Label communication of acute and residual toxicity to honey bees (*Apis mellifera* L.) on insecticides of high-risk to Oregon hives does not align with federal recommendations

by
Matthew T. Bucy

A THESIS

submitted to

Oregon State University

Honors College

in partial fulfillment of
the requirements for the
degree of

Honors Baccalaureate of Science in Environmental Sciences
(Honors Scholar)

Presented March 29, 2019
Commencement June 2019

AN ABSTRACT OF THE THESIS OF

Matthew T. Bucy for the degree of Honors Baccalaureate of Science in Environmental Sciences presented on March 29, 2019. Title: Label communication of acute and residual toxicity to honey bees (*Apis mellifera* L.) on insecticides of high- risk to Oregon hives does not align with federal recommendations.

Abstract approved:____

Andony Melathopoulos

BACKGROUND: Training pesticide applicators on how to understand a product's toxicity to honey bees (*Apis mellifera* L.) by reading the product label is a way of reducing pesticide exposure to bees. Many applicator resources focus on how to interpret the United States Environmental Protection Agency's (USEPA's) recommended language for communicating this toxicity. To effectively educate applicators, it must be determined if labels follow USEPA recommendations in how they communicate toxicity to honey bees, and if not, what patterns exist in these deviations from the recommended language (hereafter, errors).

RESULTS: As a case study, the USEPA master labels of insecticides used in 16 high- risk situations to Oregon hives were compiled. Of the 232 labels analyzed, 31.5% had at least one error. The percent of labels with at least one error varied across application situations and chemical subgroups, and between commercial products and garden products. Errors were not limited to one particular high- risk situation or one particular chemical subgroup, and were not exclusive to commercial products or to garden products. The most common error represented a direct contradiction between USEPA language used and toxicity class of product active ingredient.

CONCLUSION: Exclusively educating applicators on how to interpret USEPA-recommended language on how to communicate toxicity to honey bees does not fully prepare applicators to interpret the labels they see in the field. Applicator education should incorporate information on how to interpret a label that uses non-USEPA-recommended language to communicate its toxicity to honey bees.

Key Words: pest control, environmental impact, insecticide, pest management, toxicology

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I understand that my project will become part of the permanent collection of Oregon State University, Honors College. My signature below authorizes release of my project to any reader upon request.

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1. INTRODUCTION

Insecticide exposure has been implicated in honey bee (*Apis mellifera* L.) colony declines and health issues.[1–4] Judicious insecticide application is a way to reduce pesticide exposure to bees, but it requires the applicator to recognize the hazards associated with different insecticide use patterns. The United States Environmental Protection Agency (USEPA) requires registrants to include information on the environmental hazards of a pesticide product on that product's label (40 C.F.R §156.80 2018). Products toxic to bees used as outdoor, foliar applications are generally required to express acute toxicity and residual toxicity to honey bees.[5,6] This information forms the Pollinating Insect Hazard Statement in the Environmental Hazards section of the label.[6] Acute toxicity is measured by calculating what dose (of active ingredient) per bee is required to kill 50% of test subjects.[5] Acute toxicity information can assist applicators in selecting the least hazardous product to honey bees when applying a product during a period of high bee activity (e.g. bloom).[7] Residual toxicity is measured by applying the end-use product to a bee-attractive plant, and observing how long it takes for honey bee mortality to decline to 25%.[5] Residual toxicity data indicates how long the residues of a product can be expected to be toxic to bees.[5] Residual toxicity information can help applicators determine whether a product applied at night during low bee activity will become sufficiently non- toxic by the following morning.[7] USEPA has recommended language for how acute and residual toxicity should be expressed in the Pollinating Insect Hazard Statement (Table 1). Some states, for example Oregon and North Carolina, require applicators to demonstrate knowledge of the Pollinating Insect Hazard Statement in order to obtain their pesticide applicator license, and they offer training programs focusing on comprehension of the Statement as part of the license recertification process.[8,9] As states are incorporating training on reading a pesticide label to determine toxicity to honey bees, it is important to assess if these labels use the USEPA-recommended language to communicate toxicity to honey bees in the first place.

We analyzed the language used to communicate acute and residual toxicity to honey bees on the labels of insecticide products used in 16 high- risk situations to Oregon honey bee colonies, looking for deviations from USEPA- recommended language (hereafter, errors) in hazard communication. A high-risk situation was defined as a pesticide use of concern for Oregon honey bee colonies. Oregon is an appropriate case study because it requires training on interpreting bee toxicity label language for commercial insecticide and fungicide applicator licensing and private applicator licensing.[10,11] In addition, the state grows a diversity of crops and consequently has diverse pest management situations, which allows us to analyze many different products. Moreover, many beekeepers remain in the state throughout the season and, if they leave Oregon, they primarily go to California for almond pollination.[12] Therefore, looking at the insecticides used in Oregon and for California almond bloom is an accurate depiction of the products Oregon honey bee colonies may be exposed to. Researchers reporting in the open literature have examined whether applicators read pesticide labels and what motivates them to do so,[13–17] which label sections they pay more attention to,[15] and their comprehension of label elements.[15,17–20] However, there is a dearth of literature examining the text of the labels themselves and of applicator behavior in the United States. This paper is one of the first to address label text clarity both in general, and in reference to any regulated environmental hazard.

Table 1. USEPA- recommended language to communicate acute and residual toxicity, linked to their corresponding toxicity categories. The keywords this analysis focused on are italicized. See the USEPA Label Review Manual Environmental Hazards chapter for full recommended text (https://www.epa.gov/pesticide-registration/label-review-manual).

Information	**Categories** [5,6]	**USEPA- recommended language** [6]
Acute toxicity: Acute honey bee contact toxicity (LD50) data.[5] Data from test performed on technical grade active ingredient [5,21]	I (*A. mellifera* contact $LD_{50} < 2$ µg/bee)	"This product is *highly toxic* to bees"
	II (*A. mellifera* contact $LD_{50} > 2$ µg/bee and < 11 µg/bee)	"This product is *moderately toxic* to bees"[i] OR "This product *is toxic* to bees"
	III (*A. mellifera* contact $LD_{50} \geq 11$ µg/bee)	Neither acute nor residual toxicity statements required on label
Residual toxicity: Data from toxicity of residues on foliage test.[5] Test is required for products with at least one acutely toxic active ingredient and with use pattern(s) that indicate *A. mellifera* exposure.[21] Test is conducted using the formulated product, not the technical grade active ingredient.[5]	Residual Toxicity ($RT_{25} <$ 8 hrs.)	"Do not apply… while bees… are *actively foraging* the treatment area" OR "Do not apply… while bees… *are actively visiting* the treatment area"
	Extended Residual Toxicity ($RT_{25} >$ 8 hrs.)[ii]	"Do not apply… if bees…*are foraging* the treatment area" OR "Do not apply… if bees…*are visiting* the treatment area"

[i] While the USEPA Label Review Manual recommends "is moderately toxic to bees" for category II products, "moderately toxic" was not seen on any of the labels analyzed in this study. "Is toxic to bees" was used instead.
[ii] RT_{25} is the endpoint for the toxicity of residues on foliage test. The endpoint indicates time required to reduce residual toxicity of the product to 25% of the test organisms. Extended residual toxicity is not formally defined, but can be inferred to mean $RT_{25} >$ 8 hrs.[5]

2. MATERIALS AND METHODS

2.1 Product selection

Products from the following 16 high- risk situations to Oregon beekeepers were analyzed:

1. Products used around bloom on 12 Oregon crops and California almonds. The 12 Oregon crops were alfalfa seed, apple, blueberry, carrot seed, cherry, clover seed, cranberry, meadowfoam, pear, pumpkin/ squash, radish seed, and watermelon. Products used for apple fruit thinning were also included. Fruit thinning products are applied for agronomic purposes but the chemical used is toxic to bees.[22] Products used during California almond bloom were included because colony rental for almond pollination is a significant income source for Oregon beekeepers.[12] In addition, the majority of American honey bee colonies are employed for honey bee pollination, and almond pollination fees represent the highest portion of total collected pollination fees for American beekeepers (Sagili R, Oregon State University, pers. comm.).[23]
2. Products used during times of peak honey bee activity in Oregon Christmas tree fields. Peak bee activity in Oregon Christmas tree fields can coincide with the time of aphid control (Sagili R, Oregon State University, pers. comm.).
3. Products used by Oregon mosquito control agents at any time of the year.
4. Garden products available to the Oregon consumer at any time of the year.

These situations of high- risk to Oregon bee colonies will hereafter be referred to as “crops.”

2.2 Developing and verifying insecticide product lists

A hierarchy was employed to develop the product list for each Oregon commercial crop. The primary sources consulted were Pest Management Strategic Plans applicable to Oregon published no earlier than 2011.[24–28] Then, additional pest management resources available through Oregon State University Extension Service, University of California Integrated Pest Management Center, and/or Washington State University Extension Service were consulted as needed.[22,29–34] Finally, entries in the Pacific Northwest Insect Management Handbook were consulted between June 2017 and August 2018 as needed (https://pnwhandbooks.org/insect). If satisfactory pest management information could not be found through this hierarchy, industry experts or Oregon State University faculty members experienced with the crop were consulted (Buckland K, 2018, pers. comm.; Sagili R, 2018, pers. comm.; Oregon Vector Control Association, 2017, pers. comm.). None of the above approaches worked for watermelon, so California pesticide use reporting data were obtained from the California Pesticide Information Portal (CalPIP) (https://calpip.cdpr.ca.gov/). A query was made for July and August 2016 pesticide use for 2015's top watermelon grossing California counties.[35] The insecticides were filtered out from the list and assumed to match the products used by Oregon watermelon growers.

The garden product list was developed by looking at Oregon- registered products available on the websites of two major home and garden stores in the Corvallis, Oregon area (Lowe's (https://www.lowes.com/store/OR-Albany/3057); WilCo Farm Stores (https://www.farmstore.com/)) in July and August 2018. Products used in situations or found in formulations not likely to adversely affect bee health (e.g., roach control, ant bait stations and stakes, etc.) were not included.

The product list for California almonds was developed from a CalPIP query for pesticide use data from agricultural almond producers around bloom in 2016 in the six top-producing counties (by weight) in that same year.[36] Products that were not insecticides were removed from the list.

Organic production guides were not consulted when developing product lists (except for blueberry) because they were not Pacific Northwest- specific. An organic production guide was only consulted for blueberry because blueberry was the first crop for which a product list was developed.[37]

To verify product lists not developed directly through consultation nor from CalPIP data, electronic surveys were sent to Oregon State University Extension faculty and answered between April and July 2018. In general, respondents confirmed if a pest was chemically controlled during the period of peak bee exposure for the specific crop. If they were, respondents selected the products used from a provided list, and were able to add new products. Respondents were able to add any pests not mentioned and the products used to control them. The survey for Christmas trees did not ask about pests and instead directly asked for verification of the list of products used when bees are most active in Oregon Christmas tree fields. Instead of a survey, the blueberry and cranberry product lists were verified in- person with extension agents experienced in those crops (DeFrancesco J., 2017, pers. comm.; Patton K., 2018, pers. comm.). Experts verified the product lists for blueberry, Christmas tree, clover seed, cranberry, pear, and pumpkin/squash. No expert verification was needed for the cherry product list because one of the committee members of this thesis was present at the Pest Management Strategic Plan work group. No expert verification was sought for the garden product list. Alfalfa seed and apple product surveys were unanswered, and their product lists were unable to be verified.

2.3 Pesticide labels

The most recent USEPA- approved master labels (and any more recent supplemental labels, if applicable) were accessed in August, September, and December 2018 from USEPA's Pesticide Product and Label System (PPLS) (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1). Oregon and California market labels may appear different than the master labels, but at minimum will include the information present on the master label.[6] Many crops used products through Special Local Need (SLN) registration, which have an additional SLN label. The PPLS master label was still the label analyzed for these products. Applicators of SLN products are legally required to also be in possession of the USEPA- approved market label, and therefore can be expected to look at this information as well.[38] If a master label was divided into sublabels, only relevant sublabels were analyzed (e.g. the agricultural sublabel was analyzed for a product used only on commercial crops). Hereafter PPLS master labels will be referred to as "labels."

2.4 Obtaining acute and residual toxicity information from pesticide labels

Label PDFs were searched for keywords "bee", "bees", "poll", "honey", "arthropod", "bene", and "target." The Environmental Hazards section of each label was also read in entirety. Labels PDFs that were not searchable were manually skimmed. Any information found in the Environmental Hazards or found from these searches that was deemed to communicate acute or residual toxicity to honey bees was recorded. The only exception to this was that any information found in a crop-specific use direction was only recorded if it was information relevant to a crop that the product is used on (based on our product lists). For example, if bee toxicity information was found in a recommendation for alfalfa seed, but that product is not used on Oregon alfalfa seed around bloom, that information was not analyzed. The general label section each piece of information came from was recorded as one of the following options: Environmental Hazards, crop- specific use directions, general use directions, pollinator- protection section (if not part of the Environmental Hazards), or other.

Information that explicitly claimed toxicity, nontoxicity, or action as a pathogen to bees or general arthropods was counted as acute toxicity information. A statement to not apply a product during a certain period, level, or type of bee activity (e.g. “Do not apply while bees are foraging,” “while bees are active,” etc.) or an explicit mention of residual toxicity was counted as residual toxicity information. These definitions were chosen to match the current USEPA recommendations as to how acute and residual toxicity should be communicated.[6] Language that matched the recommendations in the USEPA Label Review Manual Environmental Hazards chapter was considered to be the correct language, and deviations from it were an error (Table 1).

2.5 Assigning errors to pesticide labels

Labels were analyzed for five types of errors (see Table 2 for descriptions and examples). Four of those errors were subcategorized as being an error communicating acute toxicity or an error communicating residual toxicity. One error specifically compared USEPA-recommended language to toxicity data. This error was only applicable to the communication of acute toxicity, because reliable residual toxicity (RT_{25}) data could not be obtained. The acute toxicity dataset was from pesticide registration/re- registration studies, and the dataset did not have information available for every active ingredient.[39] It is worth noting that USEPA label reviewers would use original data evaluation records in the review process, rather than the pesticide registration/re- registration dataset.[39]

2.6 Analysis

We used R 3.5.1 to assign errors to label language.[40–42] These product lists were assumed to represent all the products used for each crop, and therefore descriptive statistics were used in place of hypothesis tests. In order to determine if the labels of insecticides used in situations of high-risk to Oregon honey bee colonies used for contracted pollination services had errors and what the nature of these errors were, we determined the following:

1. Out of all the labels, how many labels had at least one error communicating acute or residual toxicity to honey bees.
2. Which error was more common: errors in communicating acute toxicity or errors in communicating residual toxicity.
3. Whether the proportion of labels with at least one error was the same for each crop analyzed.
4. If the proportion of labels with at least one error was the same for each chemical subgroup represented (specifically the Insecticide Resistance Action Committee Mode of Action Classification Scheme (IRAC MoA) subgroups).[43]
5. If commercial product labels with at least one error were higher in proportion compared to garden product labels with at least one error.

6. Whether instances of inconsistent toxicity language were most commonly found (1) within a label's Environmental Hazards (2) between a label's Environmental Hazards and crop- specific use directions or (3) between a label's Environmental Hazards and any other section(s). Inconsistent communication is of particular concern, because it could result in a label having conflicting instructions for applicators on how to reduce pesticide exposure to honey bees. Moreover, inconsistencies can appear contradictory, which may result in applicator confusion and which raises the issue of the legal enforceability of the label.

Table 2. Description of each error analyzed in this project, with examples of what each error would look like.

Error	Description	Example	Significance
Missing (acute/ residual) toxicity information	One toxicity type is communicated on the label, but the other is not.	Acute toxicity: "Pollinator Advisory: …do not use…on blooming crops when bees are *actively foraging*."[44] [no acute toxicity statement anywhere on label][44]	Omitting information on either toxicity fails to provide an applicator the full information needed to make a judicious decision about which products to apply during high-risk periods for bees.
		Residual toxicity: "Environmental Hazards: This product is *highly toxic* to honey bees and other bees. Do not apply to plants in bloom."[45] [no residual toxicity statement anywhere on label][45]	

(Acute/residual) toxicity is not communicated with USEPA-recommended language	Toxicity language deviates from USEPA- guidelines. For acute toxicity, this includes: (a) claims of nontoxicity or action as pathogen (b) claims of toxicity expressed with uncertain language (c) claims of toxicity for specific exposure routes, residue status, or honeybee life stages or d) claims of toxicity or nontoxicity for general arthropods. For residual toxicity, this includes (a) a specific claim of residual toxicity or (b) any description of bee activity during which an applicator cannot apply the product that is not described using USEPA-recommended language.	Acute toxicity: "Environmental Hazards: This product is toxic to certain nontarget terrestrial arthropods."[46] Residual toxicity: "Environmental Hazards: Do not apply this pesticide to blooming, pollen-shedding or nectar-producing parts of plants if bees *may forage* on the plants during this time period."[47]	Educational materials cover USEPA-recommended language. Applicators are likely not trained on how to interpret acute and residual toxicity information when expressed in ways other than what the USEPA recommends. Therefore, labels that use language other than what the USEPA recommends are unclear as to the hazards the product poses to bees.
Inconsistent (acute/residual) toxicity language	Toxicity communicated inconsistently on the label	Acute toxicity: "This product *is toxic* to honey bees if bees are exposed to direct application. However, dried residues of this product *are non-toxic* to honey bees"[48]	Applicators are trained to interpret a single statement of high or moderate toxicity and a single statement of extended or not-extended residual toxicity and to select products accordingly. Inconsistent toxicity

		Residual toxicity: "Environmental Hazards: … Do not apply this product or allow it to drift to blooming crops or weeds if bees *are visiting* the treatment area…. Specific Use Directions- Alfalfa and Alfalfa Grown for Seed: Avoid application when bees are *actively foraging*."[49]	statements would confuse an applicator, and would provide different information to applicators who read different label sections. Toxicity information is supposed to reflect a risk assessment, so any inconsistent communication raises questions about the underlying data.
USEPA-recommended (acute/ residual) toxicity language not located in Environmental Hazards	USEPA-recommended language is found on the label, but it is not found in the Environmental Hazards section	Acute toxicity: "Bee Hazard: The product *is toxic* to bees exposed to direct treatment"[50] [not a part of the Environmental Hazard statement][50]	Applicators are taught to find honey bee hazard information in the Environmental Hazards section. If it is located elsewhere, an applicator may not see it.
		Residual toxicity: "Suitability for Integrated Pest Management Programs: … do not apply… directly to bees that are *actively foraging* in the field." [not a part of the Environmental Hazard statement][51]	
	USEPA-recommended acute toxicity language	Acute toxicity:	Data shows the product's active ingredient to be

USEPA-recommended acute toxicity language does not align with active ingredient toxicity	was used, but did not align with the acute toxicity data (honey bee contact LD_{50}) of product's active ingredient that was most toxic to bees.	A label that has no acute toxicity statement on label, but has an active ingredient in toxicity class I. [52] A product containing such an active ingredient would be recommended to have the "highly toxic" acute toxicity statement.[6,39] (This error did not apply to residual toxicity information)	moderately or highly toxic to bees, yet this information is not communicated to the applicator. An applicator may then unknowingly apply a product hazardous to bees.

3. RESULTS

We analyzed 232 labels and found that 73 had at least one error communicating acute toxicity or residual toxicity to honey bees (31.5% of all labels). Of the labels with at least one error, 31 (42.5%) only had errors communicating acute toxicity, 15 (20.5%) only had errors communicating residual toxicity, and 27 (37.0%) had errors communicating both. There were 35 labels that had more than one error. The 3 most common errors were: (1) USEPA-recommended acute toxicity language does not align with active ingredient toxicity, (2) use of not- recommended residual toxicity language and (3) use of not- recommended acute toxicity language (Table 3). The acute toxicity dataset was large enough to analyze 164 labels (70.7% of all labels analyzed) for how their acute toxicity language aligned with active ingredient toxicity.

Table 3. Counts of how many times each error occurred in the labels selected for this project. Since labels could have more than one error, these counts do not sum up to the total number of labels analyzed.

Error	Count
USEPA- recommended acute toxicity language does not align with active ingredient toxicity	41
Not recommended residual toxicity language used	24
Not recommended acute toxicity language used	15
Inconsistent residual toxicity language	13
Missing residual toxicity information	11
USEPA- recommended residual toxicity language not located in Environmental Hazards	6
Inconsistent acute toxicity language	5
USEPA- recommended acute toxicity language not located in Environmental Hazards	2
Missing acute toxicity information	1

All 41 products whose USEPA- recommended acute toxicity language did not align with their active ingredient toxicity had active ingredients in toxicity class I ("highly toxic to bees").[39] Of these 41 labels, 28 lacked an acute toxicity statement altogether. The remaining 13 contained the statement "is toxic to bees," which is the recommended statement for products containing active ingredients in the less toxic class II.[6] The majority of these 41 labels (26 products, 63.4%) were for garden products. Five of the remaining 15 commercial products whose labels had this error are used on more than one crop.

There were 20 instances of inconsistent acute or residual toxicity language, found across 18 labels (Figure 1; Table 3). Inconsistencies were primarily found within a label's Environmental Hazards section, and were primarily inconsistent communication of residual toxicity. There were five instances of inconsistent acute toxicity language, all of which were within the Environmental Hazards section of each label.

Errors were found on the labels of products used on all but one crop (meadowfoam), but the percent of labels with at least one error was not consistent by crop (Figure 2). For three crops the percent of labels with at least one error was 50% or higher (radish seed, pear, and Christmas tree). For six crops, 25% of product labels or fewer had at least one error (mosquito control, almond, watermelon, carrot seed, clover seed and meadowfoam). Notably, the percent of commercial product labels with at least one error was less than that of the garden product labels (26.3% vs. 48.3%).

Products used in the 16 selected high- risk situations to Oregon beekeepers represent 30 different IRAC MoA subgroups (Figures 3 and 4). Ten subgroups had more than five labels included in the project. Of these ten subgroups, diamides and *Bacillus thuringiensis* and the proteins they produce had the lowest percent of labels with at least one error (0% out of 6 labels each), while spinosyns had the highest percent (100% of 10 labels). The four subgroups with the most product labels included in this project (and corresponding percentage of labels with at least one error) are pyrethroids/pyrethrins (32.9% of 85 labels), neonicotinoids (36.8% of 19 labels), organophosphates (21.1% of 19 labels), and carbamates (76.9% of 13 labels).

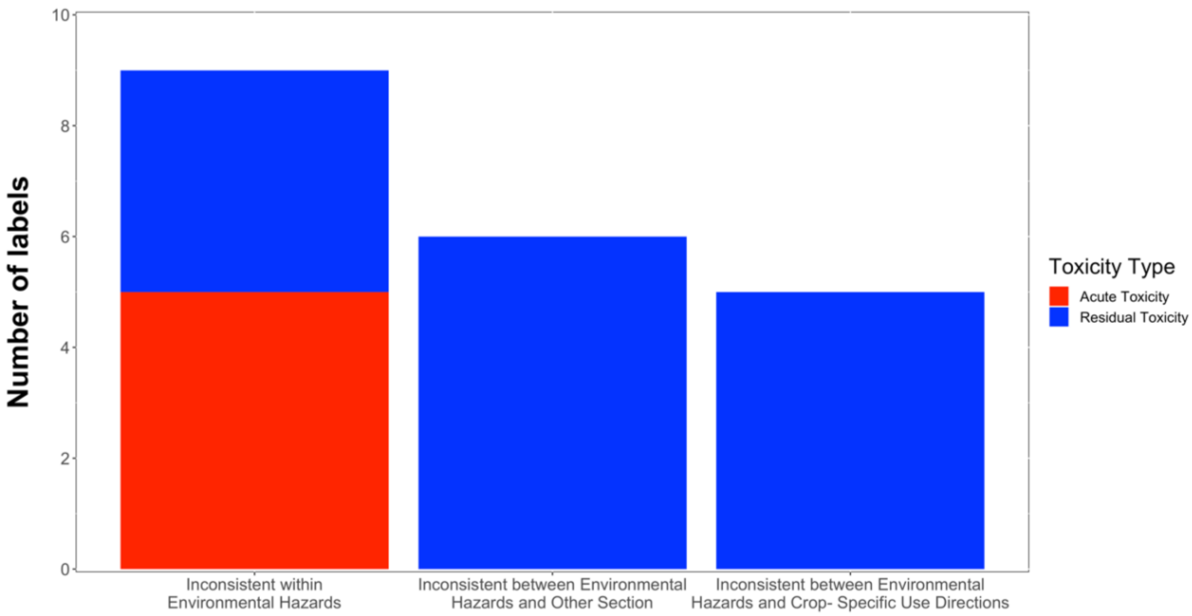

Figure 1. Instances of inconsistent communication of acute and residual toxicity, grouped into (1) instances of toxicity being communicated inconsistently within a label's Environmental Hazards section (2) instances of toxicity being communicated inconsistently between a label's Environmental Hazards section and another label section that is not crop-specific use directions and (3) instances of toxicity being communicated inconsistently between a label's Environmental Hazards section and crop- specific use directions for crops included in this project that growers use that product on.

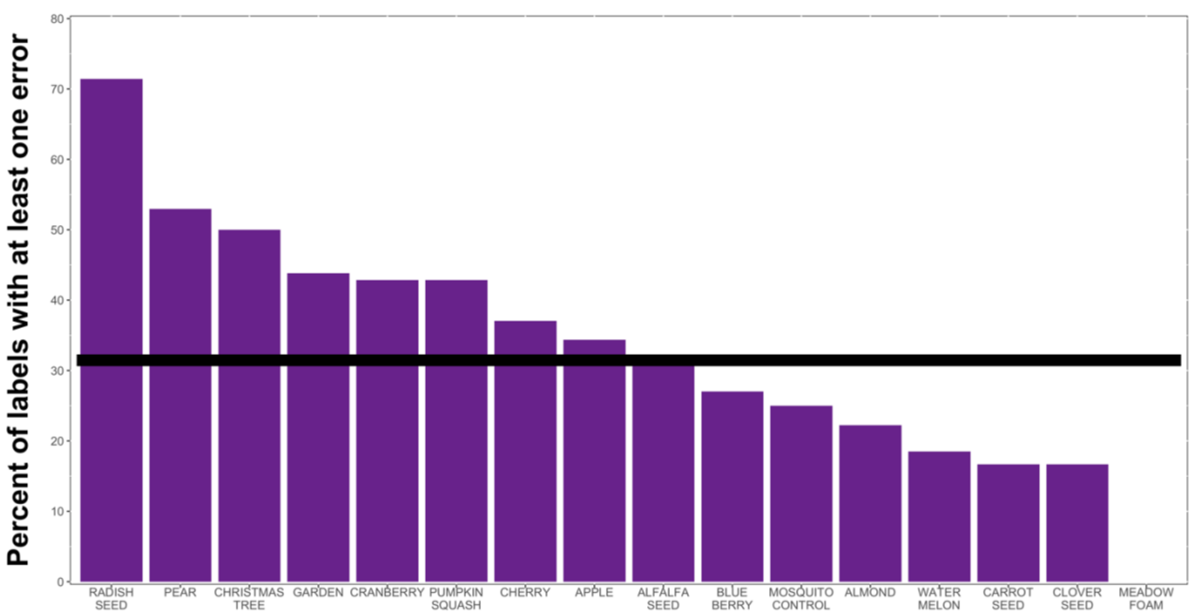

Figure 2. Percent of each crop's product labels with at least one error. The horizontal black line represents the overall percent of product labels with at least one error (31.5%). Meadowfoam was the only crop to not have any labels with at least one error, out of 2 total labels.

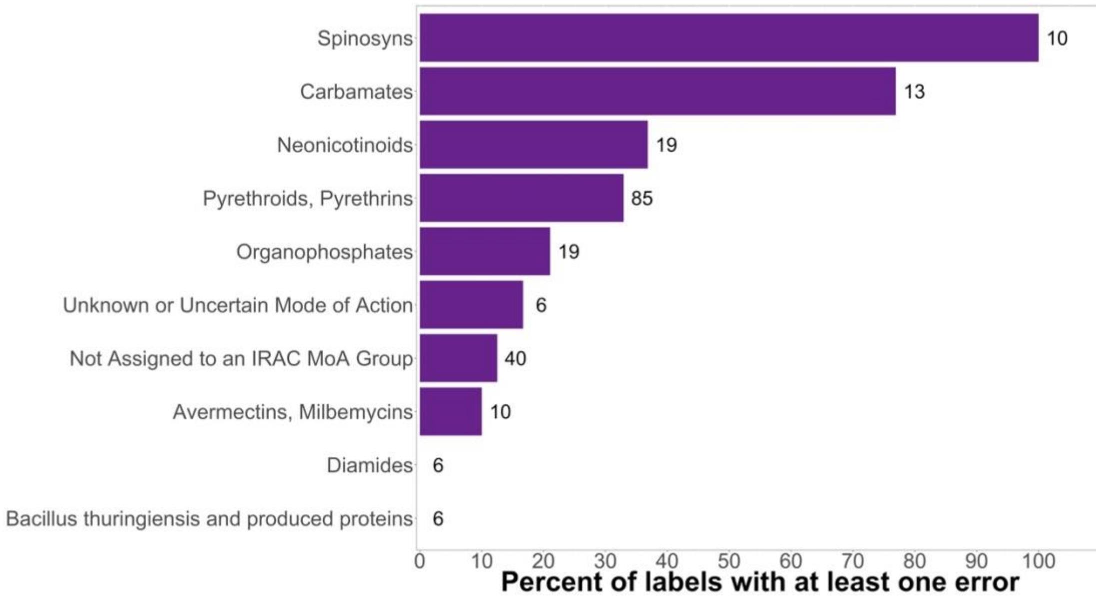

Figure 3 The percent of each Insecticide Resistance Action Committee (IRAC) mode of action (MoA) subgroup's total observed labels with at least one error, for the subgroups with more than 5 labels total. The total number of observed labels that belonged to each subgroup is labeled to the right of each bar. Each subgroup's percent of labels with at least one error was calculated based on the total number of observed products for that subgroup. Some products had multiple active ingredients, and therefore belonged to more than one IRAC MoA group.

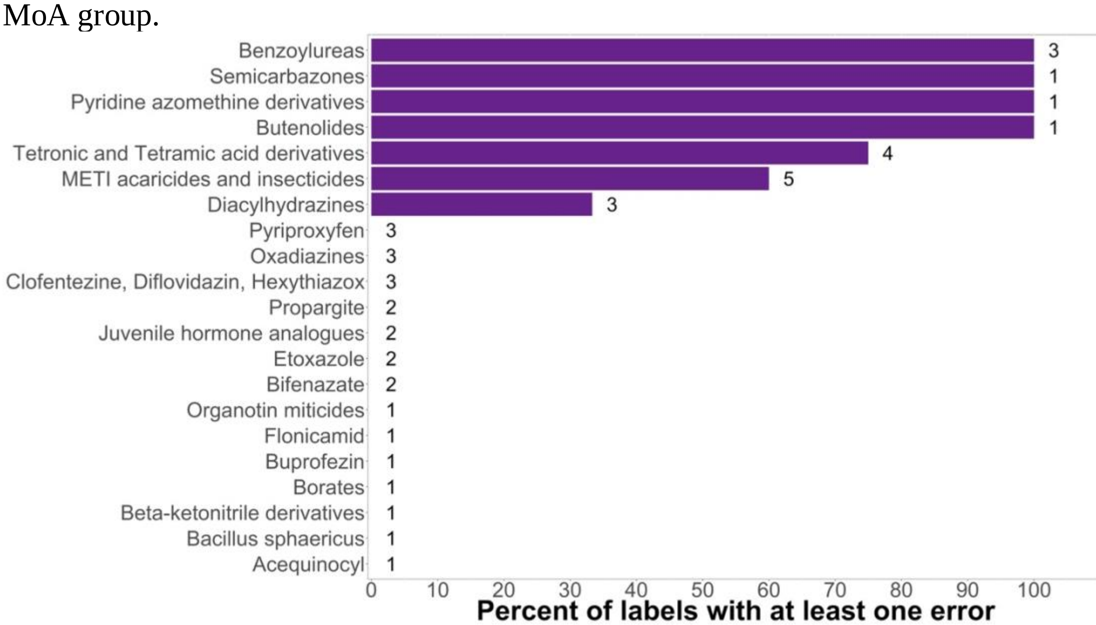

Figure 4 The percent of each Insecticide Resistance Action Committee (IRAC) mode of action (MoA) subgroup's total observed labels with at least one error, for the subgroups with 5 or fewer total labels. The total number of observed labels that belonged to each subgroup is labeled to the right of each bar. Each subgroup's percent of labels with at least one error was

calculated based on the total number of observed products for that subgroup. Some products had multiple active ingredients, and therefore belonged to more than one IRAC MoA group.

4. DISCUSSION

Existing literature has examined applicator comprehension of pesticide labels but has not examined whether those labels follow regulatory agency guidance as to how they should be written. Examining the prevalence of deviations from recommended language is necessary in developing effective applicator education programs. Knowing in what ways labels deviate from these recommendations and incorporating this knowledge into educational material will better help applicators grasp the environmental hazards of what they are applying and what precautions they should take.

This was the first study to look for deviations from USEPA recommendations in the communication of environmental hazards on the pesticide label. Specifically, this study showed that deviations exists for the language used to communicate acute and residual toxicity to honey bees on the labels of insecticide products used in situations of high- risk to Oregon beekeepers. The data show that errors in communicating acute and/or residual toxicity are prevalent, with 31.5% of labels having at least one error. Errors are found on the labels of products used on different crops, of products belonging to different chemical subgroups, and of both commercial and garden use products. Errors communicating acute toxicity were more common than errors communicating residual toxicity. This is potentially because acute toxicity data was available (albeit as an incomplete dataset) and could be compared to the acute toxicity language labels used. All error categories other than the language not aligning with toxicity data had more instances of residual toxicity communication errors than acute toxicity communication errors. Therefore, had a residual toxicity dataset been available, the results may have supported that errors communicating residual toxicity are more common. Inconsistent toxicity communication can be found throughout a label, and applicators should be taught what to do if they encounter inconsistent communication of acute or residual toxicity to honey bees. A higher proportion of garden labels having at least one error compared to commercial labels is concerning because homeowners lack the training requirements of licensed applicators on how to interpret the information on a pesticide label. This higher proportion could be in part due to the fact that garden product use patterns were not considered. All analyzed garden products were registered for outdoor use. However, the omission of an acute toxicity statement may have been justified for products with a use pattern considered to be non- hazardous to bees (e.g. a product that would not be used as a foliar application on blooming plants). This could explain why most of the labels whose USEPA- recommended acute toxicity language did not align with their active ingredient toxicity were garden product labels.

The major limitation of this study is that the product lists for each crop were developed differently, and not all sources were equally reliable. The most reliable data are the pesticide use report data from CalPIP. Comparable data are not available for Oregon. CalPIP data encompassed more than just the major products growers were applying, which may not be the case for the other resources consulted. CalPIP data also accounted for the use of active ingredients that would have been difficult to match up to specific products through only consulting pest management documents and faculty/industry experts (e.g. horticultural oil). Lists developed from pest management documents that were unable to be verified with an extension agent or crop expert were the least reliable. These lists contained the fewest products, while lists developed from CalPIP data contained the most products. Exclusively utilizing pesticide use report data and grower surveys would result in more reliable product lists, and more reliable estimates as to the percent of products a grower would use with label errors communicating toxicity to honey bees.

This study did not analyze use patterns and did not attempt to quantify associated risk, and instead treated all product labels equally. Giving more weight to errors found in the labels of the most used products would better estimate the risk these errors pose to commercial honey bee stocks. In addition, some pesticide labels may use different language to communicate acute and residual toxicity that was recommended under a 2017 USEPA policy.[53] However, no label analyzed in this project appeared to use the language recommended by this new acute risk mitigation policy. The USEPA Label Review Manual has also not been updated to reflect this new policy, and it can therefore be assumed applicators will be trained and new labels will be modeled after the USEPA-recommended language analyzed for this project.[6] Additionally, omitting components of the Environmental Hazards, including the Pollinating Insect Hazard Statement, may be justified if the product use pattern is expected to pose sufficiently low risk to bees.[6]

Language is subjective, and definitively categorizing information as communicating acute or residual toxicity was difficult. The categorization criteria used in this study was aligned with the currently- recommended language as much as possible. There was label language that may be relevant to pollinator protection that was not specifically analyzed in this project because, by our definitions, it did not communicate acute toxicity or residual toxicity. For example, “Drift of this product onto beehives or off-site to pollinator attractive habitat can result in bee kills” is helpful information for an applicator.[54] Such a statement does not explicitly communicate acute or residual toxicity based on this project’s definitions, and therefore was not analyzed. This example statement is from the language required for nitroguanidine neonicotinoid products.[55] Much of the newly required neonicotinoid- specific language was unaccounted for by this analysis because it did not meet the appropriate criteria as explicitly communicating acute toxicity or residual toxicity. Some labels also gave specific windows of time during which product residues would be toxic (e.g. many spinosyn-based products). The USEPA Label Review Manual does not mention guidelines for putting specific durations of toxicity on a label. These statements were not counted as an error and their accuracy was not investigated.

In addition, while a label may not use the USEPA- recommended language to communicate toxicity to bees, an applicator might find that language easier to comprehend. Applicator comprehension should also be studied to find the most effective way of communicating acute and residual toxicity to honey bees.

Toxicity to bees is only one environmental hazard communicated on US product labels. In light of our findings, the communication of other environmental hazards, such as hazards to birds, fish and aquatic invertebrates, ought to be analyzed for any deviations from USEPA recommendations. A comprehensive 2017 USEPA policy for evaluating risks of pesticides to pollinators will further change how hazards to honey bees will be communicated to applicators.[53] This recent change to label communication presents an opportunity to address the errors uncovered by this project and to assess applicator comprehension to make labels as consistent and comprehensible as possible.

5. CONCLUSION

The labels of insecticide products used in situations of high- risk to Oregon honey bees deviate from USEPA recommendations in their communication of acute and residual toxicity to honey bees. These errors are found regardless of the crop the product is used on, the chemical subgroup of the product, or whether the product is for commercial or garden use. Consequently, applicators that are only taught how to interpret error- free labels may not be fully prepared to interpret the hazards to honey bees as expressed on the labels they may see in the field. Our work suggests that applicator education needs to incorporate material on how to effectively interpret a label with errors. Label communication of acute and residual toxicity to honey bees should ultimately be made as consistent and error- free as possible to help applicators minimize the risk of the products they apply to managed and wild bees.

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