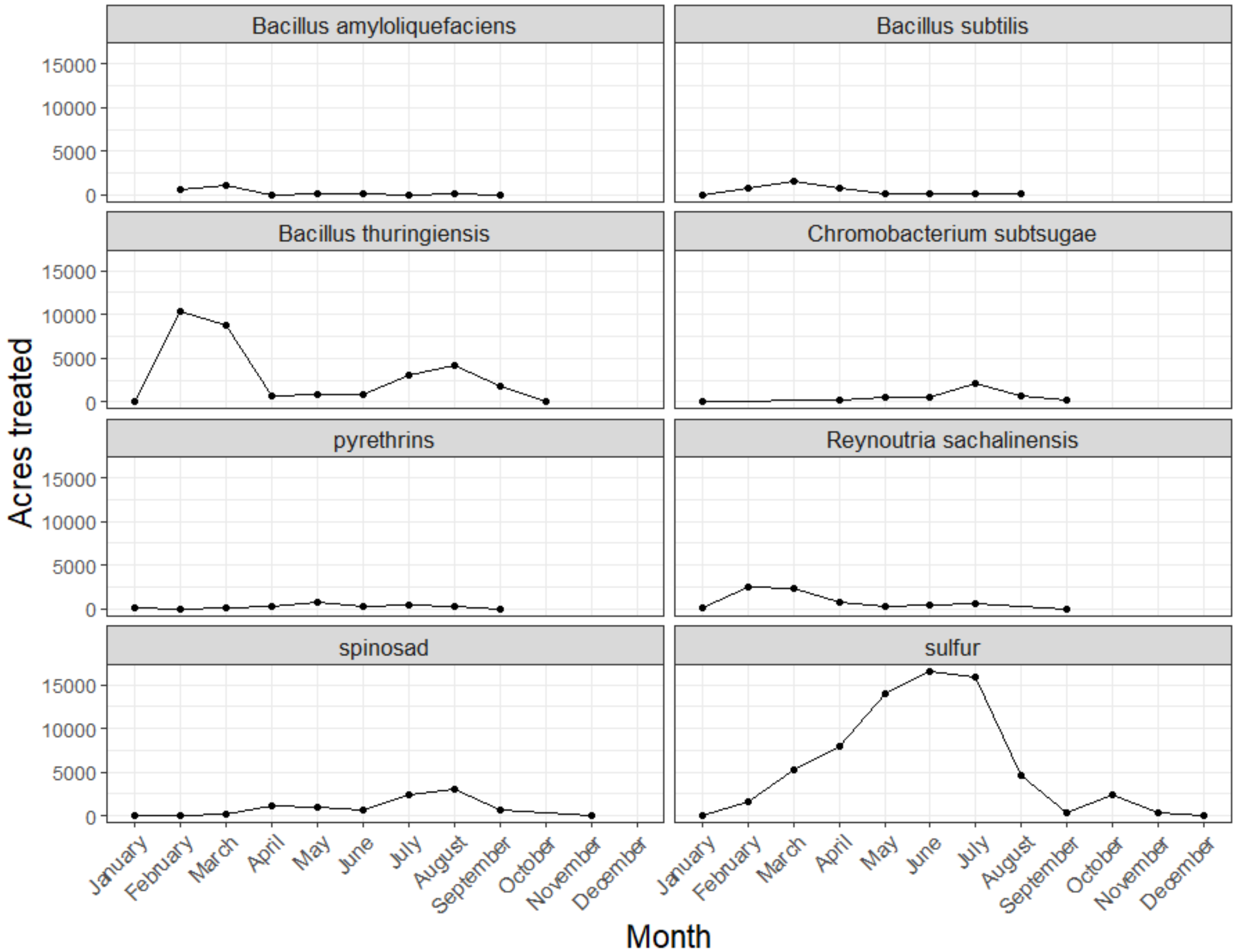

Figure 3. Average monthly acres treated in conventional fields with selected organic active ingredients (AIs). Values were calculated by dividing monthly totals (2015-2019) for each AI by the number of years in our study period (five). Standard errors were not calculated due to some AIs only being applied in a single year.

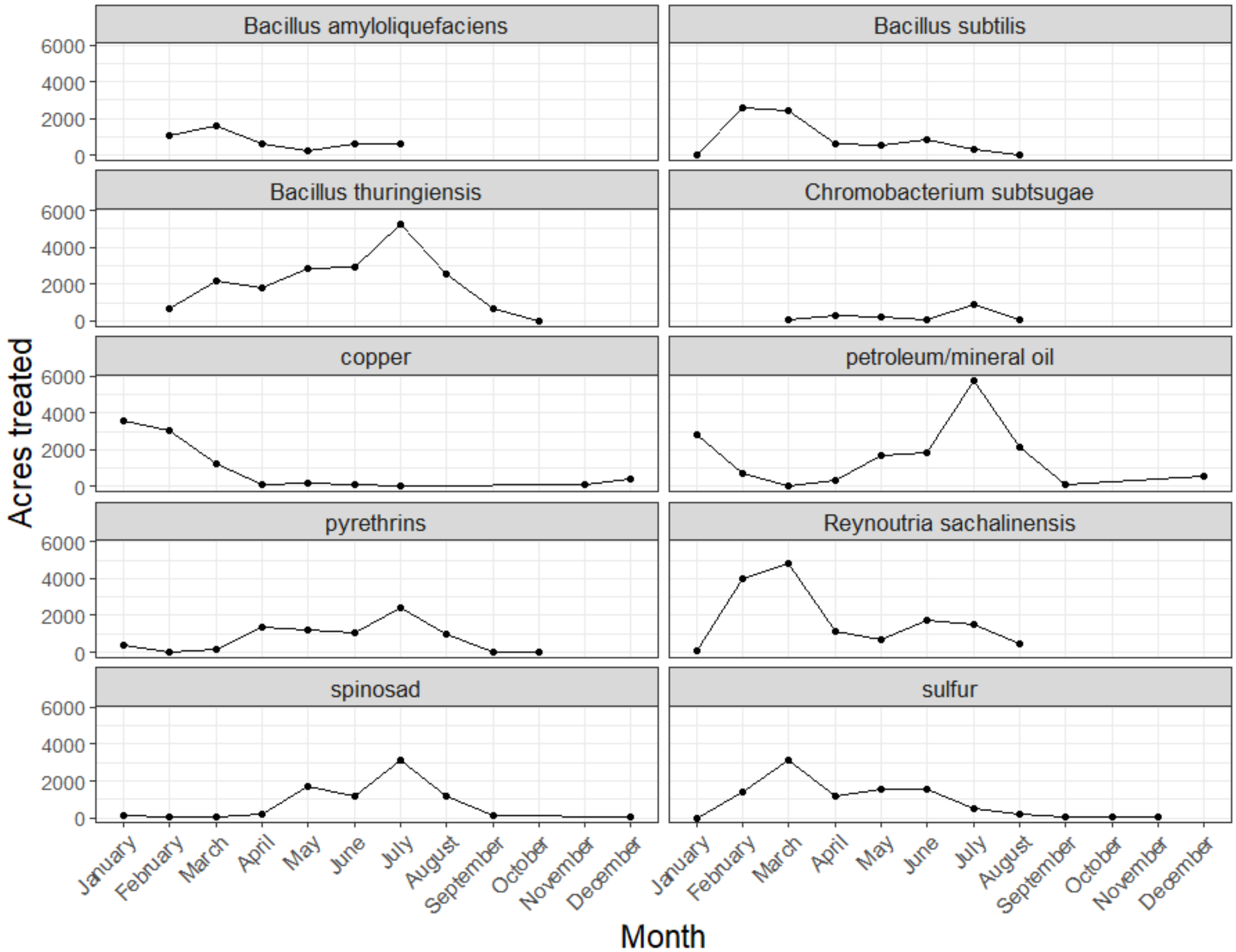

Figure 4. Average monthly acres treated in organic fields with selected organic active ingredients (AIs). Values were calculated by dividing monthly totals (2015-2019) for each AI by the number of years in our study period (five). Standard errors were not calculated due to some AIs only being applied in a single year.

Mating disruption (active ingredient: (z,z)-11,13-hexadecadienal) has been developed for NOW, and there are currently five commercially available products on the market (Checkmate NOW®, Suterra; Isomate NOW®, Pacific Biocontrol; Semios NOW® and NOW Eco®, Semios; Cidetrak®, Trece), two of which are organic-allowed products (Cidetrak®, Trece; NOW Eco®, Semios), although NOW Eco® has only recently become allowed for use in organic and so is not captured in this report.

While use of mating disruption was extensive in conventional orchards, there were fewer than 250 acres of use in organic. This may be due to the unique labor requirements of the Cidetrak® product. While most of the mating disruption products utilize aerosol emitters placed at 1-2 emitters/acre, the Cidetrak®

technology relies upon polymeric emitters that need to be hung from the tree canopy at a rate of 20 emitters/acre. This requirement may have reduced adoption due to the increased labor requirements for installation and end-of-season removal.

Records from the PUR also indicate some negligible use of additional mating disruption products, including e-e-8,10-dodecadien-1-ol (Checkmate CM®, for codling moth, Tortricidae: *Cydia pomonella*), z,e-9,12-tetradecadien-1-yl acetate and (z)-11-hexadecen-1-yl acetate (Checkmate BAW-F®, for beet armyworm, *Spodoptera exigua*) and z-8-dodecenol, e-8-dodecenyl acetate, and z-8-dodecenyl acetate (Checkmate OFM®, for oriental fruit moth, Tortricidae: *Grapholita molesta*).

Reporting of mating disruption in the PUR database is potentially skewed due to the unique method of product application. Unlike other pesticides, the use of aerosol mating disruption (i.e. 'puffers') is frequently contracted through the vendor, who then oversees installation, initiation and take-down of the mating disruption product. In many cases this leads to confusion over who should report use of the AI to DPR. Furthermore, there is evidently some additional confusion about reporting requirements for mating disruption products, since many do not consider them a traditional 'chemical control'. As evidence of this, certain products appear to be under-reported in the PUR database, including Semios, Trece and Pacific Biocontrol.

Finally, several products may be used to control both NOW and large plant bugs, in some cases simultaneously. In the spring, pyrethrins (PyGanic®, MGK) and *Chromobacterium substugae* strain praa4-1 (Grandevo®, Marrone) are most likely used to target plant bugs, but growers may see some added benefit of potential NOW control. In contrast, NOW is more likely to be the primary target of summer applications of pyrethrins, *Chromobacterium substugae* strain praa4-1, azadiracthrin, and *Burkholderia* sp. strain a396 (Venerate®, Marrone) (see Large Plant Bug section below for more information)

Large Plant Bugs

Pyrethrins is mostly applied in April - May and again in July (Figure 3 and Figure 4), with total use averaging just under 10,000 acres treated per year. While this use pattern mimics spring and summer applications for NOW, growers are more likely using this AI for control of large plant bugs, similar to pyrethroids in conventional orchards. The large plant bugs include the leaffooted plant bug (Coreidae: *Leptoglossus zonatus*), green stink bug (Pentatomidae: *Acrosternum hilare*), redshouldered stink bug (Pentatomidae: *Thyanta custator accerra*) and Uhler stink bug (Pentatomidae: *Chlorochroa uhleri*).

Chromobacterium subtsugae strain praa4-1 (Grandevo®, Marrone) is less commonly used, averaging approximately 5,700 acres treated per year, but follows a similar use pattern as *Bt* and spinosad (Figure 3 and Figure 4). Like pyrethrins, the purpose of spring applications of *C. subtsugae* is less clear, since they may be primarily targeting large plant bugs and/or NOW at this time of year.

Azadirachtin (i.e. neem oil, margosa oil) is applied to approximately 4,200 acres per year and is mostly used in July, ostensibly for control of NOW and/or plant bugs. There is another use peak in January, albeit smaller, which may be for control of brown and red mites. Various azadirachtin products are utilized, the most common include Azera® (MGK), Debug Turbo® (Agro Logistic Systems), Aza-Direct® (Gowan) and Neemix® (Certis).

Burkholderia sp. strain a396 (Venerate®, Marrone) is also mostly applied in July/August, with some other applications in June. Similar to the other products, these application timings may be for control of NOW, mites and/or plant bugs. On average, 4,300 acres are treated with *Burkholderia* sp. per year.

Mites and Scale

As mentioned, oils are applied as a delayed dormant for control of both disease and arthropods, including San Jose scale (Diaspididae: *Quadraspidiotus perniciosus)*, brown mite (Tetranychidae: *Bryobia rubrioculus)* and European red mites (Tetranychidae: *Panonychus ulmi*). Organic growers also apply oils in the summer for mite control (Figure 4), with peak use in July likely targeting web-spinning spider mites (Tetranychidae: *Tetranychus* spp.). Another product used for mite control is *Paecilomyces fumosoroseus* apopka strain 97 (PFR-97TM®, Certis), the use of which peaks in June/July. Both *Burkholderia* sp. strain a396 (Venerate®, Marrone) and azadirachtin (various products) may also be used for control of mites, with use records indicating that the former may be a summer application and the latter a delayed dormant application.

Albeit negligible, the combined use of citronellol (3,7-dimethyl-6-octen-1-ol), nerolidol, farnesol, and geraniol (combined into a product called Biomite®, Arysta) was seen over the June - August period. These compounds are derived from mite pheromones and thought to enhance activity of males, which increases efficacy when combined with a miticide.

Finally, as mentioned earlier, potassium silicate (Sil-MATRIX®, Certis) and sulfur may also have some activity against mites, and use during the summer period may be for both disease and mite control. Here the overall use of potassium silicate was negligible relative to the other organic mite/scale and disease products.

Nematodes

Use of organic nematicides was generally negligible, although records indicate some applications of *Myrothedium verrucaria*, dried fermentation solids (DiTera DF®, Valent) in April/May, as well as some very limited use of *Purpureocillium lilaciunum* strain 251 (MeloCon WG®, Certis) sporadically across the spring period. There was also an instance where quillaja (Nema-Q®, Brandt), an extract of the soap bark plant (Quillajaceae: *Quillaja saponaria*) was applied as a nematicide in the spring and summer in some conventional fields.

Arthropod Management – Other

Iron phosphate (Bug-N-Sluggo®, Certis) was reported only in conventional fields. This is a pest control product recommended for control of a wide range of organisms including ants, earwigs, cutworms, slugs and snails. Boric acid (Boric Acid Roach Gel®, PIC) was also recorded in some conventional fields, ostensibly for control of roaches, although these are not a known pest of almonds.

Disease Management

Delayed Dormant (December – January)

Fungicide applications during the delayed dormant period (December – January) target a wide range of fungal and bacterial diseases, including shot hole (Incertae sedis: *Stigmina carpophila)* and scab (Venturiaceae: *Cladosporium carpophilum*). As mentioned, mineral and petroleum oils are primarily used for disease control during this period, as well as for mite control in summer (May - July), with the latter use primarily limited to organic growers since conventional have more effective miticides available (Figure 4). Various coppers are also applied as a delayed dormant for disease control (Figure 4). Copper hydroxide is the most common, but other formulations include copper, copper oxychloride, copper oxide, copper octanoate and copper sulfate. All of these are used for disease control. While much less common, use of lime-sulfur can also be seen at this time for control of similar diseases.

Almond Bloom (February – March)

Almond bloom occurs over the February – March period and is another critical time for control of fungal and bacterial pathogens such as brown rot (Sclerotiniaceae: *Monilinia laxa*), scab, anthracnose (Glomerellaceae: *Colletotrichum gloeosporioides*), shot hole and jacket rot (Sclerotiniaceae: *Botrytis cinerea*; *Monilinia laxa*; *Sclerotinia sclerotiorum*). The most commonly used organic fungicide during bloom is *Reynoutria sachalinensis* (Regalia®, Marrone), which is applied both at bloom and then again in June/July, the latter likely as a preventative against bacterial pathogens such as scab, anthracnose, shot hole, rust (Uropyxidaceae: *Tranzschelia discolor*), and Alternaria leaf spot (Pleosporaceae: *Alternaria* spp.) (Figure 3 and Figure 4). In organic fields, sulfur is commonly applied at bloom, with an additional peak of applications in May, which is likely for control of similar diseases (e.g. rust) and possibly mites (Figure 4). This is in contrast to non-organic fields, where use of sulfur was mostly restricted to June/July, which is likely just for disease control, but not mites (Figure 3).

Additional organic products with moderate use around the bloom period include *Bacillus subtilis* strain QST 713 (Serenade®, Agraquest), *Bacillus amyloliquefaciens* strain d747 (Double Nickel 55®, Certis), and *Streptomyces lydicus* wyec 108 (Actinovate AG®, Natural Industries Inc.) (Figure 3 and Figure 4).

There was also some recorded use at bloom, albeit negligible, of peroxyacetic acid (OxiDate®, Biosafe Systems), *Aureobasidium pullulans* strain dsm 14940 (Botector®, Westbridge) and *Ulocladium oudemansii* (u3 strain) (BotryStop®, Bioworks). Some conventional growers also applied peroxyacetic acid in mid-summer (July), most likely for disease control (e.g. hull rot), but some growers may also use this product to clean out irrigation lines.

Summer Applications (April – August)

During the summer period (April – August), the most commonly used organic fungicide is *Reynoutria sachalinensis* (Regalia®, Marrone), which has use peaks during both the bloom (February - March) and summer periods (June/July) (Figure 3 and Figure 4). Sulfur is also used in the summer. While applications peak at bloom and again in May, there is fairly consistent use over the April - June period and then it tails off in July/August. Other organic products that are commonly applied in the late spring or summer period include *Bacillus amyloliquefaciens* strain d747 (Double Nickel 55®, Certis) and *Streptomyces lydicus* wyec 108 (Actinovate AG®, Natural Industries Inc.).

There was also some negligible use of *Bacillus mycoides* isolate j (LifeGard®, Certis) and potassium silicate (Sil-MATRIX, Certis) during the summer period. The former is a biostimulant that claims to enhance protection against diseases while the latter is a fungicide that potentially has activity against mites as well.

Finally, use of *Aspergillus flavus* strain af36 (AF36 Prevail®, Arizona Cotton Research and Production Council) was recorded over the May-July period, although only in conventional fields. This product is used for control of *Aspergillus* spp. fungal pathogens that lead to the production of aflatoxins, which are known human carcinogens that are heavily regulated in key markets. Control of NOW is important for management of *Aspergillus*, since this fungus is associated with infestations by this pest. AF36 is relatively new on the market and use in almonds and pistachios has been steadily increasing over the past 5 years.

Practices Not Included in PUR

Biological Controls

Classical Biological Control

There are some parasitoids and predators native to California that have been documented to attack NOW. This group includes the larval parasitoids *Parasierola* (=*Perisierola*) *breviceps* (Bethylidae), *Mesostenus gracilis* (Ichneumonidae), and *Microbracon hebetor* (Braconidae) as well as multiple predators that attack the eggs and/or larvae: a predaceous mite (Ascidae: *Blattisocius tarsalis* [=*tineivorus*]), small plant bugs (Miridae: *Phytocoris* spp.), green and brown lacewing larvae (Chrysopidae: *Chrysoperla* spp.; Hemerobiidae: *Hemerobius* spp.), as well as a predaceous beetle (Cleridae: *Cymatodera ovipennis*). Early research on NOW in California determined that none of these native natural enemies were suitable for adequate control of NOW, and so more effective natural enemies were sought out from other areas of the world. This resulted in the introduction of the egg-larval parasitoid *Copidosoma* (=*Pentalitomastix*) *plethorica* (Encyrtidae) from Mexico in the 1960s, followed by the introduction of the larval parasitoid *Goniozus legneri* (Bethlyidae) from Uruguay in the 1970s. Both parasitoids have established in California and can be found attacking NOW in almond orchards. That said, each of these parasitoids has unique behavioral features that cause them to be less effective when NOW is in low abundance. Since growers are trying to achieve <2% infestation rate, these biological controls must be augmented by other strategies.

Augmentative Biological Control

Some natural enemies that could potentially be useful for control of almond pests are available through commercial insectaries, such as green lacewings (Chrysopidae: *Chrysoperla* spp.), predatory mites (Phytoseiidae: *Neoeiulus californicus*), sixspotted thrips (Thripidae: *Scolothrips sexmaculatus*) and the NOW parasitoid *Goniozus legneri* (Bethylidae). That said, the extent to which organic almond growers rely on augmentation of natural enemies to increase biological control of key pests appears to be somewhat limited, although there are commercial applicators that market natural enemy release programs in almonds.

Conservation Biological Control

Some organic almond growers may also try to enhance biological control of key pests by providing habitat, such as hedgerows and cover crops, to conserve and support a wide range of natural enemies for multiple crop pests. As with natural enemy augmentation, the full extent of these practices is unclear but appears to be fairly limited.

The primary natural enemy of leaffooted plant bugs (Coreidae: *Leptoglossus* spp.) is the egg parasitoid *Hadronotus* (=*Gryon*) *pennsylvanicus* (Scelionidae). This parasitoid is known to attack a wide range of coreid pests that includes multiple species of *Leptoglossus* spp. and *Anasa* spp., and it is thought that this wide host range limits the ability of *H. pennsylvanicus* to build up large populations in almond orchards in a timely manner. Furthermore, almonds are most vulnerable early in the season when *L. zonatus* adults move out of their overwintering aggregations, colonize the orchard and feed on the developing almonds. Given this phenology, there is no time for an egg parasitoid to limit the impacts of *L. zonatus* early in the season.

Recent studies have also documented the ability of naturally occurring populations of sixspotted thrips (Thripidae: *Scolothrips sexmaculatus*) to control webspinning spider mites (Tetranychidae: *Tetranychus* spp.) in almond orchards. This predatory thrips exhibit a density-dependent response to changes in mite populations, which in some situations allows them to rapidly build up their population and provide suitable biological control. The landscape ecology of sixspotted thrips is not well understood, and as such their efficacy may vary across different regions of the Central Valley.

Cultural Controls

Winter Sanitation

The most common cultural practice for pest management in organic almonds is winter sanitation of remnant "mummy" nuts for control of NOW. NOW overwinter as larvae or pupae in the unharvested remnant nuts that reside in the tree canopy and on the orchard floor over the winter period. As such, the removal and destruction of these overwintering hosts is a fundamental component of management for this pest, not just almonds but in pistachios and walnuts as well. Not only do these remnant nuts serve as overwintering sites for NOW, but first flight adult moths in the spring will also utilize them as a reproductive substrate. While almost all tree nut growers are aware of the need to sanitize their orchards, implementation of this practice can sometimes be limited due to high costs and/or unavailability of labor and equipment. Additionally, inclement weather and poor orchard conditions can further impede a grower's ability to operate heavy equipment on wet soils. The latter is a delicate tradeoff, since it is thought that shaking trees to remove remnant mummy nuts is most effective following a rain or fog event.

Habitat Diversification and Weed Control

As mentioned above, some growers do experiment with on-farm habitat diversification (e.g. hedgerows, cover crops) to support and enhance natural enemies of crop pests. At the same time, some growers try to minimize weedy habitat since it can potentially support populations of small and large plant bugs in the spring, which can then colonize the tree canopy in the early summer when resident weedy vegetation dries out. In the absence of effective organic herbicides, most organic growers resort to mowing, tillage and/or flaming to eliminate weedy vegetation.

Timely Harvest and Varietal Selection

Finally, timely/early harvest and varietal selection can influence crop infestation by NOW. That said, harvesting in a timely manner is primarily a logistical constraint, rather than a management decision, although a study recently demonstrated that deficit irrigation could be used to advance harvest date in almond. Varietal selection is even more limiting. While hard-shell varieties (e.g. Padre, Mission, Carmel) have been shown to be more resistant to NOW infestation, they are less valuable and more difficult to crack out than soft-shell varieties. Furthermore, NOW can still develop on the hulls of these hard-shell varieties, so they are certainly not immune to infestation. While some hard-shell varieties are planted in California (e.g. Butte/Padre orchards), growers generally tend to prefer soft-shell varieties for economic reasons and then use other chemical, biological and cultural strategies to manage NOW.