IMPORTANCE OF IPM PRACTICES FOR PESTICIDE RESISTANCE MANAGEMENT

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ABSTRACT

Insects can, and often do, develop resistance to insecticides. This causes issues for pest managers when "control failures" occur, and can create long-term challenges for pest management when active ingredients or whole insecticide groups are rendered ineffective. The Insecticide Resistance Action Committee has created a mode of action classification scheme to support the stewardship of insecticides. This paper summarizes how resistance develops and discusses emerging issues with insecticide resistance in alfalfa. Resistance to pyrethroids for the alfalfa weevil has been documented or suspected across the Western United States and into Canada. Preventing and addressing insecticide resistance is critical to maintaining the viability of insecticides as tools. This paper discusses the role of Integrated Pest Management (IPM) in resistance management and various ways that insecticide tools can be used. Finally, this paper highlights specific IPM approaches that can be used for pest management in alfalfa to help manage insecticide resistance.

INTRODUCTION

Insect pests have displayed a propensity for developing resistance to insecticides, which threatens the ability of pest managers to control these pests. Hundreds of insect and mite species worldwide are resistant to pesticides of various active ingredients (pesticide that controls a pest; Sparks and Nauen 2015). With the loss of effective pesticide chemistries, pressure is put on the remaining materials and any new materials that can be developed and commercialized.

There is confirmed insecticide resistance or suspected resistance for alfalfa pest management in the Western US, specifically for alfalfa weevils. It is therefore a good time to discuss how resistance to insecticides develops, examples of insecticide resistance for alfalfa pests, what practices can be used to combat insecticide resistance, and how these practices can be applied to pest management in alfalfa. Integrated pest management (IPM) and best management practices for crop production are the backbone of resistance management, which seeks to prevent or delay the development of resistance. Critically, loss of chemical tools because of insecticide resistance can challenge successful IPM practices and make crop production a more expensive and challenging endeavor.

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HOW RESISTANCE DEVELOPS

Resistance to insecticides arises at the intersection of pest genetics and intensive use of insecticides. Resistance occurs when the sensitivity of a pest population to an insecticide changes and the previously effective dosage no longer controls the pest. In brief (and simplifying), individual insects vary in their genetic background, and some miniscule proportion of the population can be resistant to an insecticide. These individuals survive an application and are "selected for," reproduce and pass on their genes, and increase the proportion of individuals that are resistant to the insecticide in the population. Through time and with repeated applications, the previously miniscule proportion that is resistant can grow until the recommended insecticide dosage no longer manages the pest at the field level. Unfortunately, resistance typically arises where pest issues are already severe because these insects face substantial selection pressure year after year when insecticides are applied to control them. Short-term solutions can create long-term problems.

Insecticides are grouped by their mode of action (MoA), which is important for understanding how resistance develops and how we can prevent resistance from developing. The Insecticide Resistance Action Committee (IRAC) has created a MoA classification that classifies insecticides by their chemical structures/target sites using codes (IRAC 2018; Sparks and Nauen 2015). Groups are represented by different numbers, with a letter added to further divide groups into sub-groups. These codes are found on labels, the IRAC website, UC IPM guidelines for alfalfa hay, and the IRAC MoA app. Cross resistance occurs when a pest becomes resistant to an insecticide and then is immediately, or very shortly, resistant to an insecticide to which it may not have ever been exposed. This occurs most frequently within classes (but also between classes/groups). This can lead to reduced efficacy or complete loss of multiple active ingredients very quickly. Risk of resistance is highest within subgroups (e.g., 3A), followed by within groups (e.g., 3). In multiple resistance, exposure of a pest to two different MoAs confers resistance independently to each insecticide through two independent genetic mechanisms.

SPECIFIC ISSUES WITH INSECTICIDE RESISTANCE FOR ALFALFA PESTS

Insecticide resistance is an issue that appears to be gaining momentum in alfalfa the last several years in several areas of California and, more broadly, across the Western United States and into Canada. This appears to primarily be an issue with alfalfa weevil, including both the western and Egyptian strain. For alfalfa weevil, insecticide resistance is nothing new. For instance, treatment failures were reported in Utah in the 1960s, with confirmed resistance to heptachlor (Adler 1964). Resistance to eight active ingredients have been reported for alfalfa weevil (APRD 2018), although these are all materials that are no longer used. Resistance to currently registered pesticides could disrupt alfalfa weevil management and create secondary pest problems. Currently, there are few active ingredients available to manage alfalfa weevil, and these are only from a couple insecticide classes (MoAs), making resistance issues more pressing. Unfortunately for alfalfa weevil management and management of other alfalfa pest, there are few new insecticides coming down the pipeline for alfalfa in the near future.

In California, insecticide resistance in weevils is clearly an issue and may be growing worse. At this point, resistance is not yet widespread geographically. The first issues arose with the widely used pyrethroids in the Intermountain region of CA, specifically in Scott Valley (Orloff et al. 2016). This is an area where alfalfa is the predominant irrigated crop, with a long alfalfa crop cycle and problematic alfalfa weevil populations (likely Western strain). Following reports of poor initial control after pyrethroids were applied in alfalfa fields in Scott Valley (applications of beta-cyfluthrin and lambda-cyhalothrin, Baythroid and Warrior, respectively), Steve Orloff and Larry Godfrey collected weevils from commercial fields. They then conducted laboratory assays to test how resistant the populations from each field were to pyrethroids using an organic field that had never been treated with pyrethroids to supply a (hopefully) susceptible population. They found very poor levels of control for populations from the conventional fields, even at four times the recommended rates (Table 1, Orloff et al. 2016). The lack of excellent control with weevils from the organic field may have been due to between-field movement of resistant weevils. Thus far, this still appears to be a relatively localized issue and not widespread in the region.

Table. 1. From: Orloff et al. 2016. Percent control of alfalfa weevil after treatment with beta-cyfluthrin or lambda-cyhalothrin (Baythroid or Warrior) at various rates.

	Insecticide rate				
	0.25×	**0.5×**	**Recommended (1×)**	**2×**	**4×**
Field	**% Mortality**				
Conventional field 1	5%	8%	5%	10%	23%
Conventional field 2	0%	5%	10%	13%	23%
Conventional field 3	23%	3%	3%	10%	35%
Conventional field 4	0%	0%	15%	8%	23%
Conventional average	**7%**	**4%**	**8%**	**10%**	**26%**
Organic field	62%	65%	92%	82%	88%

There appear to be additional issues in southern CA concerning insecticide resistance for pyrethroid insecticides among populations of alfalfa weevil (Egyptian strain) in the Palo Verde Valley. This work was performed by Mike Rethwisch with UCCE and the UC Davis entomology IPM lab. Based on reports of beta-cyfluthrin (Baythroid XL) losing effectiveness, resistance was suspected. Another pyrethroid, lambda-cyhalothrin was still considered to be effective. Laboratory assays were conducted with weevil larvae collected from a field that had never been sprayed with pyrethroid insecticides (an organic field), a field that had seen infrequent use, and a field with annual use. Labelled rates were applied to foliage and exposed to weevil larvae in the lab. Lambda-cyhalothrin (Warrior II at higher labelled rate) provided control for weevils from the field that had never had pyrethroids applied (Fig. 1). For weevils from the fields with histories of pyrethroid use, the tested pyrethroids were less effective. Even the field that had seen more limited use of pyrethroids still suffered from lower levels of control. In a separate assay, mortality was also low after exposure to lambda-cyhalothrin (Warrior II) for weevils collected from a field one week after an application of the same material (Fig. 2). For this assay, chlorpyrifos still caused substantial mortality. In a field trial outside of Blythe, CA, performance of Warrior II at the high rate (1.92 oz.) provided some, but not substantial control (78% 9 days after treatment). This was in contrast to indoxacarb (Steward, 4 and 6 oz. rates), which provided 96-97% control. This suggests that there may be some building levels of resistance to pyrethroids, but that other classes of insecticides can still provide acceptable levels of control at this location.

These studies provide evidence for pyrethroid resistance for alfalfa weevil in the Palo Verde Valley. Similar to the Intermountain region of CA, this still appears to be a relatively localized issue. However, this could become a persistent issue and we anticipate examining the issue more closely in upcoming seasons.

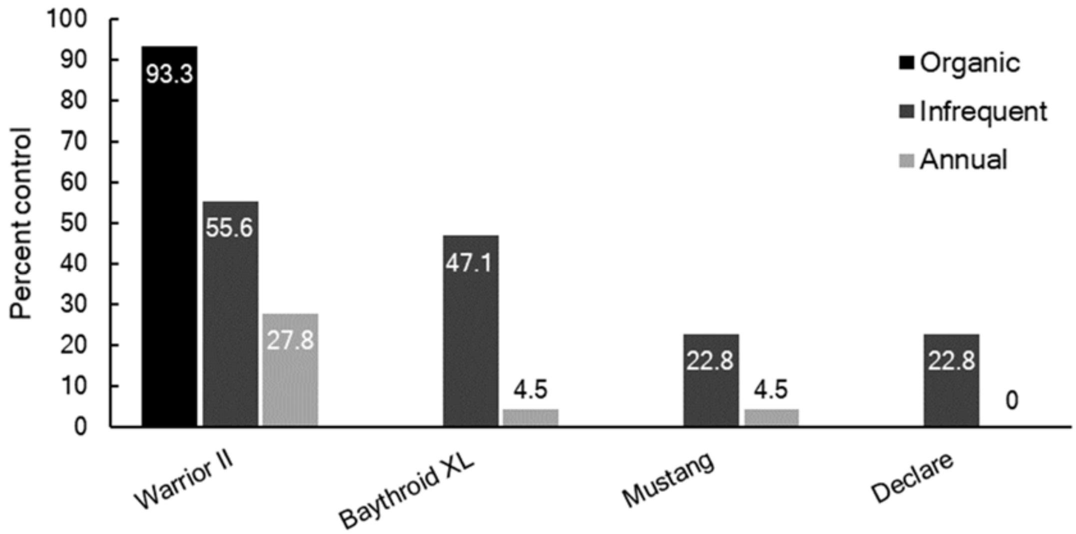

Fig. 1. Efficacy of various insecticides against alfalfa weevils collected from fields that differed in their history of pyrethroid use from a laboratory assay. The organic field had never had a pyrethroids applied, while the intermediate-use fields had annual gaps in their pyrethroid use and the high-use fields had pyrethroids used on an annual basis. All insecticides were not tested for weevils from the organic field.

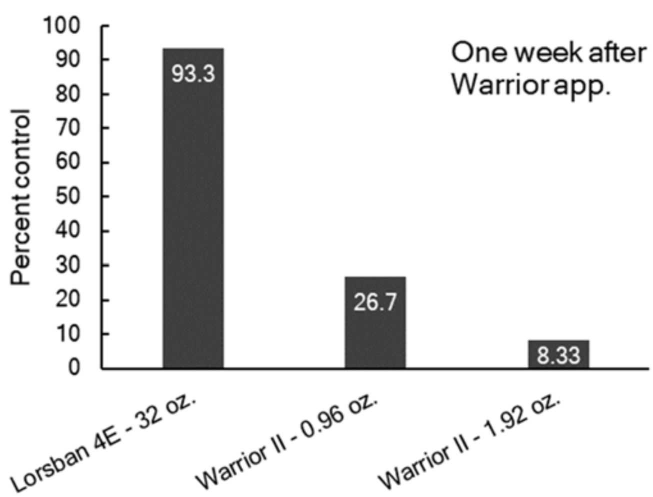

Fig. 2. Efficacy of insecticides against alfalfa weevils collected one week after a Warrior application in a field. Efficacy was evaluated in a laboratory assay.

More broadly, there appear to be issues developing across the Western United states and up into the alfalfa-producing regions of Alberta, Canada. Again, thus far, the cases of resistance or possible resistance appear to be isolated and for pyrethroid insecticides. These details may not necessarily remain the case. Thus far, there has been fairly limited work assessing whether or not “control failures” are due to resistance or some other issue (e.g., interactions of insecticides with weather, poor coverage, or extended hatch). There does, however, appear to be growing concern about pyrethroid insecticides providing poorer levels of control for alfalfa weevils than was previously seen. In Alberta, trials targeting what appeared to be resistant weevils showed that even at fifty times the recommended rate for lambda-cyhalothrin, weevil mortality was very low (Glen 2017).

In California, there generally do not appear to be substantial issues with insecticide resistance thus far in alfalfa with other key pests. These pests would include the species of aphids that attack alfalfa (pea aphid, blue alfalfa aphid, spotted alfalfa aphid, and cowpea aphid) and the various caterpillar species (alfalfa caterpillar, Western yellowstriped armyworm, and beet armyworm). However, this certainly doesn’t mean that there are not low levels of insecticide resistance. At the very least, it is important that pest managers keep resistance in mind when managing these pests. Aphid and caterpillar pests have repeatedly become resistant across cropping systems (APRD 2018), so it reasonable to guess that problems will develop at some point with sufficient pressure imposed by repeated applications of the same active ingredient or active ingredients within the same MoA group.

PREVENTING AND ADDRESSING INSECTICIDE RESISTANCE

How can we reduce the likelihood that insecticide resistance will develop? First, is the use of IPM. The creation of the building blocks of IPM was in fact motivated in the 1950s by in part by growing issues with insecticide resistance (Stern et al. 1959). Resistance management relies on following the tenets of IPM because, in simple terms, without insecticide applications, there is no selection for resistance. By preventing pest populations from reaching damaging levels in the first place through alternative tactics, it may be possible to avoid insecticide applications or to reduce the number needed within and across seasons. Furthermore, resistance management can be achieved by limiting applications to only when necessary and warranted. Resistance management is a crucial component of IPM because it extends the life of insecticides that are crucial for IPM.

Good basic agronomic practices, as well as cultural practices that target key pests are a good starting point when thinking broadly about resistance management. A healthy crop can better resist or tolerate insects and damage, which may make an insecticide application unnecessary. Proper nutrient management, weed management, and water management all combine to produce a vigorous crop. Making full use of cultural practices such as host plant resistance, crop rotation, or cutting schedules, can provide alternative management options and reduce the number of insecticide applications needed through time. Where possible, promotion or reliance on natural enemy communities may reduce the burden that is placed on insecticides for controlling pests.

If it looks like insecticide applications will likely be necessary, following the principles of IPM is still an important part of resistance management. Routinely monitoring pests and using proper action thresholds help ensure that only necessary applications are made. Again, reducing the number of applications, whenever possible or feasible, is one of the crucial first steps for resistance management. If you are making an application, follow label recommendations for rates. Reducing the rate below the labelled rate could promote resistance if efficacy is sub-optimal. Routine monitoring of pests post-application will help identify resistance issues early and make a response possible. Contact local extension personnel if you believe you have a resistance issue.

There are a number of possible ways to use insecticides that differ in their IRAC codes to help prevent resistance or address resistance if it does appear. The methods will vary in effectiveness depending on the pest/pest management system. To properly assess the options we need to know many details about the biology of the pest (number of generations, dispersal patterns, mating patterns) and how the pest interacts with the insecticide (genetics of resistance, percent mortality for susceptible or resistant), but we can make generalizations. Typically, rotating through insecticides with different codes is the best option (NOT rotating between different trade names). For example there are many types of pyrethroids (3A), but for resistance management you should rotate to another group, such as an oxadiazine (indoxacarb, 22) or an organophosphate (1B). Keep in mind how many generations of the pest there are when possible, and try to target different generations of the pest with materials with different codes. For pests with one generation, this means you should target the single generation with the same insecticide and then rotate between years. Remember that rotating between insecticides with the same code is not a rotation.

In some cases, using mixtures of insecticides with different codes/MoAs can delay resistance for a given pest, but this tactic is less favored for insecticides than rotations because of possible issues that arise satisfying assumptions about pest biology and the efficacy of the mixture components. Using a mixture (e.g., a tank mixture of a 1B and 3A insecticide) ideally relies on each insecticide to kill insects that are resistant to the other insecticide. In practice, mixtures risk simultaneously selecting for resistance to both insecticides, and ultimately, insecticides in both groups. Mixtures also run into issues, especially for pests that readily disperse between fields, when mixtures and single insecticides are used across the landscape. A mixture of multiple insecticides of the same group is definitely not recommended. Mixtures of insecticides can be used if warranted by thresholds and *if* each insecticide is independently target different pests and each insecticide has activity against only one pest (e.g., flupyradifurone [4D] + methoxyfenozide [18]).

How long it takes resistance to develop or how long it takes resistance to disappear are good questions, but can be difficult to resolve. As with figuring out the best way to deploy insecticides, the answers depend on biology of the species, genetics of resistance, how the insecticide is used across the landscape, and many other factors. Even with repeated use of the same insecticide, in some systems, and with some pest species, resistance simply doesn’t appear for many years. However, in others, pests will repeatedly become resistant to different active ingredients in only a few years and display high rates of cross resistance within insecticide groups or even between groups, severely limiting management options. Similarly, a pest species may revert to a susceptible state relatively quickly, or resistance may persist indefinitely once it has been acquired. This will depend on a variety of factors, including if resistance comes with a “cost” to the pest, how readily susceptible individuals can disperse into the area, and if the insecticide is still used in the landscape. In the end, it is good to assume that we cannot simply expect a pest to become susceptible again if we stop using an insecticide.

INSECTICIDE RESISTANCE MANAGEMENT FOR ALFALFA PESTS

For resistance management for alfalfa pests, it is important to keep in mind the generalizations described above, but we can also make some specific recommendations. For instance, ensuring that proper, regionally specific agronomic practices are followed will not only help generate higher yields and higher quality, but will also help the crop better resist or tolerate any pests. Over- and under-watering, nutrient deficiency, too frequent cutting schedules, herbicide injury to the alfalfa, and poor alfalfa stand can make damage by weevils more problematic. In contrast, a healthy stand will be better able to compensate for any damage. For aphid management, carefully choose varieties and use an aphid-resistant variety, especially if you anticipate moderate to high aphid pressure. Between a resistant variety and natural enemy communities, maintained by minimizing unnecessary insecticide use and using selective materials, applications for aphids can be minimized.

For all pests in alfalfa, but especially for alfalfa weevil, the number of effective options (that also don't have crop damage issues) are very limited overall and extremely limited with regard to IRAC codes. For example, for alfalfa weevil, options are currently limited to organophosphates (Malathion, Lorsban), pyrethroids (Mustang, Warrior, Baythroid), an oxadiazine (Steward), and spinosyns (Entrust) in organic systems (Long et al. 2017). The organophosphates may not be perpetually available because of changes in regulations (see chlorpyrifos). This makes resistance management that much more critical. Rotating between groups between years (or within years if a second generation is present and warrants management) will help avoid resistance. If spraying twice for alfalfa weevil in one season and against the same generation, not rotating materials is best. In addition, because weevils can disperse several miles, ideally follow a resistance management plan at the farm level and use the same material in different fields within the same time periods.

Insecticide resistance issues with alfalfa weevil highlight the need to both follow good resistance management practices to prevent development of resistance and to monitor for resistance. Not following good practices, such as repeated use of one pyrethroid insecticide year-after-year, or only rotating within pyrethroid (3A) insecticides (e.g., between Warrior and Baythroid or Warrior and Mustang) is a recipe for resistance. Failure to control pests can happen due to a variety of reasons, not all of which are resistance. Follow best practices for applications to help achieve adequate control, including following the label to achieve good spray coverage, use of recommended surfactants, and making applications under amenable environmental conditions. Repeated applications, each with poor coverage, can promote resistance. Following best practices is also important to provide a better sense of whether or not resistance is actually an issue. Working with extension personnel to determine if suspected resistance is actually resistance can be important if management options will be changed. Using more expensive materials may increase costs in the short term, but could provide more management options in the longer term if severe resistance issues are avoided.

CONCLUSIONS

Considering resistance management when using insecticides to manage insect pests is critical for maintaining our ability to use a range of chemical tools. Resistance management starts with good agronomic practices and following the basics of IPM (cultural controls when possible, relying on natural enemies, and use of thresholds). Rotating insecticide groups (MoAs) and paying attention to IRAC codes is a key part of resistance management. The development of resistance to pyrethroids and the growing reports of possible resistance for alfalfa weevil emphasizes that pest managers need to consider resistance management in alfalfa production.

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