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Surveys and Needs Assessments

Outlook of Pyrethroid Insecticides for Pest Management in the Salinas Valley of California

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Abstract

Vegetable and strawberry (*Fragaria* × *ananassa* Duchesne ex Rozier) pest management involves intensive use of insecticides. Recently, pyrethroid insecticide residues toxic to benthic organisms (e.g., *Hyalella azteca* Saussure) were detected in the surface water of the Salinas Valley, California, resulting in the establishment of a Total Maximum Daily Load level for bifenthrin, cypermethrin, and lambda-cyhalothrin. Three discussion sessions and surveys were conducted during grower meetings held in Salinas, California, in 2016, regarding integrated pest management and critical use patterns of pyrethroid insecticides. Survey results were filtered to include only responses from qualified participants involved in pest management decisions on lettuce (*Lactuca sativa* L.), celery (*Apium graveolens var. dulce* Mill.), spinach (*Spinacia oleracea* L.), *Brassica* crops, and strawberry. Results indicated that there were many important crop-specific pests that were currently being controlled by pyrethroids, for example, western tarnished plant bug, *Lygus hesperus* Knight (Hemiptera: Miridae); *Bagrada hilaris* (Burmeister) (Hemiptera: Pentatomidae); cabbage looper, *Trichoplusia ni* (Hübner) (Lepidoptera: Noctuidae); and root maggots, *Delia* spp. (Diptera: Anthomyiidae). Participants suggested that the carbamate, methomyl, was the only effective alternative to pyrethroid insecticides for these pests. Although some lower risk controls may be useful on organic crops where there tends to be a higher tolerance for damage, lower risk controls will not be useful in conventional cropping systems until there is a higher tolerance for damage in the product. The survey indicated that insecticides selected for pest management were chosen based on cost, efficacy, low mammalian toxicity, and short reentry and preharvest intervals.

Key words: lettuce, celery, broccoli, strawberry, California's Central Coast

California's Salinas Valley is well-known worldwide for its vegetable production, especially lettuce (*Lactuca sativa* L.), *Brassica* crops [broccoli (*Brassica oleracea* var. *italica* Plenck) and cauliflower (*Brassica oleracea* L. var. *botrytis*)], spinach (*Spinacia oleracea* L.), and strawberry (*Fragaria* × *ananassa* Duchesne ex Rozier). Lettuce and *Brassica* crops were valued at $1.4 billion and $679 million USD, and grown on >44,174 and 34,390 ha, respectively, in the Salinas Valley (Monterey County Crop Report 2014). Strawberry constitutes $709 million USD in Monterey County. The Mediterranean climate and fertile soils (up to 4% organic matter) support production of other specialty crops such as artichoke (*Cynara cardunculus* var. *scolymus* L.), celery (*Apium graveolens var. dulce* Mill.), Brussels sprouts (*Brassica oleracea* var. *gemmifera*), and caneberries, red raspberry (*Rubus strigosus* L.) and blackberry (*Rubus ursinus* L.) as well as wine grapes (*Vitis vinifera* L.), nursery, and other agricultural industries. All together, the agricultural industry of the Salinas Valley is valued at $4.49 billion USD.

Farming high-value crops brings many pest management challenges. There are several economically important pests on the major crops grown in California's Salinas Valley. The soil pests, garden symphylan, *Scutigerella immaculata* (Newport) (Symphyla: Scutigerellidae), and seedcorn maggot, *Delia platura* (Meigen) (Diptera: Anthomyiidae), attack the developing roots of a wide range of direct-seeded and transplanted crops, whereas springtails, *Protaphorura fimata* Gisin (Poduromorpha: Onychiuridae), and bulb mites [*Rhizoglyphus* spp. (Sarcoptiformes: Acaridae), *Tyrophagus* spp. (Sarcoptiformes: Acaridae)] attack the germinating seeds of direct-seeded crops such as lettuce, broccoli, and onion (*Allium cepa* L.; Joseph 2015, Joseph et al. 2015). The major aphid pests affecting lettuce are green peach aphid, *Myzus persicae* (Sulzer) (Hemiptera: Aphididae), *Nasonovia ribis-nigri* (Mosley) (Hemiptera: Aphididae), and foxglove aphid, *Aulacorthum solani* (Kaltenbach) (Hemiptera: Aphididae), whereas cabbage aphid, *Brevicoryne brassicae* (L.) (Hemiptera: Aphididae) attacks *Brassica* crops (Natwick 2009a, b). The western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), and leafminers [pea leafminer, *Liriomyza langei* (Frick) (Diptera: Agromyzidae);

Table 1. Questionnaire used for the survey in the pyrethroid insecticide use second grower meeting at University of California Cooperative Extension—Monterey County, Salinas, CA, in 2016

No.	Questions[a]	Response rate (%)
1.*	Where are the crops you work with located?	29/39 (74%)
2.*	Which of the following best identifies your job?	37/39 (95%)
3.	How many lettuce acres do you currently make pest control decisions for?	23/39 (59%)
4.	How many cole crop acres do you currently make pest control decisions for?	25/39 (64%)
5.	How many celery acres do you currently make pest control decisions for?	24/39 (62%)
6.	How many strawberry acres do you currently make pest control decisions for?	22/39 (56%)
7.*	Respond only if you work with lettuce: Which pyrethroid insecticides do you use most for lettuce pest management?	16/39 (41%)
8.*	When do you decide to apply a pyrethroid insecticide?	23/39 (59%)
9.*	What factors do you consider when choosing pyrethroid insecticides for pest management?	22/39 (56%)
10.*	Respond only if you work with lettuce: Which lettuce pests do you control using permethrin?	16/39 (41%)
11.*	Respond only if you work with celery: Which celery pests do you control using permethrin?	15/39 (38%)
12.*	Respond only if you work with spinach: Which spinach pests do you control using permethrin?	11/39 (28%)
13.*	Respond only if you work with strawberry: Which strawberry pests do you control using bifenthrin?	14/39 (36%)
14.*	Which insecticides do you use to manage painted bug?	18/39 (46%)
15.*	Which insecticides are used to manage root maggots, springtails, and garden symphylan?	19/39 (49%)
16.	What would be the next best alternative after pyrethroids for controlling pests (e.g., to control lygus bug in lettuce?)	17/39 (44%)

*Participants could check more than one choice.

[a] This questionnaire was focused on major crops and pests in the Salinas Valley of California. The participants included PCAs, farm managers, and growers. Those individuals involved in academia or agro-chemical companies did not participate in the survey.

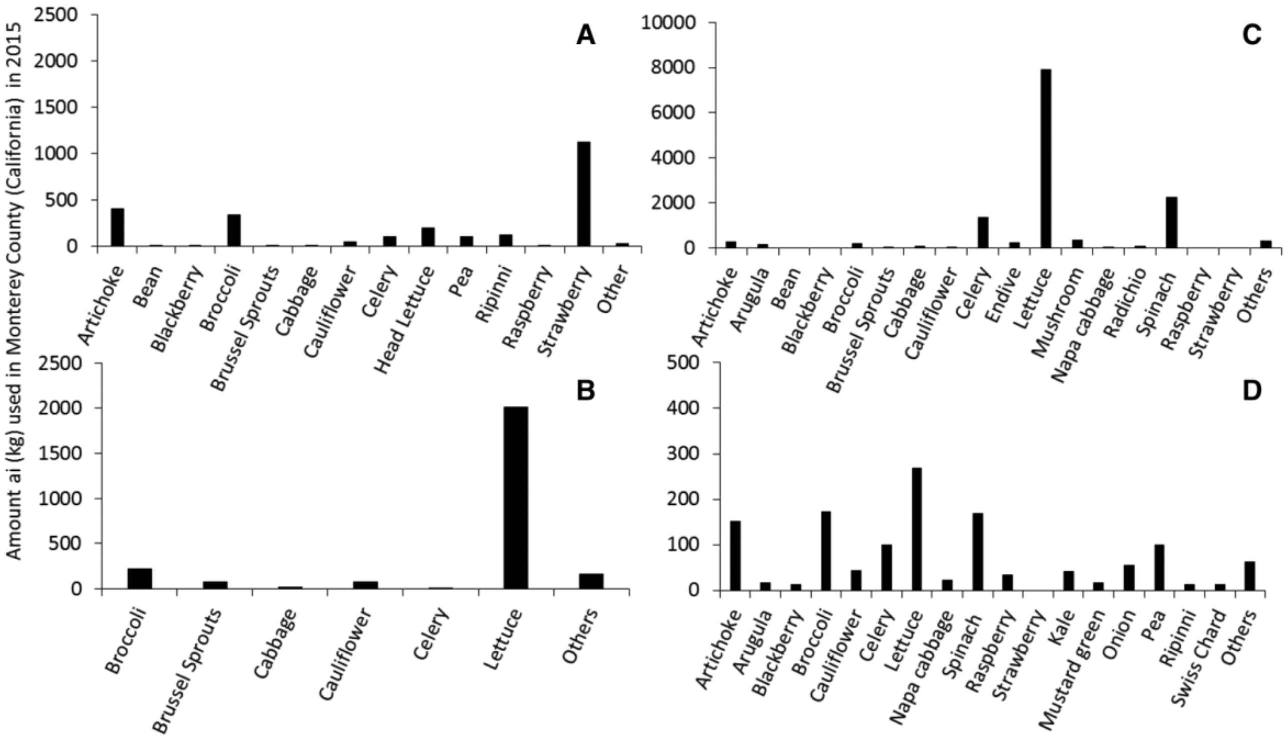

Fig. 1. Amount of insecticide active ingredient (kg)—(**A**) bifenthrin, (**B**) lambda-cyhalothrin, (**C**) permethrin, and (**D**) cypermethrin—used on various crops in Monterey County, CA, in 2015 (Agricultural Commissioner, Pesticide Use Report, Monterey County).

American serpentine leafminer, *Liriomyza trifolii* (Burgess) (Diptera: Agromyzidae); and vegetable leafminer, *Liriomyza sativae* (Blanchard) (Diptera: Agromyzidae)] are major pests of lettuce, celery, and strawberry. Plant-feeding heteropteran pests, primarily western tarnished plant bug or lygus bug, *Lygus hesperus* Knight (Hemiptera: Miridae), affect all the vegetable crops, including lettuce and celery and strawberry (Zalom et al. 2012, Joseph et al. 2016a), whereas *Bagrada hilaris* (Burmeister) (Hemiptera: Pentatomidae) is attracted to *Brassica* crops (Joseph 2014, Joseph et al. 2016b). The root-feeding cabbage maggot, *Delia radicum* (L.) (Diptera: Anthomyiidae), is a serious problem mainly in *Brassica* crops (primarily broccoli and cauliflower) in the Salinas Valley (Joseph and Martinez 2014).

Pest management in the Salinas Valley is primarily based on intensive use of insecticides such as organophosphates, pyrethroids, neonicotinoids, carbamates, and various reduced-risk insecticides. High insecticide use has resulted in issues for many organisms and environmental entities that were not the intended target of the pesticides ("nontarget"), as was the case of organophosphate insecticides (chlorpyrifos and diazinon). Chlorpyrifos and diazinon are strictly regulated by the Central Coast Regional Water Board (California Environmental Protection Agency [CEPA] 2013) after high levels of residues were detected in the water bodies (Hunt et al. 2003), posing risks to nontarget organisms and public health through contaminated water. Pyrethroid insecticides are now on the verge of being regulated as well (Central Coast Regional Water Quality Control Board [CCRWQCB] 2016) owing to the detection of toxic levels—particularly, bifenthrin, cypermethrin, and lambda-cypermethrin—in the lower reaches of the Salinas River, as they were transported attached to suspended sediments (Anderson et al. 2003a, b, 2006; Starner et al. 2006; Ng and Weston 2009; Schmidt et al. 2010).

Pyrethroid insecticides were derived from modified pyrethrins found in dried and powdered flower heads of *Chrysanthemum* spp., especially, *Chrysanthemum cinerariaefolium* (Soderlund and Bloomquist 1989). Permethrin was the first photostable pyrethroid insecticide developed for the worldwide agro-chemical industry (Elliott et al. 1973). Thereafter, several other pyrethroid insecticides were developed. As more and more pyrethroid insecticides came out of patent, they were manufactured by several agro-chemical companies, resulting in an increased supply of inexpensive, effective pesticide products with high toxicity to aquatic organisms. Currently, pyrethroid insecticides are recommended for a wide range of insect pests on vegetable crops, strawberry, and caneberry (Godfrey and Trumble 2008; Natwick 2009a,b; Zalom et al. 2012). Three discussion sessions and surveys were conducted to determine the critical use pattern of pyrethroid insecticides in vegetable and small fruits in the wake of potential use restrictions in the Salinas Valley of California and to discuss critical pest management issues of lettuce growers.

Fig. 2. The counties in the Central Coast region of California where the survey participants in the second meeting operate. Same participants have operations in multiple counties in the Central Coast region of California; thus, the survey questions were focused on Salinas Valley of California.

Materials and Methods

The importance of pyrethroid insecticides for pest management and effectiveness of alternative pesticides in vegetables and small fruit crops were discussed in three meetings with growers and pesticide applicators at University of California Cooperative Extension (UCCE), Monterey County in Salinas, CA, in March and April 2016. Using an audience response system (Turning Technologies, LLC., Youngstown, OH), facilitators collected anonymous information about current pest management practices, with a particular focus on use of pyrethroids and their effectiveness, as well as participants' perspectives on alternatives to pyrethroids. The participants selected from multiple choice option(s) after viewing the questions on PowerPoint slides projected on a large screen. One of the options was "other" and wherever possible, the "other" responses were clarified by asking follow-up questions.

In the first meeting (23 March 2016), three pest control advisers (PCAs) were engaged in a detailed discussion on critical use of pyrethroid insecticides for vegetable and small fruit pest control. The results of this meeting were used to develop a survey questionnaire for the second meeting. The second meeting, titled "Pyrethroid Insecticide Use in Salinas Valley: Facing the Future," was held on 29 March 2016, where mostly PCAs participated. The survey of second meeting participants contained a series of multiple-choice questions focused specifically on pyrethroid insecticide use (Table 1). Some questions, especially questions from 10 to 13 in Table 1, were formulated based on the first meeting and after assessing the 2015 pesticide use report (PUR) obtained from the Agricultural Commissioner, Monterey County, CA (Fig. 1). The 2015 PUR shows which pyrethroids were mostly used in Salinas Valley, California—bifenthrin was primarily used in strawberry, whereas permethrin was mostly used in lettuce, celery, and spinach (Fig. 1).

Table 2. Percentage of participants serving by crop and area in the Central Coast region of California in the second meeting

Crop	Area served (ha)[a]						
	0[b]	< 12.1	12.1–80.8	80.9–202.2	202.3–404.5	404.6– 2023.3	>2023.4
Lettuce	43	4	0	4	9	26	13
Brassicas	44	0	4	20	4	24	4
Celery	54	0	25	4	8	4	4
Strawberry	73	0	14	5	9	0	0

[a] The areas served mainly in Monterey, Santa Cruz, and San Benito Counties of California.

[b] Not directly involved in prescribing insecticide recommendation in California. Percentages were calculated by crop (s) or row. The second meeting was composed of 39 participants including a mix of PCAs, growers, industry board, and regulators.

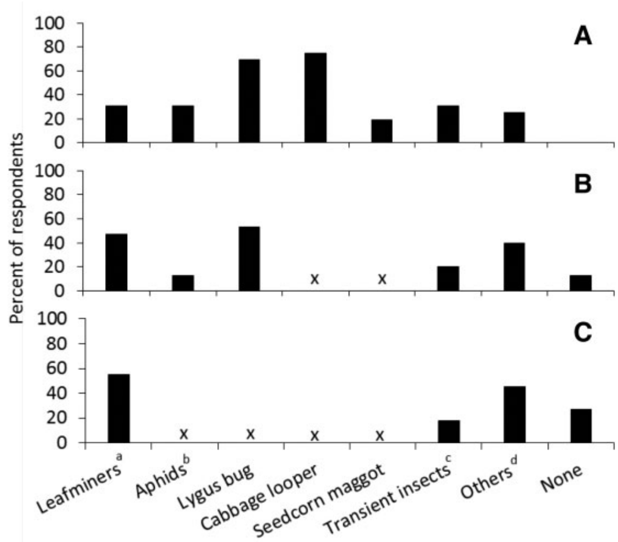

Fig. 3. Percentage of survey participants recommending permethrin insecticide in the Salinas Valley of California during the second meeting in (**A**) lettuce (16 participants), (**B**) celery (15 participants), and (**C**) spinach (11 participants). The participants were allowed to choose multiple pest or pest complexes. The symbol x = option not provided. [a]Leafminer species considered were pea leafminer, *Liriomyza langei* (Frick) (Diptera: Agromyzidae); American serpentine leafminer, *L. trifolii* (Burgess) (Diptera: Agromyzidae); and vegetable leafminer, *L. sativae* (Blanchard) (Diptera: Agromyzidae). In spinach, only adults were targeted. [b]Aphid species considered were *Nasonovia ribis-nigri* (Mosley) (Hemiptera: Aphididae); green peach aphid, *Myzus persicae* (Sulzer) (Hemiptera: Aphididae); and foxglove aphid, *Aulacorthum solani* (Kaltenbach) (Hemiptera: Aphididae). [c]Transient insects = not regular pests (beneficial insects or unknown arthropods such as thrips, aphids, springtails, wasps, flies, true bugs). [d]Other = other lepidopteran pests, thrips, etc.

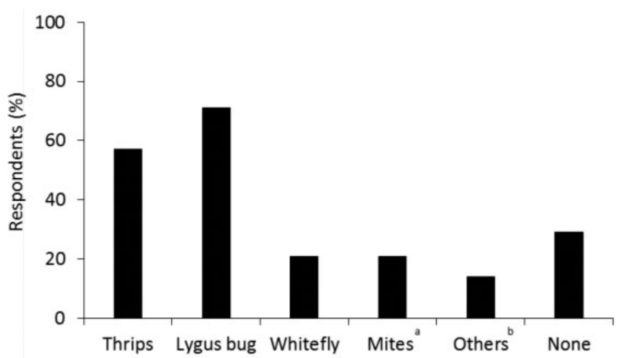

Fig. 4. Percentage of participants recommending bifenthrin insecticide in strawberry (14 participants) in the Salinas Valley of California during the second meeting. The participants were allowed to choose multiple pests or pest complexes. [a]Mites = twospotted spider mite and cyclamen mite. [b]Other = aphids and vinegar flies.

The third meeting followed the pyrethroid regulatory workshop on March 29 later in the afternoon, where 18 invited participants representing a mix of PCAs, growers, industry board, and regulators further clarified the answers to survey questions.

Results

Results from the second and third meeting surveys are filtered to include only qualified participants involved in pest management

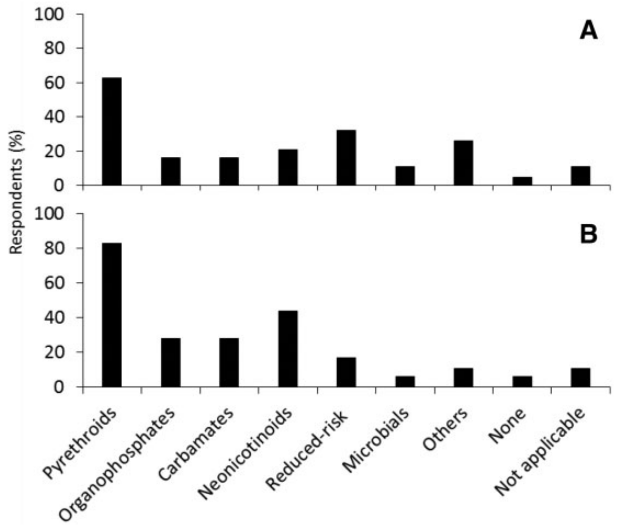

Fig. 5. The insecticide classes or types survey participants considered for (**A**) soil pests (e.g., root maggots, springtail, garden symphylan) and (**B**) *Bagrada hilaris* control in the Salinas Valley of California during second meeting.

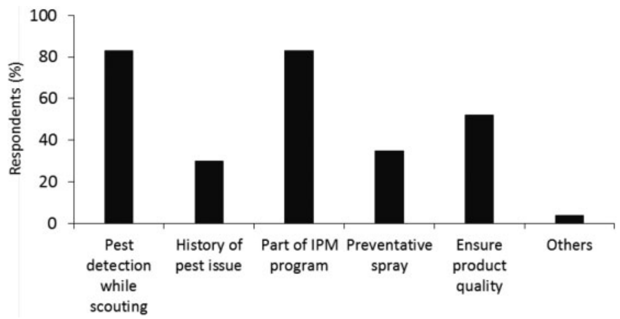

Fig. 6. Basis for management decisions by the pest management administrators (e.g., PCA, grower) in the Salinas Valley of California during the second meeting.

decisions such as PCAs or managers. The main points obtained from the first meeting are included in the discussion session.

Participant Type, Crop Area

The participants had the opportunity to respond to more than one option. The majority of the 39 participants surveyed were from Monterey, Santa Cruz, and San Benito Counties of California (Fig. 2). The participants were PCAs (54%), representatives of the plant protection companies (22%), growers (11%), and certified crop advisers (11%). Some participants identified themselves also as University researchers or staff (16%) and students (16%). The majority of the participants served, on average, >8984.0 cumulative hectares of lettuce, *Brassica* crops, and celery (Table 2).

Pests Targeted by Pyrethroid Insecticides

Although permethrin was listed as a management choice for all the pests, it was primarily recommended to control western tarnished plant bug and cabbage looper, *Trichoplusia ni* (Hübner) (Lepidoptera: Noctuidae), in lettuce (Fig. 3A). In celery, participants target western tarnished plant bug and leafminer adults using permethrin sprays (Fig. 3B), whereas in spinach, it was used to manage leafminer adults and other pests (primarily, lepidopteran larvae;

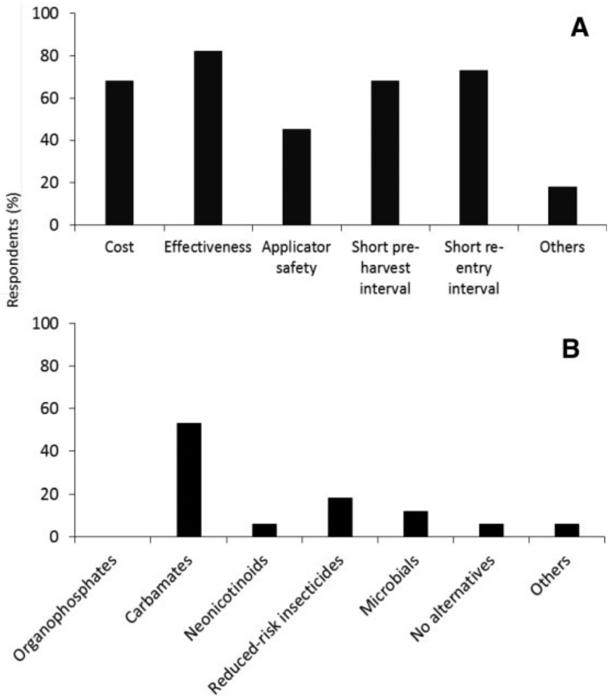

Fig. 7. (**A**) Insecticide attributes considered by the pest management administrators (e.g., PCA, grower), and (**B**) their choice of alternative insecticide(s) to pyrethroid insecticides during second meeting.

Fig. 3C). Also, the participants recommend permethrin use for transient insects in all three crops.

In strawberry, the major use of bifenthrin was for western tarnished plant bug and thrips control, although bifenthrin was also considered for the control of other key pests listed in the survey (Fig. 4). More participants considered pyrethroid insecticides for the control of *B. hilaris* and soil pests such as cabbage maggot, garden symphylan, and springtail (Fig. 5) than other insecticide classes or types. Responses for use of reduced-risk insecticides such as spinosad, biopesticides (e.g., azadirachtin), growth regulators (novaluron), and microbial insecticides for soil pest management, varied among participants. Similarly, neonicotinoid followed by organophosphate and carbamate insecticides were considered for *B. hilaris* control.

Pest Management Decisions and Alternatives

Survey respondents (PCAs and personnel involved in pest management) indicated that detection of a pest while scouting and use of pyrethroids as part of an integrated pest management (IPM) program were the two most important reasons when deciding to apply a pyrethroid pesticide. Other decision-making factors included the need to ensure product quality, use as a preventive spray, and lastly, use because of a history of pest issues (Fig. 6).

If a decision to use an insecticide was made, several attributes and factors specific to the insecticide class or active ingredient were considered, such as cost, effectiveness, applicator safety, and short reentry and preharvest intervals (Fig. 7A). When asked about possible alternatives to pyrethroid insecticides, most of the respondents chose a carbamate insecticide (Fig. 7B), specifically methomyl.

Participants (18) of the third meeting were a mix of people who worked with lettuce pest management (growers, managers, PCAs, certified crop advisors [CCAs]) and regulators who spoke at the earlier workshop. Participants worked with lettuce pest management of all listed lettuce types (leaf, romaine, butterhead, iceberg, and head) for both conventional and organic production systems in Monterey County, and some also in other nearby counties. Given that the meeting followed the pyrethroid regulatory workshop and offered an opportunity to convey the importance of pyrethroids to the regulators, the discussion tended to weigh heavily on the lack of viable alternatives to pyrethroids for markets with zero tolerance to damage, as opposed to organic markets, for example. However, a survey at the end of the meeting focused on the effectiveness of IPM solutions on some of the key pests in lettuce. Participants ranked thrips, *Frankliniella* spp., western tarnished plant bug, and leafminers, *Liriomyza* spp. as most important pests in lettuce production, followed by downy mildew, *Bremia lactucae* Regel (Peronosporales: Peronosporaceae), aphid complex (e.g., lettuce aphid, and green peach aphid), armyworm complex [beet armyworm, *Spodoptera exigua* (Hübner) (Lepidoptera: Noctuidae) and fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae)], and loopers [cabbage looper and alfalfa looper, *Autographa californica* (Speyer) (Lepidoptera: Noctuidae)]. More focus should be given to the development of strategies for management of soil pests (e.g., garden symphylan, springtails, and *Pythium* spp. (Pythiales: Pythiaceae)). The control strategies that were discussed and their effectiveness as evaluated by participants are listed in Table 3. Participants identified *Bacillus thuringiensis* (Bacillales: Bacillaceae), pyrethrins, neem oil, and spinosad as effective organic pest control methods.

At the end of the discussion session, questions focused on the effectiveness of cultural and biological control pest management practices were presented using an audience response system. Responses of participants who identified that they do not make pest control decision for any acreage were filtered out of the presented results.

There were six participants representing a mixture of PCAs, growers and managers, and CCAs (more than one response was possible) who worked with lettuce pest management in Monterey County, with some additional acreage in other adjacent counties, namely, San Benito and San Luis Obispo. Participants identified that they make pest management decisions for a total acreage between 1,000 and 4,999 acres (three participants) and >5,000 acres (three participants). These responses may not reflect the size of the actual individual lettuce growing operations, as small production systems may be included in the totals. Participants worked with all listed lettuce types (leaf, romaine, butterhead, iceberg, and head). Three participants chose "Other," indicating verbally that they also worked with spring mix (salad mix composed of lettuce and other leafy greens). All participants had >5 yr of experience working in pest management of lettuce. Responses are summarized in the Table 4—Effectiveness of selected cultural and biological control pest management practices in lettuce.

Discussion

Based on the surveys as well as pre- and postmeeting discussion sessions, pyrethroid insecticides play a critical role in the management of vegetable and strawberry pests in the Salinas Valley. In vegetables, pyrethroid insecticides are an especially important tool; permethrin is primarily used to control lygus bug, cabbage looper, and leafminer adults. Pyrethroid insecticides are effective against lygus bug (Joseph and Bolda 2016), a polyphagous and highly mobile insect pest (Zalom et al. 2012) requiring a quick knockdown pesticide that can be used on many sites. Cabbage looper can be a serious pest in lettuce, celery, and spinach, especially in spring and early summer months (March–May) as well as fall (late August–November). Based

Table 3. The top lettuce pests and effective strategies for their control in the Salinas Valley of California in the third meeting

Pest[a]	What works[b]	What doesn't work
Thrips	■ Pyrethroids ■ Lannate (methomyl) ■ Radiant (spinetoram) ■ Entrust (spinosad)	"Organic"
Western tarnished plant bug	■ Pyrethroids ■ Lannate (methomyl) ■ Acephate (for head lettuce only) ■ Dimethoate ■ Possibly some neonicotinoids	
Leafminers	■ Pyrethroids (knockdown of adults) ■ Trigard (crymozine) ■ Agri-mek (abamectin) ■ Coragen (chlorantraniliprole) ■ Lannate (methomyl) ■ Radiant (spinetoram) ■ Neemix (azadirachtin) ■ Entrust (spinosad) ■ Dimethoate	
Downey mildew	■ Irrigation: furrow or drip—reduce leaf wetting ■ Resistant varieties ■ Timing of sprays	
Aphid complex	■ Resistant varieties (for lettuce aphid) ■ Platinum (thiamethoxam) ■ Admire (imidacloprid) ■ Movento (spirotetramat) ■ Actara (thiamethoxam) ■ Acephate ■ Sequoia (sulfoxaflor) ■ Monitor (methamidophos)	■ Ladybugs ■ Biological control
Armyworms	■ Lannate (methomyl) ■ Radiant (spinetoram) ■ Coragen (chlorantraniliprole) ■ Belt (flubendiamide) ■ Possibly diazinon	■ *Bacillus thuringiensis* and biological control (higher cost and less effective)
Loopers	■ Pyrethroids	
Soil pathogens (e.g., *Verticillium*, *Sclerotinia*, *Pythium*)	■ Crop rotation (*Brassica* for *Sclerotinia*; broccoli, strawberry for *Pythium*) ■ Field selection, when possible ■ Seasonal timing of planting, when possible ■ Fumigation	

[a] Include arthropods and pathogens.
[b] Cultural, biological, and chemical strategies currently deployed for pest management were suggested. The third meeting was composed of 18 invited participants including a mix of PCAs, growers, industry board, and regulators mainly serving Salinas Valley of California.

on the survey, PCAs indicated that pyrethroid insecticides are used to knockdown the moths and early instars of loopers before they bore into the center of the plant. Permethrin is used to prevent leafminer adults from feeding and oviposition, although more research is required to validate insecticide efficacy against leafminer adults.

The survey suggested that PCAs are inclined to use pyrethroid insecticides for *B. hilaris* (also referred as bagrada bug), an invasive stink bug in the United States (Reed et al. 2013, Joseph and Godfrey 2016). Recent studies showed that pyrethroids are the most effective tool in combating *B. hilaris* in broccoli fields (Palumbo 2011, Palumbo et al. 2013, Joseph and Godfrey 2016). The participants also indicated that pyrethroids are considered even for other stink bugs, especially *Euschistus conspersus* (Uhler) (Hemiptera: Pentatomidae) and the Say stink bug complex [*Chlorochroa sayi* (Stål) (Hemiptera: Pentatomidae) and *Chlorochroa uhleri* (Stål) (Hemiptera: Pentatomidae)], detected occasionally in the Salinas Valley fields.

Pyrethroid insecticides were particularly considered by our survey participants to control soil pests including cabbage maggot, garden symphylan, and springtail in vegetables. Previous research showed that pyrethroids were as effective as organophosphates or carbamates against cabbage maggot (Joseph and Zarate 2015), garden symphylan (Joseph 2015), and springtail (Joseph 2017 in press).

Despite the lack of many alternatives to pyrethroids, the survey at the end of the lettuce discussion showed that various other IPM methods have been tried and had some effectiveness, especially for organic growers with a higher tolerance for slight produce damage. Participants indicated that pest management practices varied depending on the eventual market for the lettuce crop, which was dictated by:

- Customer tolerance for damage or pest presence, which can range from zero tolerance and rejected orders at one extreme to some allowable damage as in the case of organic markets at the other extreme.

Table 4. Effectiveness of selected cultural and biological control pest management practices in lettuce in the Salinas Valley of California in the third meeting

Questions[a]	No. of responses	Effective	Not effective	Effectiveness varies depending on pest	Have never tried it
How effective is the use of the low-risk, selective pesticide Bt (*Bacillus thuringiensis*) for many caterpillar pests?	5	–	2	3	–
How effective is removing pest habitat (weeds and crop residues) that may harbor insect pests or disease vectors?	5	1	2	2	–
How effective is discing fields to destroy larvae/pupae of pests (e.g., armyworms)?	6	–	2	1	3
How effective is crop rotation to control weeds and some diseases (Anthracnose, varnish spot, Verticillium wilt)?	6	4	–	2	–
How effective is the reduction of leaf wetting by using furrow or drip irrigation to prevent/reduce certain diseases (Anthracnose, bacterial leaf spot, corky root, downy mildew, varnish spot)?	6	6	–	–	–
How effective is the use of resistant varieties to prevent some diseases (beet western yellows, big vein, downy mildew, lettuce dieback, tipburn, turnip mosaic)?	6	3	–	3	–
How effective is biological control for certain pests (corn earworm, armyworms, aphid, leafminers, loopers, whiteflies)?	6	–	4	2	–
Do you monitor for natural enemies of pests?	6	5	1	–	–
Have you ever purchased natural enemies to control pests?	6	3	–	1	2
Have you ever planted hedgerows or plant borders to increase natural enemy abundance to control pests?	6	3	2	1	–
How effective is preirrigation of the field before planting lettuce in order to germinate and destroy weed seedlings?	6	4	–	2	–

[a] Questions were related to the tactic and its effectiveness. The third meeting was composed of 18 invited participants including a mix of PCAs, growers, industry board, and regulators mainly serving Salinas Valley of California.

- Country maximum residue limits (MRL) for various pesticides, which dictates the pest management of produce for international exports.
- Processor or certification requirements: For example, allowable pesticides may be dictated for organic certification or for contracted orders.

Pest control advisers in the survey indicated that they use pyrethroids instead of insecticides in the other classes because pyrethroid insecticides have several key benefits: First, pyrethroids have shorter preharvest intervals (≤24 h) compared with other insecticides registered for use on leafy crops. This attribute is especially desirable to PCAs to prevent quality issues in leafy vegetables and strawberry. Any cosmetic injury caused by insect feeding and oviposition or the detection of live or dead insects or their body parts in the harvested produce will result in the crop being classified as poor quality. Thrips, aphids, and other transient arthropods such as flies or wasps are commonly found trapped between leaves, degrading product quality. Even detection of beneficial insects such as larvae of lady beetles, syrphid flies, and lace wings will decrease the quality grading (Fig. 8). These unwanted arthropods are often referred as "trash" or "junk bugs" by PCAs or pest management personnel. Depending on market price, the severity of these quality issues at harvest can result in rejection of the field, causing severe economic loss. To address these issues, meeting participants indicated that at least one or two routine sprays with contact insecticides are typically administered a day or two before harvest. Thus, because of their short preharvest interval, pyrethroid insecticides are considered the best choice for these clean-up sprays before harvest.

Second, pyrethroid insecticides have shorter reentry intervals relative to other insecticides, mostly 24 h or less. Shorter reentry allows field crews to enter the field and frequently administer timely cultural practices such as irrigation, thinning, cultivation for weed management, and fertilizer application. In strawberry, this short reentry interval is even more important, as fruits are harvested twice a week and therefore need regular field visits. Thus, having an insecticide tool with a short reentry interval such as pyrethroids in the tool chest is a valuable benefit for pest management and production in vegetable and small fruit systems.

The survey participants indicated that they are concerned about the exposure to alternative insecticides, particularly methomyl, if pyrethroid insecticides are restricted. Pyrethroid insecticides have lower mammalian toxicity than other insecticides such as organophosphates or carbamates (Table 5). As discussion participants pointed out, when applying pyrethroids, there is no need for pre- and postblood tests to measure acetylcholine levels required by applicators applying organophosphate and carbamate insecticides in order to maintain a valid applicator license. These tests also take time and cost money. Because the human body can rapidly metabolize pyrethroid insecticides and excrete most of the metabolites from its system, these insecticides have lower toxicity than other insecticides (Leng et al. 1997). This attribute of pyrethroid insecticides poses a lower risk to the applicators in an event of accidental exposure to pyrethroid insecticides while spraying or handling.

Another benefit identified by survey participants was the cost. Pyrethroid insecticides are cheaper relative to other insecticides. The cost of some pyrethroid insecticides is <US$12.30 per ha, which help growers remain competitive in the market by reducing the pest management cost. The cost of most pyrethroids is low because these insecticides are now off-patent and several agro-chemical companies are manufacturing the same active ingredient. Also, the low cost of

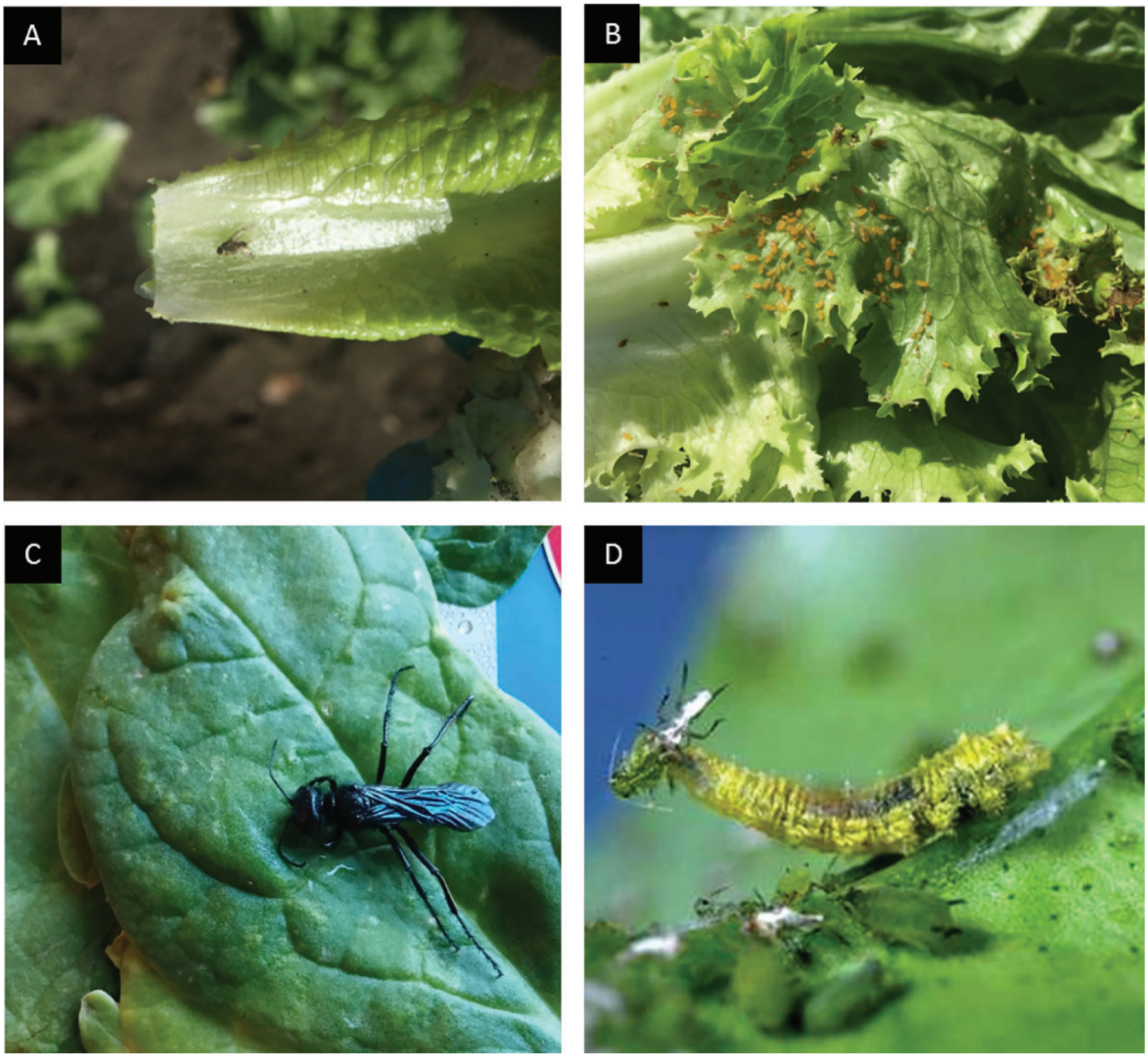

Fig. 8. Potential live or dead insects in the harvested produce can reduce quality: (**A**) a fly, (**B**) lettuce aphid, (**C**) a wasp, and (**D**) syrphid larva. Even though beneficial insects (C and D) consume pests, their presence at harvest may result in the crop being graded as poor quality. Photo credits (A–C) Shimat V. Joseph, and (D) Jack K. Clark.

these insecticides adds little to the overall pest management cost, which encourages growers to add it into the tank along with other active ingredients as a preventive tactic.

When asked what they will do if pyrethroid insecticide use regulations come into effect, survey participants responded that they will be pushed to switch to an alternate insecticide with less burdensome regulations. When regulation on use of organophosphate insecticides (chlorpyrifos and diazinon) took effect in 2010 in the Salinas Valley, growers refrained from using organophosphate insecticides (Fig. 9A and B) and switched to other alternate insecticides to avoid the extra regulatory burdens (California Department of Pesticide Regulation [CDPR] 2016). Use regulations will most likely require growers to deploy mitigation measures such as wider buffer strips, tactics to filter run-off water from the ranch (e.g., vegetative ditches), and regular monitoring of water run-off. Implementation of these mitigation measures often require taking land out of production. Given the high value of the agricultural land in the Salinas Valley (US$7,410–9,880 per ha), most growers would rather avoid use of regulated pesticides than give up any land.

The survey participants included PCAs or pest managers representing major plant protection and grower companies and do not represent the view point of several independent PCAs or growers who did not attend the meeting. Based on the participants, if pyrethroid insecticides are strictly regulated, the probable alternate insecticide they would choose is the carbamate, methomyl. In some instances, methomyl is being used. For example, lettuce exported to foreign markets such as Taiwan require a methomyl treatment 14 d before harvest. However, methomyl use has issues as well. Methomyl has a longer reentry (48 h) and preharvest (7 d) interval in lettuce and celery. Tolerance of methomyl residues has been discontinued on strawberry by the EPA in 2007, so it is not an alternative for lygus bug control. The cost of methomyl application is US$98 per ha, which is about 10× more than using a pyrethroid insecticide. Use of methomyl will result in greater risks to applicator

Table 5. Toxicity of insecticides used in various commodities in Salinas Valley

Chemical class	Chemical name	Brand name (Manufacturer)	Signal word	Toxic to[b]	Toxicological information[c]					Ecological information			
					Oral	Dermal	Inhalation	Eye irritant	Skin irritant	Algae	Crustacea	Fish	Honey bee
Pyrethroid	Zeta-cypermethrin	Mustang	Warning	Aquatic invertebrates, bees, fish, oyster, shrimp	234 mg/kg LD_{50} rat	>2,000 mg/kg LD_{50} rabbit	>0.89 mg/liter LC_{50} 4 h rat	Mildly irritating rabbit	Slightly or nonirritating rabbit	>1 mg/liter 72 h EC_{50}	0.14 µg/liter 48 h EC_{50}	0.69 µg/liter 96 h LC_{50}	—
Pyrethroid	Bifenthrin	Capture	Warning	Aquatic invertebrates, aquatic organisms, bees, fish	262 mg/kg LD_{50} rat	>2,000 mg/kg LD_{50} rabbit	1.86 mg/liter LC_{50} 4 h rat	Minimally irritating rabbit	Nonirritating	0.822 mg/liter 72 h EC_{50}	0.11 µg/liter 48 h EC_{50}	0.1 µg/liter 96 h LC_{50}	—
Pyrethroid	Lambda-cyhalothrin	Warrior II	Warning	Aquatic organisms, bees, fish, wildlife	310 mg/kg LD_{50} female rat	>2,000 mg/kg LD_{50} rabbit	3.12 mg/liter LC_{50} 4 h female rat	Mildly irritating[d] rabbit	Moderately irritating[d] rabbit	—	0.04 ppb 48 h EC_{50}	0.19 ppb 96 h LC_{50}	—
Pyrethroid	Permethrin	Perm-UP	Warning	Aquatic invertebrates, aquatic organisms, bees, fish	—	—	—	—	—	—	0.02–7.6 µg/liter LC_{50}	0.05–315 µg/liter 96 h LC_{50}	—
Pyrethroid	Beta-cyfluthrin	Baythroid	Warning	Aquatic invertebrates, aquatic organisms, bees, fish	647/695 mg/kg LD_{50} male/ female rat	>2,000 mg/kg LD_{50} rabbit	0.7 mg/liter LC_{50} 4 h male rat	Severe irritation rabbit	Moderate irritation rabbit	>0.01 mg/liter 72 h IC_{50}	0.00029 mg/liter 48 h EC_{50}	0.000068 mg/liter 96 h LC_{50}	—
Carbamate	Carbaryl	Carbaryl 5% Bait	Caution	Aquatic invertebrates	3,310 mg/kg LD_{50} rat	>2,000 mg/kg LD_{50} rabbit	4.9 mg/liter LC50 4 h rat	Mild irritation rabbit	No irritation rabbit	—	0.00067 mg/liter 48 h EC_{50}	4.3 to 6.76 mg/ liter 96 h LC_{50}	1.54 to 26.5 µg/bee LC_{50}
Carbamate	Methomyl	Lannate	Danger-Poison	Aquatic invertebrates, aquatic organisms, bees, fish, mammals	23 mg/kg LD_{50} rat	>2,000 mg/kg LD_{50} rabbit	0.258 mg/liter 4 h LC_{50} rat	Slight irritation rabbit	No irritation rabbit	>100 mg/liter 72 h ErC_{50}	0.017 mg/liter 48 h EC_{50}	0.63 mg/liter 96 h LC_{50}	—
Organophosphate	Acephate	Orthene	Caution	Bees, birds	688/1,127 LD_{50} male/female rat	>2,000 mg/kg LD_{50} rabbit	>61.7 mg/liter 4 h LC_{50} rat	Slight irritant rabbit	Slight irritant rabbit	—	—	—	—
Organophosphate	Diazinon	Diazinon	Caution	Aquatic organisms, bees, bird, crab, fish, shrimp, waterfowl, wildlife	66 mg/kg LD_{50} rat	>2,150 mg/kg LD_{50} rat	>2.33 mg/liter 4 h rat	Mildly irritating	Mildly irritating	17.3 mg/liter 120 h EC_{50}	0.0004 to 0.00096 mg/liter 48 h EC_{50}	0.000072 to 5.2 mg/liter 96 h LC_{50}	—
Organophosphate	Dimethoate	Dimethoate	Warning	Aquatic invertebrates, bees, insect pollinators, wildlife	425 mg/kg LD_{50} rat	2,020 mg/kg LD_{50} rat	—	Substantial but temporary eye injury rabbit	Slight irritant	—	2.0 mg/liter 48 h EC_{50}	30.2 mg/liter 96 h LC_{50}	0.15 µ/bee acute oral LD_{50} 0.12 u/bee contact
Organophosphate	Oxydemeton-methyl	MSR spray	Danger-Poison	Aquatic organisms, bees, fish, wildlife	>138 mg/kg/ >125 mg/kg LD_{50} female/ male rat	>359 mg/kg/> 253 mg/kg LD_{50} male/female rabbit	>0.73/>0.60 mg/liter LC_{50} 1 h male/female rat	Mild irritant	Slightly irritating	—	—	—	—

[a] Brand name manufacturers: Mustang (FMC Corporation); Capture (FMC Corporation); Warrior II (Syngental Crop Protection LLC), Lambda-cy; Perm-UP (United Phosphorous, Inc.); Baythroid (Bayer CropScience); carbaryl bait (Drexel Chemical Company); Lannate (E. I. DuPont de Nemours and Company); Orthene (Amvac Chemical Corporation); Diazinon (Makhteshim Agan of North America, Inc.); Dimethoate (Loveland Products, Inc.); MSR spray (Gowan Company).

[b] From Agrian website: accessed 11 July 2016. https://home.agrian.com/.

[c] References: FMC safety data sheet for Mustang insecticide (20 April 2015); FMC safety data sheet for Capture 2EC-CAL insecticide (17 April 2015); Syngenta safety data sheet for Warrior II with Zeon technology insecticide (18 January 2016); United Phosphorous safety data sheet for Perm-UP 25DF insecticide (02 May 2015); Bayer material safety data sheet for Baythroid XL insecticide (21 April 2016); Drexel safety data sheet for Carbaryl 5% Bait (22 July 2016); DuPont safety data sheet for Lannate SP insecticide (19 February 2016); Amvac material safety data sheet for Orthene 97 insecticide (11 May 2012); Makhteshim Agan safety data sheet for Diazinon 50W insecticide (25 September 2015); Loveland safety data sheet for Dimethoate 400 insecticide (14 January 2015); Gowan material safety data sheet for MSR spray concentrate insecticide (12 June 2008); all accessed 11 July 2016.

[d] Based on results from similar products as stated on label.

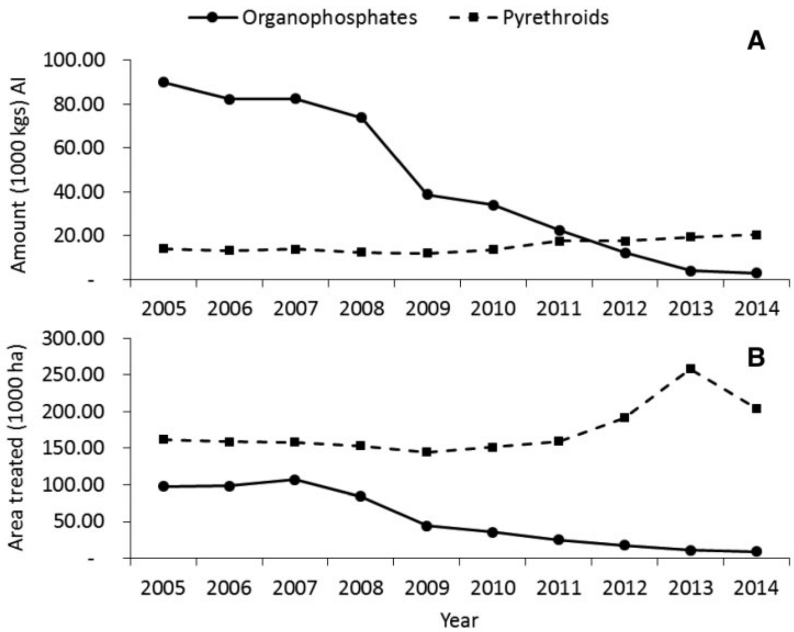

Fig. 9. (**A**) Amount and (**B**) hectarage of organophosphate (chlorpyrifos and diazinon) and pyrethroid insecticides used on all major crops in Monterey County, CA, between 2005 and 2014 (California Department of Pesticide Regulation, Pesticide Use Report, Monterey County).

safety from accidental exposure and involves regular acetylcholine blood tests, further increasing application costs.

Clearly, there is a problem with water quality due to pyrethroids. If history with organophosphate regulation is an indicator, regulation of pyrethroids may result in a switch to pesticides with human health and environmental concerns that are as bad or worse than pyrethroids. The outcome of a series of discussion sessions and a survey suggest that pyrethroid insecticides are a critical tool for pest management in the toolbox of vegetable crops and strawberry growers in the Salinas Valley. The shorter reentry and preharvest intervals, as well as low mammalian toxicity, and low cost of pyrethroid insecticides make them fit well into a pest management program. Moreover, pyrethroid insecticides are an important mode of action to be included in a spray program for pesticide resistance management. Multiple exposures of insecticides with the same modes of action to same generation of pest will accelerate the development of insecticide resistance.

The purpose of the surveys and discussions were to learn how strawberry and vegetable growers, PCAs, and industry in the Salinas Valley define IPM, and how potential pyrethroid regulatory changes might affect established IPM programs. Learning about key pests, from the growers and PCAs perspective, and how key pest managers in these systems might change their pest management practices if regulation came about will be used by UCCE to determine research next steps to ensure continuity of vegetable and strawberry IPM. Another benefit is increased understanding of what biological control and cultural pest management practices work and do not work, leading to better information extended through pest management guidelines by the University of California. The perceptions and opinions of the survey participants presented here could be used by regulators to better understand pesticide use in agricultural production systems and the results of regulatory decisions. Other pest managers who face this or similar regulatory issues can learn from this example and be better prepared to mitigate usage or reformulate their IPM programs.

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