Application of the Industrial Hygiene Hierarchy of Controls to Prioritize and Promote Safer Methods of Pest Control: A Case Study

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SYNOPSIS

In 2005, the California Department of Public Health, Occupational Health Branch (OHB) investigated an incident of pesticide exposure and identified 27 vineyard workers who became ill due to drift of cyfluthrin, a pesticide being applied to a neighboring orange field to control katydids. Another pest, citrus thrips, was also present in the field. We investigated safer alternatives for katydid and thrips control to prevent illness due to pesticide exposure and used the industrial hygiene hierarchy of controls to prioritize the control methods.

OHB evaluated factors that contributed to pesticide exposure and identified safer alternatives by conducting literature reviews on katydid and thrips control, drift prevention technology, and other relevant topics, and by interviewing integrated pest management advisors, conventional and organic growers, equipment manufacturers, county agricultural commissioners, pest control advisors, regulatory agencies, and others. We prioritized methods using the industrial hygiene hierarchy of controls. We identified safer pest control practices that incorporated hazard elimination, chemical substitution, engineering controls, and administrative controls, including employer policies and government regulations.

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The United States is a major contributor to worldwide pesticide use.[1–3] California is the top agricultural state in the U.S., with substantial amounts of pesticides used to maintain high-volume agricultural production.[4,5] In 2006, more than 190 million pounds of pesticide use was reported in California, of which 88% was in production agriculture.[6]

Pesticides, considered an important component of large-scale agriculture, are the only toxic chemicals intentionally released into the environment to deliberately cause harm to living things.[7] Toxicity and intentional broadcast are unique factors that can lead to hazardous exposures from pesticide drift beyond intended targets.

The U.S. Environmental Protection Agency defines pesticide drift as "the physical movement of a pesticide through air at the time of pesticide application or soon thereafter, to any site other than that intended for application."[8] There are many ways to apply pesticides, including aerial spraying, chemigation, ground injection, and use of spray rigs pulled by tractors, all of which have the potential to result in drift. Drift is of concern to workers, neighboring communities, neighboring crops, waterways, and wildlife.[9]

In California, suspected pesticide illness and work-related illnesses and injuries are reportable conditions. The Occupational Pesticide Illness Prevention Program (OPIPP) in the California Department of Public Health, Occupational Health Branch conducts surveillance of work-related pesticide illness using these mandatory reports. Between 1998 and 2005, pesticide drift accounted for 16% of all pesticide-related illness cases reported by OPIPP. Drift is of particular concern to farmworkers, as 67% of all drift-related pesticide illnesses occurred in this worker group.[10]

In May 2005, OPIPP investigated a pesticide drift incident in Kern County that resulted in illness. A commercial pesticide application team sprayed a mixture of cyfluthrin, spinosad, petroleum oil, and water in an orange orchard to control katydids and citrus thrips. Specifically, spinosad was used to control thrips; cyfluthrin was added to control katydids, since spinosad is less effective at controlling this pest.[11–13] The pesticide mixture was applied by air blast sprayers pulled by enclosed tractors that traveled up and down rows and turned around on a dirt road that bordered the field. In an adjacent vineyard, 27 farmworkers were pruning and tying grape vines. The foreman for the pesticide applicators noticed the workers in the vineyard and suspended the application temporarily. The pesticide applicator foreman spoke with both the foreman for the vineyard workers and with his own supervisor, but for unclear reasons, he decided to continue spraying even though the vineyard workers were still in the adjacent field.[11,14] Shortly after spraying was resumed, some of the workers noticed a chemical odor and began feeling ill. A 911 call was made and emergency responders arrived to provide care to the workers. Ultimately, all 27 farmworkers were transported to emergency departments. Symptoms reported by the workers included paresthesia, headache, nausea, eye irritation, muscle weakness, anxiety, and shortness of breath. Additionally, health effects were reported by four of the six emergency responders. OPIPP classified all 27 farmworkers and four emergency responders as pesticide illness attributed primarily to cyfluthrin.[11]

As part of our investigation, we identified several factors that contributed to illness due to pesticide drift.[11] These included the inherent toxicity of cyfluthrin, pesticide application by air blast sprayer, unpredictability of weather conditions, lack of requirements to notify neighboring employers about planned applications, and miscommunication among workers. For this article, we evaluated multiple strategies for preventing similar drift incidents.

METHODS

In order to recommend approaches to reduce pesticide illness due to drift, we evaluated methods that address the risk factors identified in our original investigation. We then used the industrial hygiene hierarchy of controls as a guiding framework to evaluate and prioritize the control methods. We conducted our evaluation as follows:

- We utilized information from our previous investigation,[11] conducted literature reviews, and interviewed key informants, including integrated pest management (IPM) specialists and regulators. Because pest control strategies are determined by commodities, pests, and geographic regions, we researched oranges, katydids, and citrus thrips, as well as the control method used (air blast sprayer application of cyfluthrin), which were all specific to the incident.
- We collaborated with an expert in sustainable agriculture to investigate current organic agricultural practices in California. As this information is primarily based on custom and practice, research was largely conducted through interviews with organic orange growers.
- We obtained information about pesticide spray technology by reviewing equipment, product, and university cooperative extension literature, and interviewing equipment manufacturers, IPM specialists, and regulators.

- We examined training and practice requirements for pesticide applicators who apply pesticides, and notification requirements for applicators and growers.

In the incident we investigated, cyfluthrin was used to control katydids; however, it is also used to control citrus thrips, typically at higher rates than will effectively control katydids.[13] Safer methods evaluated in this article apply to the control of both pests.

RESULTS

Commodity

In 2002, California was the second-largest orange producer in the U.S., following Florida, with 21% of total production. Oranges accounted for 72% of all citrus fruit grown in California.[15] In 2006, the total value of orange sales was more than $600 million.[16] Ninety-four percent of all California navel orange acreage and 64% of Valencia orange acreage are in the San Joaquin Valley, where Kern County is located.[15]

At least seven primary and 12 secondary insect and mite pests affect oranges in the San Joaquin Valley. The variety and abundance of pests vary by season. Other common pests found during the spring and summer, when katydids and citrus thrips are most active, include the citrus red mite, brown garden snails, and California red scale.[15,17]

Pests

Katydids resemble grasshoppers, albeit with long antennae. A few katydids can damage large quantities of fruit due to the way they feed: a katydid will take a single bite of a young fruit and then move on to another site on the same or nearby fruit. Feeding results in scar tissue and distortion of the fruit as it grows. Katydids also eat holes in leaves, flowers, and maturing fruit. If flowers or young fruit sustain enough damage, the young fruit can fall off the tree.[13,17,18]

Citrus thrips as adults are small, orange-yellow insects with wings. The larval stages are the most damaging to young fruit; adult thrips do not scar fruit. Citrus thrips cause damage to fruit by puncturing and feeding on epidermal cells of young fruit, leaving scars on the rind.[19] The scar grows as the fruit grows. Citrus thrips damage does not interfere with the flavor or overall quality of the fruit beneath the peel.[12]

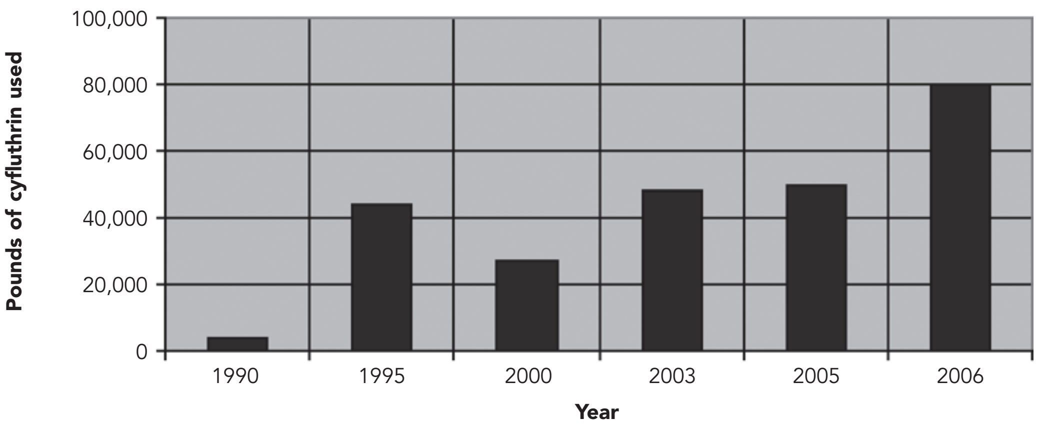
Mature fruit damaged by these two pests is edible. However, the cosmetic damage does affect the marketability of oranges. Scarred fruit will be downgraded from “fancy” to “choice” or “for juice only” and purchased at a lower price, which affects farmers’ income.[18]

Insecticide

Cyfluthrin is a type II pyrethroid pesticide that kills insects by prolonging the inactivation of sodium channels in their nervous systems.[20,21] The use of cyfluthrin has increased nearly 20-fold in California during the last 17 years (Figure 1). Cyfluthrin use in agriculture has increased more than 22-fold during this same time period. In 2006, 80,178 pounds of cyfluthrin were used: 78.8% in structural pest control, 20.2% in agriculture, and the majority of the remaining (0.8%) in landscaping.[22]

Although it has replaced other, more acutely toxic pesticides such as organophosphates and carbamates, cyfluthrin is considered moderately toxic to mammals. Cyfluthrin-containing products can be classified as

Figure 1. Cyfluthrin use in California



Source: California Department of Pesticide Regulation. Annual statewide pesticide use reporting. 2006 [cited 2008 Mar 4]. Available from: URL: http://www.cdpr.ca.gov/docs/pur/purmain.htm either acute toxicity category III, with the signal word "caution," or toxicity category I, bearing the signal word "danger."[23,24] The label for the pesticide formulation used in the Kern County drift incident indicated the signal word "danger" due to its potential to cause eye damage. The label lists as human health effects irreversible eye damage and allergic skin reactions, and states that the product is harmful if swallowed or absorbed through the skin and may be fatal if inhaled. In addition, the label specifies that this pesticide is extremely toxic to fish and aquatic invertebrates and highly toxic to bees. The restricted entry interval for this cyfluthrin formulation is 12 hours, meaning that workers are to be kept out of the treated field for at least 12 hours after treatment.[25]

Cyfluthrin is currently under review by the California Department of Pesticide Regulation (CDPR) as a potential teratogen and reproductive toxin.[26] Cyfluthrin is highly toxic to marine and freshwater organisms and is among a group of pyrethroid pesticides that are being reevaluated by CDPR because of their widespread presence as residues in the sediment of both agricultural and urban waterways at levels toxic to an aquatic indicator species.[23,27]

Besides toxicity, other drawbacks to relying on pesticides for pest control are pest resistance and pest resurgence.[9,28] Growers who use repeated applications of a pesticide are more likely to experience resistance problems. Citrus thrips have a history of rapidly developing resistance to frequent and repeated use of pesticides. Specifically, cyfluthrin resistance has been documented among citrus thrips in several orange groves in Kern County.[19] Katydids also have the potential to become resistant to cyfluthrin.[13] For several reasons, pest resurgence also occurs when pesticides are used. Use of nonselective, broad-spectrum pesticides such as cyfluthrin removes natural predators and competitors. At the same time, sublethal doses of pesticides can also bring about a phenomenon known as hormoligosis—an increased vigor (such as increased metabolism and/or increased reproductive behaviors) in the target pests.[29]

Pest control methods

We categorized pest control methods that we identified according to the industrial hygiene hierarchy of controls (Figure 2).

1. Elimination. According to the industrial hygiene hierarchy of controls, elimination is the optimal method of protection against a hazard and is the only completely effective method of preventing drift. For controlling citrus thrips, this could entail eliminating the spraying of pesticides altogether, as the damage due to this pest is cosmetic, involving only the peel and not the flesh of the fruit. This would require reeducating consumers to accept scarred fruit, which is a difficult endeavor as consumers consider external insect damage to be an indicator of interior damage or inferior quality in texture or flavor. To growers, the financial risks of this strategy are currently high. Navel and Valencia orange growers in California who have their fruit juiced make

Figure 2. The industrial hygiene hierarchy of controls

Category of control (with examples typical in industry)	*Specific recommendations/ findings for pest control*	*Level of protection*
1. Elimination of the hazard	• Do not use pesticides. • Use soil building, cover crops, plant-based fertilizers, and compost. • Use biological controls.	Most protective
2. Substitution of material	Use less toxic pesticides.	↓
3. Engineering controls (e.g., isolation and ventilation)	Nozzle placement, droplet size, equipment calibration, baffles, deflectors, air induction nozzles, tree-sensing technology	↓
4. Administrative controls (e.g., worker scheduling, worker rotation, education/training, and work practices)	Written policies, provision for better communication, notification of neighboring properties, background checks on pesticide applicators, training, hierarchy of controls/drift prevention	↓
5. PPE	Not relevant to prevention of drift-related illness	Least protective (PPE used as last line of defense)

Sources: Adapted from: Scharf T, Vaught C, Kidd P, Steiner LJ, Kowalski KM, Wiehagen WJ, et al. Toward a typology of dynamic and hazardous work environments. Hum Ecol Risk Assess 2001;7:1827-41; and: National Institute for Occupational Safety and Health (US). Health Hazard Evaluation Report no. HETA-93-0035-2481: American Buildings Company, El Paso, Illinois. Cincinnati: NIOSH; 1995.

PPE = personal protective equipment

little or no money because production costs may be higher than returns.[18,30] Although mature fruit with katydid scarring can also be juiced, damage caused by this pest is more likely to cause some of the fruit to fall off the tree. Thus, complete elimination of pesticides may be economically riskier for the grower if katydids are present.

Another way to eliminate the spraying of pesticides is to apply the practices of either organic agriculture or IPM. Organic and IPM methods share many similarities in their approach to avoiding pesticide use. The practice of IPM is based on combining methods such as biological controls, habitat manipulation, cultural practices, and resistant plant varieties. Pesticides are to be used only if monitoring guidelines suggest they are needed. Pest control methods are selected to minimize effects on human health, beneficial and nontarget organisms, and the environment.[31] Organic agriculture can be considered to be along a continuum of IPM strategies. Organic farmers commit to using a more limited range of pesticides. The Organic Trade Association defines organic production as one that "is based on a system of farming that maintains and replenishes soil fertility without the use of toxic and persistent pesticides and fertilizers."[32] Organic foods must be produced without antibiotics, synthetic hormones, genetic engineering, sewage sludge, irradiation, and other specified practices.

Much organic agricultural practice is regional and most information is passed on by word-of-mouth or through organic growers' cooperatives.[33] In contrast to the thrips problems recounted by conventional farmers and their pest control advisors (PCAs) in California's Central Valley, most organic farmers interviewed experienced only minor thrips problems.[12] These farmers stated that organic farming involves more than simply forgoing the use of pesticides. Organic practices are multifactorial and range from eliminating all synthetic chemicals and becoming organic by default to actively building a healthy ecosystem that provides the ideal environment to nurture crops. The various elements of this method include developing healthy soil, using cover crops, scouting for pests and beneficial insects, applying compost, releasing beneficial insects, and making appropriate planting choices.

Organic growers build soil nutrients through the use of compost rather than synthetic fertilizers.[34] Some farmers incorporate one or more fermented herbal tea extracts into foliar sprays to supply plant nutrients, stimulate plant growth, and suppress disease. Organic farmers may also apply liquid manure comprised of a combination of fermented herbs, fish emulsion, and/or seaweed extracts.[12]

Another practice used by organic farmers includes allowing weeds to grow between rows and cover cropping, which provide a habitat for beneficial insects, reduce heat stress and frost damage, improve water penetration into soil, and provide mulch when mowed. Some types of cover crops can also fix nitrogen in the soil. Examples of cover crops are vetch, bell beans, peas, clover, and grains. However, while cover crops may help when only thrips are present, katydids can use cover crops and weeds as a habitat in the early spring and can move to the orchard crop later.[35]

Scouting, or monitoring for insect pests and their predators to determine when to use added pest control methods, is an important part of organic farming, as well as an essential practice in IPM. Added biological controls or pesticides are not used until pests reach potentially damaging levels.[13,19] When scouting for thrips, it is important to not only count the numbers of thrips, but also to distinguish citrus thrips from flower thrips, which do not damage the fruit.[19] Because a few katydids can damage many fruit, detecting one feeding katydid per tree requires action to prevent economic loss.[13]

Both organic and IPM practitioners also look for the presence and numbers of beneficial insects, which are predators or parasites of pests. Examples of insects that feed on thrips are lacewings, predaceous mites, parasitoid wasps, minute pirate bugs, coccinellids, and spiders.[12,19] Although parasitic wasps do attack katydid eggs, biologic controls are less effective in controlling katydid damage.[13] If insufficient numbers of predatory insects are present, they can be purchased and released as biological controls. This type of control can be considered elimination on the hierarchy, because it does not substitute a chemical hazard.

Crop and planting choices can help to prevent outbreaks of some pests. For example, Valencia oranges are less susceptible to thrips damage than navel oranges and would be less likely to need treatment.[19] Larger tree spacing may reduce pest loads. In addition, planting a variety of tree species may attract a greater diversity of beneficial insects and reduce the economic damage caused by a pest affecting a particular species.[12]

2. Substitution. Frequently, pest densities may be too high to be adequately controlled with natural enemies. When pesticide use is unavoidable, substitution with the least toxic alternative is next on the hierarchy of controls. Several lower toxicity pesticides can be used on organic crops under the U.S. Department of Agriculture's organic rules.[36] Typically, these are derived from plants or microbes (Figure 3).[12]

These lower toxicity substitutes can also have drawbacks. Some can affect beneficial insects, such

Figure 3. Less toxic alternatives to cyfluthrin for controlling citrus thrips in organic farming

Pesticide	*Derivative*	*Acute toxicity*[a]	*Chronic toxicity*	*Affects beneficial insects?*[b]	*Other*[b]
Sabadilla	Botanical—sabadilla lily	Low: eye/throat irritation	Developmental effects above maternal toxicity[c]	No	Effective for 3–4 days; 24-hour restricted entry interval
Spinosad (can also be used to control early stages of katydids)	Microbe—actinomycete *S. spinosa*	Low[d]	None reported[d,e]	Most not harmed, but toxic to bees when wet	Use should be avoided when pollinators are foraging
Neem	Botanical—from seeds of the neem tree	Low: eye/skin irritation[f]	None reported[f]	Minimal—targets herbivorous insects	Sometimes hard to find; can be expensive
Mineral oil—narrow range 415 and 440 oils	Petroleum product	Low: eye/skin irritation[g]	None reported[g]	Yes, but does not kill winged predatory insects	Possible toxicity to some aquatic organisms[g]

[a]Low = mammalian oral LD_{50} ~400–5,000 milligrams per kilogram of body weight

[b]Bunin LJ. Alternatives to the use of cyfluthrin to control citrus thrips damage in the orange growing industry: final report. Sacramento: California Department of Public Health, Occupational Health Branch; 2008. Also available from: URL: http://www.cdph.ca.gov/programs/ohsep/Documents/thripscontrol.pdf [cited 2009 Jan 26].

[c]Environmental Protection Agency (US). Reregistration eligibility decision exposure and risk assessment on lower risk pesticide chemicals sabadilla alkaloids. 2004 Sep 27 [cited 2008 Mar 19]. Available from: URL: http://www.epa.gov/oppsrrd1/REDs/sabadilla_red.pdf

[d]National Organic Standards Board Technical Advisory Panel Review. Spinosad—crops. 2002 [cited 2008 Mar 18]. Available from: URL: http://www.omri.org/spinosad_final.pdf

[e]Stebbins KE, Bond DM, Novilla MN, Reasor MJ. Spinosad insecticide: subchronic and chronic toxicity and lack of carcinogenicity in CD-1 mice. Toxicol Sci 2002;65:276-87. Also available from: URL: http://toxsci.oxfordjournals.org/cgi/reprint/65/2/276.pdf [cited 2008 Mar 19].

[f]Environmental Protection Agency (US). Neem oil; tolerance exemptions. Federal Register 1995;60:63950-3. Also available from: URL: http://www.epa.gov/EPA-PEST/1995/December/Day-13/pr-494.html [cited 2008 Mar 19].

[g]Environmental Protection Agency (US). Reregistration eligibility decision exposure and risk assessment on lower risk pesticide chemicals; CASE: aliphatic solvents (3004); active ingredients: mineral oils (063502) & aliphatic petroleum hydrocarbons (063503). Arlington (VA): EPA; 2006. Also available from: URL: http://www.epa.gov/oppsrrd1/REDs/aliphatic_solvents_red.pdf [cited 2008 Mar 19].

LD_{50} = lethal dose, 50%

as predatory insects and bees, or may be effective for a limited time following application.[12] Furthermore, these less toxic pesticides may also have adverse health effects (Figure 3).[12,37–41]

Another option that can reduce the potential for harm is to use the lowest known effective rate of a pesticide. Using the lowest effective dose of a pesticide may mitigate the negative impacts of pesticides. This includes reducing damage to natural insect enemies. Protecting natural enemies helps in the long-term management of some pest problems and, in turn, can prevent the need for additional pesticide use.[42] For the pesticide application that preceded the May 2005 incident, cyfluthrin was chosen to control katydids, but was used at about a third of the full rate of cyfluthrin specified by the label.

As is true with conventional pesticides, the use of less toxic alternatives requires simultaneous use of other types of controls to decrease drift and prevent worker exposure.

3. Engineering controls. Whether a grower uses conventional pesticides or less toxic substances, engineering controls should be used to reduce the potential for drift onto nontarget areas.

Air blast sprayers operate by pumping the spray mixture into an airstream. The spray comes out through nozzles, which are aimed at the target. While pesticides applied by this method are highly susceptible to drift, adjustments can be made to the sprayer to decrease, but not eliminate, the potential for drift. Correct nozzle selection is essential, as a nozzle's droplet size spectrum determines deposition and drift. Smaller droplets stay airborne longer and have a greater tendency to drift.[43,44] For example, in still air a 100-micron droplet will take approximately three times longer to fall to the ground than a 200-micron particle, and in windy conditions will travel about three times farther.[45,46] If droplets are too large, they provide ineffective coverage, waste product, and cause pollution by dripping onto the ground.[42–44]

Correct targeting of the tree is also important. Nozzles need to be placed in the correct orientation relative to tree size and shape, sometimes with the highest and lowest nozzles blocked off to prevent spraying pesticide into open spaces above or below the trees.[25,47] Other control methods include the use of baffles, deflectors, and air induction nozzles.[43,48] Equipment must also be calibrated to adjust ground speed, nozzle flow, and fan air speeds.[44,49] Unfortunately, applicators may not always make adjustments, as they may be viewed as too difficult and time-consuming.[47]

Retrofitting or purchasing air blast sprayers with higher technology options to prevent spraying into the spaces between trees also reduces the possibility of drift. In the incident we investigated, spaces between rows may have allowed the pesticides to become airborne without spraying any tree.[14] Sensing systems such as electronic eyes and sonar and laser imaging systems can sense or image a space and shut off the spray. Some can even adjust the nozzle pattern according to the size of the tree.[44] When sensing technology is used, sprayers must be shut off when they are pulled outside the row of trees so that cars and other large objects (e.g., passing vehicles) are not inadvertently targeted.

4. Administrative controls. Administrative controls constitute a variety of measures. Miscommunication among work crews, failure to notify the adjacent grower, lack of ability to communicate instantly, and an individual's decision to continue spraying after discovering workers in the neighboring field were contributing factors in the incident we investigated. Several controls would have addressed these issues:

- Written policies that include contingencies for what steps will be taken if conditions become unfavorable and clear procedures regarding what the applicator should do if workers are discovered in adjacent fields;
- Written policies that make clear that the pesticide applicator will be expected to calibrate equipment, adjust nozzles, and use all other available controls to prevent drift and use less product;
- Instant communication methods that facilitate appropriate action during changing conditions. When a delay in stopping an application may make a difference to the amount of spray going off-site, two-way radios would be a faster, better means of communication;
- Regulations requiring notification of neighboring properties of scheduled pesticide applications. In California, regulations do not require that operators of all nearby properties be notified of planned pesticide applications. Such a requirement would help prevent pesticide exposure incidents by:
    - Allowing operators of nearby properties, including farms, homes, schools, and office buildings, to make decisions that may affect the health of workers and community members. They may be able to adjust work schedules and locations, make changes to ventilation systems, and keep windows closed.
    - Encouraging better accountability for pesticide applicators, which will improve application practices.
    - Raising property operators' awareness of sensitive neighboring properties (e.g., daycare centers, retirement homes, or neighboring workers).
    - Raising awareness among neighbors, so that if drift is suspected, the operator of the property being treated can be notified, the application halted, and further exposure or harm prevented.

Additional administrative controls that may prevent drift are:

- Ensuring that the pesticide applicator's licensing and training records comply with regulations and that there is no record of fines, suspensions, or other regulatory actions against the applicator.
- Continued and targeted training that incorporates the hierarchy of controls for growers, PCAs, and farm labor contractors.

The federal Worker Protection Standard (WPS) and the corresponding regulations in California, the Pesticide Worker Safety regulations, are intended to protect agricultural workers.[50,51] These regulations mandate pesticide safety training for fieldworkers and handlers, hazard communication, field postings, decontamination facilities, provision of emergency medical care, and other measures. The provisions of the WPS and the California regulations include administrative controls such as entry restrictions following pesticide application to a field. However, these regulations apply only to the employees or contracted labor of the agricultural establishment responsible for the pesticide application and not to workers on neighboring properties. Neighboring employers must also implement the requirements of these regulations to protect their own workers, but the regulations do not address protections from pesticides that drift from other fields.

DISCUSSION

Agricultural pesticide use may result in illness and lead to a vicious cycle of increased pesticide usage.[9,29] Pesticide drift is a significant cause of occupational illness. Preventing pesticide drift, exposure, and illness requires a multifactorial approach, including reducing or eliminating pesticide use.

The industrial hygiene hierarchy of controls is a useful framework to protect workers from exposure to all types of hazardous exposures in the workplace. It places a higher priority on more protective controls (e.g., hazard elimination and substitution) over less protective methods (e.g., engineering controls such as ventilation or isolation, and workplace policies).[52,53] Personal protective equipment (PPE) is always considered a last resort and should only be used as a method of exposure control when all other controls have been implemented and have not sufficiently reduced the hazard. We did not consider PPE for prevention of exposure due to pesticide drift, as its use will not prevent drift. Moreover, it is not appropriate to require workers to use PPE to prevent drift-related illness.

Each level of the hierarchy of controls can help to prevent pesticide drift and illness. For example, some communities have successfully implemented administrative controls such as advance notification to decrease pesticide drift.[54] Typically, multiple types of controls are used simultaneously. Substitution of a less toxic pesticide may be implemented with tree-targeting technology and optimal nozzle type, as well as with administrative controls such as worker training and workplace policies. Often, engineering controls must also rely on administrative controls such as worker training.

Most pesticide regulations and conventional agricultural practices focus on control methods lower down in the hierarchy. For example, regulations and label requirements address mainly PPE, work practices, and hazard isolation such as closed systems. Moreover, the hierarchy is not typically used specifically to prevent pesticide illnesses, including those due to drift. Decision makers may ignore the top levels of the hierarchy due to the perception that implementing these types of controls is too difficult and expensive.[55] In organic farming, pesticides are often eliminated or substituted primarily to address environmental and consumer concerns, rather than to prevent worker exposures and illnesses. Nonetheless, perhaps without fully appreciating it, organic growers and IPM practitioners are already utilizing the hierarchy of controls.

Disseminating the knowledge of growers who are able to produce marketable crops without pesticides or with safer alternatives will help conventional growers to make the transition to safer pest control practices.[56] For individual farmers, obtaining information about safer controls can be time-consuming and labor-intensive because the practical instruction needed is often passed on by oral history and must be actively sought, the initial costs of eliminating pesticide use may be high, and the benefits of decreased pesticide use are often not widely marketed to conventional growers.[57] Eliminating or reducing pesticide use may be daunting for many conventional growers without the support and encouragement of both the scientific and local grower communities. Making the transition from conventional to organic production carries some risk due to economic factors and because it requires significant changes in management practices and a new set of skills and knowledge.[33,58] Without easy access to information, growers who are shifting to organic agriculture are forced to find successful farming practices through trial and error.[33]

Limitations

The main limitation of our work was that to address the cause of illness identified in our investigation of the drift episode, we considered only two pests and one hazard. Farms are dynamic systems, and pest control can be complicated. This affects and sometimes limits the choices a grower can make regarding pest control.

Moreover, health and safety interventions should ensure that elimination of one hazard does not introduce another. While we considered some of the health hazards posed by the low toxicity pesticides used in organic agriculture, our work did not address other factors, such as ergonomic stresses that may be introduced due to increased manual labor needs. Finally, while sustainable agricultural methods such as those we have described have universal advantages, further work, including biomonitoring and economic studies, is needed to definitively demonstrate the beneficial effects of these methods on farmworker health.[59]

CONCLUSION

Our work demonstrates that public health programs can play an important role in preventing pesticide illness by researching and recommending specific pest control methods based on the hierarchy of controls.

Occupational health and safety practitioners, regulators, PCAs, and others who work in agriculture should promote hazard elimination- and substitution-based control strategies to ensure the health of workers, community members, consumers, and the environment, and constitute an important element in sustainable agriculture.[55,60,61] Disseminating these concepts, such as promoting the use of safer alternatives and validating new methods that eliminate the use of pesticides, is best accomplished through collaborations across government, academia, communities, and private industry.

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