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Minimizing Pesticide Risk to Bees in Fruit Crops

Photos by Zachary Huang (first two, left) and Jason Gibbs (second two, right), MSU Entomology

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SUMMARY

1. Bees are essential for pollination of many fruit crops.
2. Bees and other pollinators can be harmed by some pesticides used to manage insects, mites and diseases in fruit crops.
3. Growers can reduce pesticide risk to bees through these approaches:
   - Develop and implement a pollination contract with your beekeeper.
   - Use integrated pest management (IPM) to reduce the need for sprays.
   - Avoid pesticide sprays during crop bloom.
   - Apply pesticides after sunset or before sunrise, or when air temperature is below 50°F.
   - Select the least toxic pesticides and formulations when possible.
   - Reduce drift onto areas outside crop fields.
   - Remove flowering weeds from crops.
   - Provide bee-friendly habitat away from crops.

INTRODUCTION

Pollinating insects, of which bees are the most important, contribute significantly to the yield and quality of fruit crops in the United States. Pollination services provided by bees are worth billions of dollars annually to fruit crop industries across the nation. Fruit crops vary in their need for bees to deliver pollen for pollination, but most — including apples, blueberries, cherries, strawberries and raspberries — will produce larger and more even fruit if their flowers are well visited by bees. For all these crops, having healthy bees to provide pollination is essential for their production, so protecting bees from pesticide risk is an important part of growing fruit crops.

This document provides information to help growers make informed decisions about how to minimize the risk of pesticides to bees. A list of insecticides and fungicides that are registered for use in the north central region of the United States is provided in the back of the document.

Types of bees that provide pollination

Fruit plantings are typically pollinated by a combination of wild and managed bees (Figure 1). More than 500 species of bees are present in the Midwest, and about 30 to 50 species are important contributors to the pollination of fruit crops.

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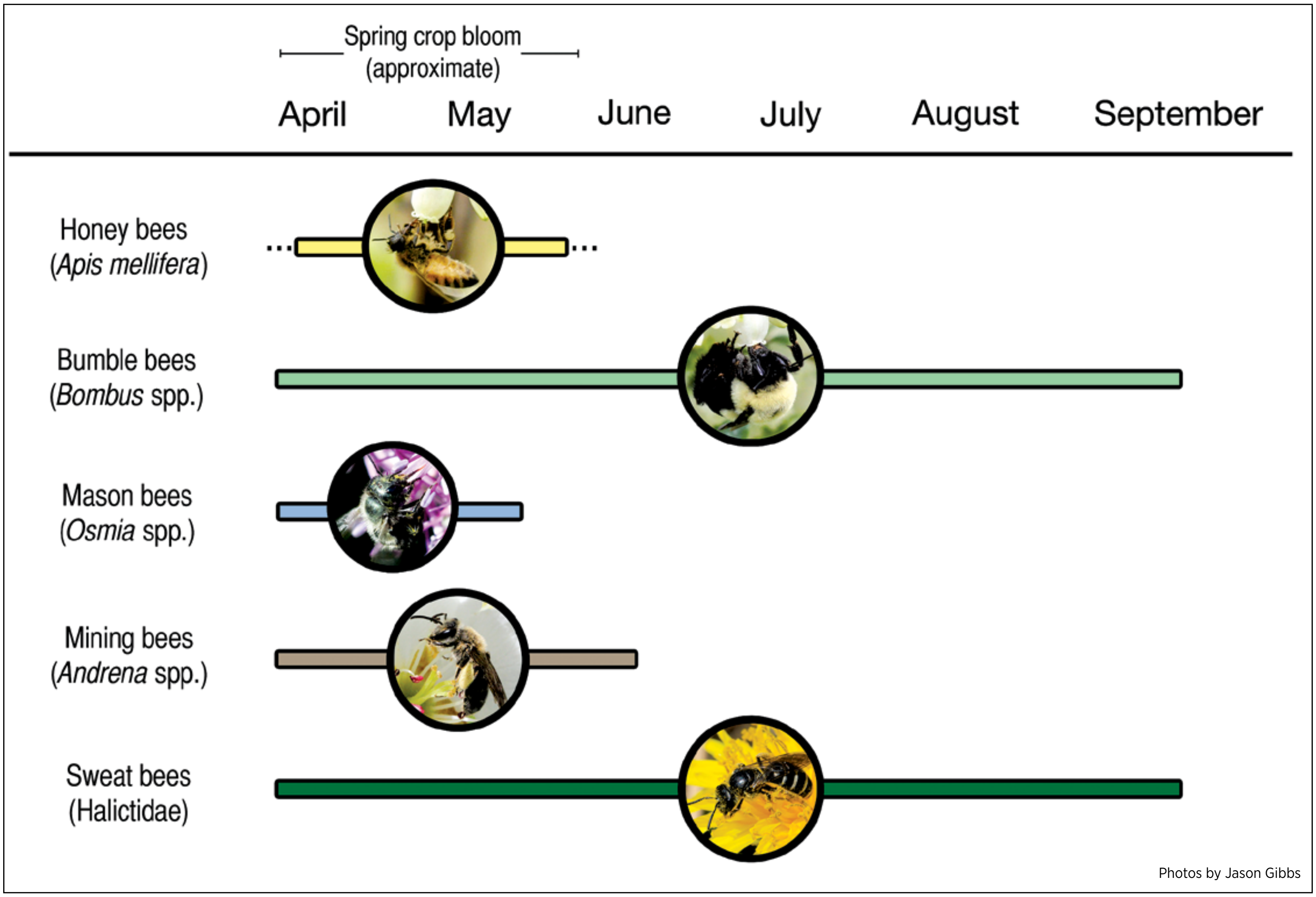
Figure 1. Overlap of the activity periods of various wild and managed bee species with spring crop bloom, and their potential activity periods through the rest of the season.



Most fruit plantings are visited by a community of wild bees that live in and around the farms and gardens where fruit crops are grown. The main bee species managed for pollination is the European honey bee *(Apis mellifera)*. Some growers may also keep managed populations of solitary mason bees (*Osmia* species) or purchase commercially available bumble bee colonies *(Bombus impatiens)*.

Many types of bees contribute to the pollination of fruit crops. Some of these are wild and unmanaged, providing a natural source of pollination. Others can be managed using nesting structures that enable growers to have a high abundance of bees in the local area (Figure 2).

The honey bee is by far the most important species for fruit crop pollination because hives are portable and can be transported into and out of fruit plantings. In the past, feral or unmanaged colonies of honey bees played a major role in pollination, but populations have declined because of parasitic mites. Now fruit growers typically rent honey bee hives from beekeepers for pollination and arrange to have hives delivered when crop plants are at early bloom and removed at petal fall.

In addition to managed honey bees, some growers manage solitary mason bees (*Osmia* species) for pollination of tree fruit. Mason bees can be induced to nest in paper or cardboard tubes or in holes drilled in wood, where they overwinter and emerge the following spring or summer. This emergence can be timed to coincide with flowering of the crop, and the bees then remain active for up to 4 weeks.

Some growers purchase colonies of bumble bees from commercial suppliers that continuously rear these bees. Colonies are purchased in time for the pollination needs of the target crop, providing an active workforce in the field during bloom. These colonies generally remain active for about 6 to 8 weeks.

Figure 2. Three types of managed bees that can be used to pollinate fruit crops. L-R: honey bee hives, bumble bee colonies, and mason bees.

Photos by Rufus Isaacs, MSU Entomology

A variety of wild bee species are active throughout the growing season, and some of them are well-suited to provide pollination of crop flowers. Most of these species cannot be commercially managed because they nest in the ground. Some have been found nesting in the grass-free strips under the fruit crop or in adjacent habitat. These bees can fly to blooming crop plants within their flight range.

Bee biology and behavior may affect responses to pesticides

Bee body size, nest location (above or below ground), flight season (what time of year the bee is active) and sociality (whether a bee is solitary or social) can all affect how bees are exposed to and affected by pesticides.

Large-bodied bees, such as honey bees and bumble bees, can generally fly greater distances than smaller bees in search of pollen and nectar resources. Honey bees have been found to fly more than a mile in search of rewarding flower patches, but many smaller wild bees fly no farther than the length of a football field in search of food. Larger bees may also be able to tolerate higher levels of certain pesticides than smaller bees, but their broader flight range means that they cover more ground and have the potential to be exposed to a wider variety of pesticides.

The social structure of bees is another important aspect that determines how they respond to pesticides. Honey bees are the classic example of social bees that have a single queen laying eggs for the colony and many adult female offspring (workers) taking care of other tasks such as caring for brood and foraging for nectar and pollen. In contrast, many wild bee species are solitary, meaning that a single adult female lays eggs, cares for offspring and makes foraging trips.

Social bees have the advantage of having many foraging bees across the landscape; if some bees die while foraging, the colony is likely to have other bees available to take their place. If a solitary bee is killed while foraging, there are no other adult females that can take her place.

PESTICIDE EFFECTS ON BEES

Pesticide application is an important consideration for both beekeepers and fruit growers because both have a stake in maintaining healthy bee populations. This requires an integrated approach to pest management by growers, who need to control target insects while doing the least harm to the pollinators. Bees are sensitive to many of the chemicals used to control pests, whether on the plants that they visit to collect nectar and pollen or in the areas where they are nesting.

Pollinator stewardship, as part of an overall IPM strategy, can allow growers to manage diseases and insect pests in their crop while also minimizing risk to pollinators.

Which pesticides affect bees?

Growers use many groups of pesticides to protect their crops, including insecticides for controlling pest insects, miticides for pest mites, fungicides for fungal diseases and herbicides for weeds. These pesticides are important tools for managing crop pests in fruit plantings, but they may also pose a risk to bees.

Insecticides are the pesticides most likely to be toxic to bees. Bees can be exposed to insecticides when materials are sprayed directly onto them or drift onto or near hives, when bees come into contact with residues on plant surfaces, or when bees collect chemicals while foraging for food or water. By law, and as described in the restrictions on labels, the use of insecticides toxic to bees is restricted during crop bloom when bees are actively foraging. Each label will provide specific guidance on the restrictions, which are based on the insecticide's toxicity to bees. Table 1 provides information on the toxicity of various insecticides used in fruit crops, ranked from very low risk to high risk to bees.

Fungicides are generally considered of limited risk to bees, and thus their use during bloom has been assumed to be relatively safe to pollinators. Recent research suggests, however, that certain fungicides, used alone or in combination with other pesticides, can have direct or indirect harmful effects on bees. They may disrupt adult bee foraging behavior or, when residues are brought back to hives and fed to larvae, they can affect bee development.

To minimize the exposure of adult and immature bees to fungicides, growers should follow integrated disease management practices including the use of risk models to determine the need for disease control during crop bloom. Plants generally release pollen and nectar in the morning, and these resources are often depleted by late afternoon. Therefore, spraying between late afternoon and very early the next morning can reduce fungicide exposure to foraging bees. Where there are options, select fungicides with lower risk rankings (Table 2).

Herbicides have little direct toxicity to bees but can have an indirect effect. By removing flowering plants in and around farms, herbicide use leads to removal of alternative sources of nectar and pollen that bees need to survive. Targeted herbicide use that removes flowering weeds in crop fields while retaining areas of the farm where flowers are allowed to grow can benefit local bee populations by providing a mixed diet from a range of flowering species. This is particularly important for colony-forming bees, such as bumble bees, that require season-long access to flowering resources to build their colonies.

Adjuvants and ***surfactants*** can also affect bee health. Adjuvants are commonly added to sprays to improve coverage, penetration or rainfastness of pesticides to increase their efficacy. Those that reduce the surface tension of the spray solution, such as oils or detergents, should be used cautiously. Sprays with these adjuvants are more likely to penetrate the waxy cuticle of bees and thus increase the toxicity of other chemicals.

Tank mixes of pesticides may cause increased risk to bees through synergistic effects, which make the toxicity of the mixture greater than that of the individual components. There is evidence that fungicides in the Fungicide Resistance Action Committee (FRAC) Group 3 can make insecticides more toxic to bees. More recently, laboratory studies with newer products have demonstrated this synergism for additional combinations of pesticides. Research on the impacts of tank mixes on bees and their colonies under field conditions is still ongoing.

For all pesticide applications, be sure to follow the label instructions on safety to bees and other pollinators. Labels can be found at www.cdms.net/. See below for more details.

What is the risk?

The risk of toxic effects from pesticides is a combination of the toxicity of the pesticide — its inherent ability to harm a bee — and the amount of exposure that a bee receives. So, a less toxic insecticide applied directly to foraging bees could have similar effects as the residues of a highly toxic insecticide that drifts onto flowering weeds. For these reasons, effective pollinator stewardship is multifaceted, combining strategies that minimize exposure — night spraying, controlling drift, avoiding bloom — with the judicious selection of pesticides to minimize toxicity.

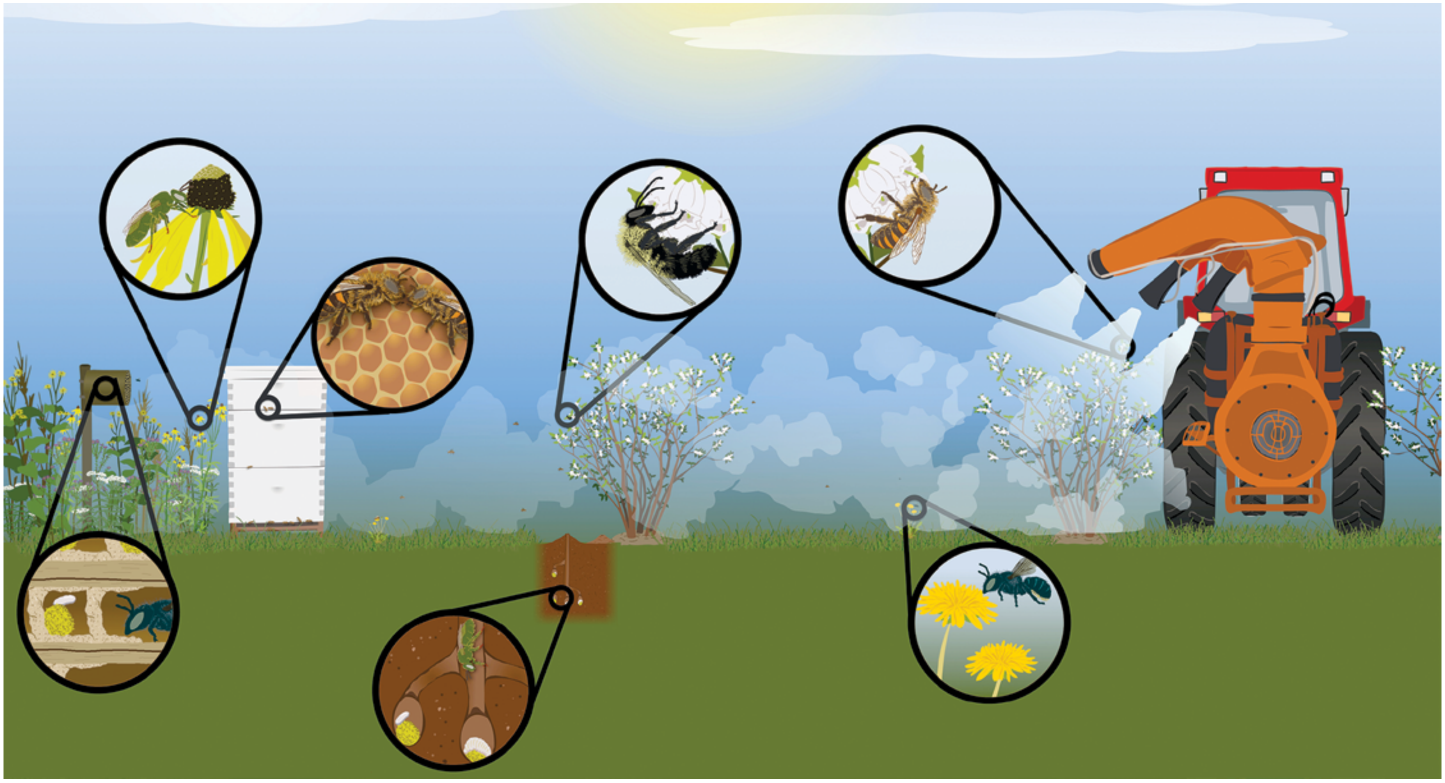
Routes of pesticide exposure

Bees are most likely to encounter pesticides while they are foraging for nectar and pollen, but there are many potential routes of exposure to pesticides, depending on the way the materials are applied and on the behavior and ecology of various bee species (Figure 3).

Direct topical exposure is the most obvious potential route of exposure, occurring when bees are flying or visiting flowers in a crop area when the pesticide is being applied. This can cause immediate harm or kill the bee, or cause a high dose of the pesticide to be brought back to the colony.

Indirect topical exposure occurs when bees contact treated surfaces such as leaves or flowers after they have been sprayed. Once a pesticide has dried or has started to degrade through exposure to sunlight and other environmental factors, the risk to bees greatly declines. This fact is often reflected in the guidance on bee safety provided on the pesticide label.

Figure 3. Routes of potential pesticide exposure to bees within sprayed crop fields and in adjacent habitat where bees forage on flowering plants and build their nests.



Some pesticides, however, can form secondary metabolites that are also harmful as they degrade. The residual toxicity to bees varies among products and has not been well-documented for most pesticides. Pesticides that are rapidly absorbed into plant tissue may also result in less indirect topical exposure.

Drift of pesticides by air movement from the target crop onto adjacent blooming weeds or onto bee nests and honey bee hives can also lead to an exposure risk for bees. Drift can be reduced by using coarse sprays and by not applying pesticides during windy conditions. It is also important to consider the formulation carefully because water-based and oil-based sprays have different drift characteristics.

Drift onto pollinators can be avoided if growers and applicators know the locations of sensitive pollinator habitat and nearby hives. The location of some beekeeping operations can be found on the DriftWatch website (**www.driftwatch.org**). Direct communication with beekeepers in the area can provide them with the opportunity to close up their hives before application of pesticides toxic to bees.

Bees may also be exposed to pesticides through oral ingestion of **contaminated pollen or nectar**. Systemic pesticides, including many neonicotinoid insecticides, can be applied as foliar sprays and are then absorbed locally into plant tissue. They can also be applied to the soil to be taken up by plant roots and distributed by the plant's vascular system. These systemic pesticides can be highly effective for the control of aphids, leafhoppers and other sucking pests, but they can also harm pollinators if found in nectar, pollen or plant guttation fluid. Some systemic insecticides are more toxic to bees than others (see Table 1). Additionally, the oral toxicity of some pesticides is much higher than the contact toxicity because of their mode of action or because the pesticide does not travel across the insect cuticle very well.

Contaminated surface water and **pesticide spills** are two other potential sources of exposure because honey bees will collect water to regulate hive temperatures in hot weather. Maintaining clean water sources on the farm and preventing pesticide spills are important ways to prevent pesticide exposure to bees.

Effects of pesticides on bees

Pesticide risks to bees is a complex issue, and much remains unknown. We have a basic understanding of the direct contact effects of pesticides on adult honey bees, in part because these data are required by the U.S. Environmental Protection Agency (EPA) before a pesticide can be registered for use. There is less information on other aspects of pesticide risk for bees, including sublethal effects, effects of chemical mixtures, and effects on brood and colony health. We currently know little about the effects of pesticides on most wild bee species, although studies have shown that some are more sensitive and others are less sensitive than honey bees to specific pesticides. Assessment of risks associated with realistic field exposures are under way and will help increase our knowledge of the implications when bees are exposed to pesticides in combination with other pesticides as well as with diseases, miticides, harmful secondary metabolites, heavy metals and a host of other environmental stressors.

The toxicity of pesticides to bees is reflected by the LD_{50} value for honey bees determined for each pesticide. This is the lethal dose that will kill 50 percent of adult honey bees in a given population and is derived from laboratory studies. This value enables comparison of the relative toxicity of pesticides. Those with higher LD_{50} values are considered safer than those with lower values.

Insecticides, fungicides and herbicides commonly registered for use in fruit crops in the United States are listed along with their LD_{50} values in Tables 1 and 2. The toxicity rankings in these tables are based on EPA categories derived from LD_{50} values. An LD_{50} threshold of 2 micrograms per bee is used, below which the EPA considers a pesticide to be highly toxic to bees and not allowed for use during bloom. Products with LD_{50} values between 2 and 11 micrograms per bee are considered to be moderately toxic. Pesticides with an LD_{50} above 11 are considered to be relatively safe for use in the presence of bees. The pesticide label will contain information on use restrictions around bees, with increasing levels of restriction for pesticides that have lower LD_{50} values.

It is important to understand that the potential risk to bees of a particular pesticide is also related to the amount of active ingredient applied and how the pesticide moves in the plant. Application rates for pest control products can vary from ounces to pounds per acre, so the application rate also determines the dose to which bees may be exposed. Pesticides may behave differently when applied to foliage or to the soil; some will remain on the surface of plants; others are absorbed. Application rate and chemical behavior are considered along with inherent toxicity in the risk assessment that determines the usage restrictions for pesticides during crop bloom, and these are reflected in the pesticide label.

Acute effects. Bees that are exposed to a pesticide with high toxicity, usually in one exposure event, may die or be incapacitated to such an extent that they cannot return to the colony or nest. For honey bees, this would be reflected in a sudden decline in foraging activity at the hive. If a hive is exposed directly, there may also be dead bees at the hive entrance, which have died and been removed by nest mates. For pesticides that can affect bee larvae, such as some insect growth regulators, observable effects may be delayed for a few weeks after exposure. For wild bees, most of which are solitary and/or ground-dwelling, it is generally difficult to spot the bee kill symptom of acute exposure events.

Symptoms of bee poisoning, shared by honey bees and wild bees, can include increased defensiveness, disorientation or confusion, lethargy, paralysis, and/or abnormally jerky or wobbly movements. They may also include loss of navigational capacity, further reducing the number of foraging bees returning to their nest or colony. Bees may exhibit different suites of symptoms depending on the chemical(s) to which they were exposed. Some of these symptoms are also associated with diseases and internal parasites, so it is important to keep a frozen sample of dead bees for pesticide testing if poisoning is suspected (see "Reporting bee kills" for more information).

Chronic effects. Some effects of pesticides are not immediately apparent but may affect growth, memory or susceptibility to disease. These effects are often, though not always, associated with repeated exposure to low doses of the chemicals. Bees visit the flowers of many plants, and long-living colonies such as honey bees and bumble bees can be exposed to a combination of pesticide residues across the landscape, from crop fields, lawns and gardens, in addition to applications of miticides for *Varroa* mite management within honey bee colonies. In one example of how chronic exposure can have long-term subtle effects, larvae that are exposed to low doses of pesticide through contaminated food may experience effects on their growth that do not immediately kill them but shorten their life and the life of the colony. The effects of this type of exposure are usually subtle and harder to detect than acute effects.

Reporting bee kills

If bee poisoning or pesticide misapplication is suspected as the reason for honey bee colony sickness or decline, beekeepers can contact their state apiarist. A nationwide list of the local representative of the Apiary Inspectors of America is available at: **www.apiaryinspectors.org/members.html**. Reports can also be made to the EPA at beekill@epa.gov or to the state lead pesticide agency.

The beekeeper should record as much information as possible about the incident (pictures, start and end dates of observed adverse activity, observed symptoms, weather conditions, etc.). For a sample to meet regulatory requirements, a representative of the Department of Agriculture or other state lead agency may need to be present at the time of collection.

Contact your state apiarist or pesticide agency before collecting bees for analysis. For more information, visit **www2.epa.gov/pollinator-protection/report-bee-kills**.

APPROACHES TO REDUCE PESTICIDE RISK TO BEES

Fruit growers, pesticide applicators and beekeepers can use a variety of common-sense strategies to protect pollinators while maintaining healthy, highly productive fruit plantings (Figure 4).

1. Cultivate grower-applicator-beekeeper communication

Pollinator stewardship begins with good communication between growers, applicators and beekeepers. Discussions during the winter and early spring can clarify how many hives will be needed and when and where to put the bees on the farm. Communication among grower neighbors is also important to make sure colony placement will not impede movement of people and machinery, and will avoid putting bees in harm's way from sprays on adjacent properties.

- Draft a written contract to clarify expectations on all sides. This contract should include expectations about record keeping by the grower, the applicator and the beekeeper, and information about where hives will be placed, who is responsible for providing water, and when the hives will be delivered and later removed. (Example contracts can be found online.)
- If a contract is not used, be sure to communicate clearly with all parties and discuss spray plans to ensure that there are no surprises.
- If rented bees are on your property, contact the beekeeper at least 48 hours before a pesticide application to allow the beekeeper time to close hives, if desired.

Regulations on pesticide safety to bees

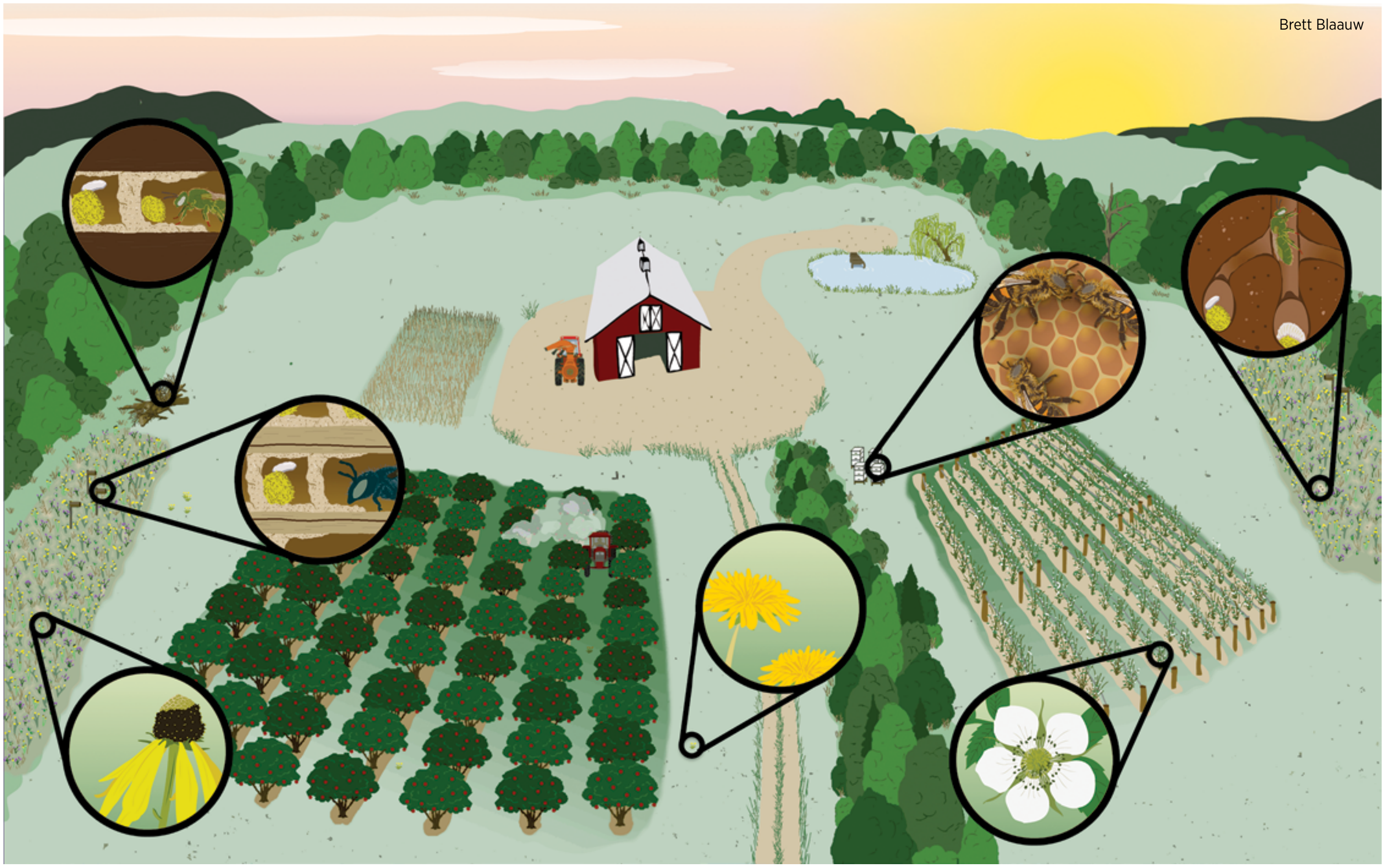
Restrictions to protect bees are reflected in almost all pesticide labels by the use of a statement in the "Environmental Hazards" or "Pollinator Safety" sections. For example, labels of insecticides that are highly toxic to bees include a statement such as: "This product is highly toxic to bees exposed to direct treatment or residues on blooming crops or weeds. Do not apply this product or allow it to drift to blooming crops if bees are visiting the treatment area."

Beginning in 2014, new and revised pesticide labels for pesticides with risk to bees will include a "Bee Advisory" box that provides detailed instructions on how the product must be applied when bees are present. To find it on the label, look for the bee hazard icon (above).

Revised labels include specific instructions such as: *"Do not apply this product while bees are foraging. Do not apply this product until flowering is complete and all petals have fallen."*

- Select a location for hives on the farm that is protected from potential spray drift.
- Place hives in safe locations rather than along drive lanes within or close to the planting. Distributing hives through large plantings can improve the evenness of pollination, but this should be done only if bee-safe practices will be followed while the colonies are in the fields.
- Know when to expect the delivery of hives and when they will be removed. For the safety of both beekeeper and bees, be sure that colonies are not placed or removed during restricted-entry intervals (REIs) following pesticide applications.
- In the company of the beekeeper, examine delivered hives so you know the health and strength of the rented hives. Those with six to eight frames each and 70 percent to 75 percent brood per frame are considered to be reasonably strong at the beginning of spring fruit crop pollination in the north central region.
- The use of DriftWatch can assist all parties in knowing where the bees are located.

Figure 4. Farmscape showing some best practices for minimizing pesticide risk to bees. These include spraying late in the day when bee activity is low, placement of honey bee hives in a protected location, locating pollinator foraging and nesting habitat away from crop fields, providing undisturbed areas for soil nesting bees, flowering plants to provide forage when the crop is not in bloom, and a clean water source within the flight range of bees on the farm.



2. Reduce pesticide risk to bees

Choose less toxic pesticides. As mentioned above, the toxicity of pesticides is represented by LD_{50} values. These show the dose that would kill 50 percent of bees from a population. The less toxic insecticides have higher LD_{50} values because it takes a higher dose to kill them. (See **Table 1** and **Table 2** on pages 10 and 13 for a comparison of insecticide and fungicide toxicity ratings for bees.) Whenever possible, choose products with lower risk to bees. Residual toxicity can be important, too, because a long-lasting pesticide has a greater chance of affecting bees than one that dissipates quickly.

Use integrated pest management. Integrated pest management is based on the coordination of scouting for pest and disease development and a combination of biological, cultural, mechanical and other tactics to minimize the amount of chemical inputs needed. Using IPM to inform pest management decisions can help reduce the cost and frequency of treating beehives for internal pests and the need for spraying crops. This should help lower the chance that bees will be exposed to pesticide residues.

Spray when bees are not foraging. Make sure to provide sufficient time between prebloom sprays and placement of hives to avoid exposing honey bees to toxic residues.

For insecticides and fungicides permitted for use during crop bloom, wait to spray until after sunset, when bees have stopped foraging.

If possible, avoid applications when low temperatures and high relative humidity allow dew formation during the night. Dew may rewet pesticides the following morning, which can increase the likelihood of bee exposure.

Do not apply pesticides that are toxic to bees until crop flowering is complete and the petals have fallen. This definition of petal fall is sometimes loosely interpreted by growers who want to get into their fields and protect them from key pests. However, working with the beekeeper to get honey bee hives removed quickly from fields at the end of bloom or delaying sprays until bloom is finished are important approaches for minimizing the risk of bee poisoning.

Reduce drift onto areas where bees are living or foraging. Reducing drift from the target crop to other areas where bees might be foraging or nesting takes some planning, but it should be considered throughout the season whenever pesticides are applied. It can also be considered during the design of new fields or farms to help mitigate risk to bees. To reduce drift onto bees and their habitat:

- Keep the spray on target.
- Turn off the sprayer when driving near hives and avoid pesticide drift onto open flowers.
- Droplet size and wind speed are the most important factors determining downwind spray deposition. Use that information to reduce drift.
- If applications are unavoidable, use larger droplet sizes (over 150 microns) to reduce drift under low humidity, high temperature or windy conditions. This can be achieved by reducing nozzle pressure, increasing the nozzle orifice diameter and using a low-drift type of nozzle.
- Avoid spraying under adverse wind speeds and air temperatures. Apply only when the wind speed is under 10 miles per hour. Keep in mind, however, that dead calm conditions (e.g., atmospheric inversion) can also allow small droplets to drift. In addition, increased evaporation under hot, dry conditions can lead to smaller droplet sizes and a higher risk of drift.
- Make sure to position honey bee or bumble bee colonies near crop fields but away from areas that will receive a direct spray. Some growers designate areas of their farm for bee placement, allowing hives to be efficiently installed and removed by their beekeeper. This can also reduce the risk of colonies being disturbed by workers and machinery.
- Be aware of neighbors with honey bee hives on their property.

Select a less toxic formulation. Pesticides come in a variety of formulations: dusts (D), wettable powders (WP), soluble powders (SP), emulsifiable concentrates (EC), solutions (SL) and granular formulations (G). Avoid dusts and wettable powders during bloom — these can adhere to the hairs on bees' bodies and be accidentally transported back to the hive or nest, where the residues may end up in the bees' food resources.

Reduce mowing and herbicide use in field perimeters. Allowing non-crop plants to flower in field margins can provide pollen and nectar resources for wild bees, whose food options may be limited in agricultural areas after crop bloom. Reduce mowing and herbicide use in field borders and edges to provide these flowering resources for bees. For this approach to be successful, take precautions to minimize pesticide drift into these nearby floral habitats.

Remove flowering plants in crop fields before spraying. If non-crop plants are flowering in fields that will be sprayed with bee-toxic pesticides, they can draw bees into hazardous situations. Mow or use selective herbicides to control flowering weeds in the crop field before applying pesticides to reduce the risk to bees.

Enhance bee habitat. After crop bloom, draw wild bees away from crop plantings by providing non-crop flowering plants in an area protected from spray drift. Planting wildflowers is the best way to support bees in any environment. In agricultural landscapes, native wildflowers or flowering cover crops planted in areas away from treated fields can provide refuges for bees that might otherwise be exposed to agricultural chemicals, in addition to providing food resources that may help increase pollinator abundance during crop bloom.

Some growers plant pollinator-friendly habitat to provide pollen and nectar for wild bees when the crop is not in bloom. Growers may use their own resources to establish these plantings, or they can participate in one of several cost-share programs available through the USDA Natural Resources Conservation Service (NRCS) or Farm Service Agency (FSA).

Manage hives with IPM. Bee exposure to pesticides does not just occur outside of the hive. Chemicals used to control insect, mite and disease pests within the hive can also be toxic to bees. They can also affect the bee response to pesticides encountered in crop fields, complicating the study of pesticide toxicity to honey bees.

If fruit growers are raising their own bees, they should be sure to follow current IPM practices for beekeeping to reduce unnecessary chemical inputs, and consider mechanical, physical and biological control options for hive pests.

Table 1. Insecticide and miticide toxicity to bees. Risk rankings are based on EPA toxicity classifications derived from the contact LD_{50} for honey bees. Not all products in this table are labeled for use in all north central region states — check with your state pesticide regulatory agency to determine whether a product is registered for use in your state.

Active ingredient	Trade name(s)	Chemical group	Mode of action*	LD_{50} (µg/bee)	Risk ranking	Reference
acequinocyl	Kanemite	Electron transport inhibitor	20B	100	Very low	1
acetamiprid	Assail	Neonicotinoid	4A	8.1	Moderate	1
avermectin/abamectin	Agri-Mek, Avid	Avermectin	6	0.002	High	5
azadirachtin	Aza-Direct, Neemix	Unknown	UN	2.5	Moderate	1
Bacillus thuringiensis var. kurstaki	Dipel, Biobit, Javelin, Deliver	Biological	11A	NA	Very low	1
bifenazate	Acramite	Unknown	UN	7.8	Moderate	1
bifenthrin	Brigade, Capture	Pyrethroid	3A	0.0146	High	1
buprofezin	Centaur, Applaud, Courier	Chitin biosynthesis inhibitor	16	200	Very low	1
Burkholderia sp.	Venerate	Biological	UN	>100	Very low	3
carbaryl	Carbaryl, Sevin	Carbamate	1A	1.1	High	1
chlorantraniliprole	Altacor	Diamide	28	100	Very low	9
chlorpyrifos	Lorsban	Organophosphate	1B	0.01	High	1
Chromobacterium subtsugae	Grandevo	Biological	UN	Not listed	High	3
clofentezine	Apollo	Growth inhibitor	10A	200	Very low	1
clothianidin	Belay, Clutch	Neonicotinoid	4A	0.00368	High	1
cyantraniliprole	Exirel	Diamide	28	Not listed	High	3
cyfluthrin	Baythroid	Pyrethroid	3A	0.037	High	1
cyfluthrin + imidacloprid	Leverage	Pyrethroid & neonicotinoid	3A, 4A	0.037, 0.0039	High	1
deltamethrin	Battalion	Pyrethroid	3A	0.0015	High	1
diazinon	Diazinon	Organophosphate	1B	0.2	High	1
dinotefuran	Venom, Scorpion	Neonicotinoid	4A	0.023	High	1
endosulfan	Thionex	Cyclodiene organochlorine	2A	4.5	Moderate	1
esfenvalerate	Asana	Pyrethroid	3A	0.017	High	2
etoxazole	Zeal	Growth inhibitor	10A	200	Very low	1
fenbutatin-oxide	Vendex	Organotin	12B	3982	Very low	1
fenpropathrin	Danitol	Pyrethroid	3A	0.05	High	3

Table 1. Insecticide and miticide toxicity to bees (continued).

Active ingredient	Trade name(s)	Chemical group	Mode of action*	LD_{50} (µg/bee)	Risk ranking	Reference
fenpyroximate	Portal	METI	21A	118.5	Very low	1
flonicamid	Beleaf	Pyridine carboxamide	9C	>100	Very low	6
flubendiamide	Belt, Synapse	Diamide	28	>200	Very low	3
flupyradifurone	Sivanto	Butenolide	4D	15.7	Low	3,8
gamma-cyhalothrin	Proaxis	Pyrethroid	3A	0.0061	High	1
hexythiazox	Savey	Growth inhibitor	10A	200	Very low	1
imidacloprid	Admire, Provado	Neonicotinoid	4A	0.0039	High	1
indoxacarb	Avaunt	Channel blocker	22A	0.18	High	7
lambda-cyhalothrin	Warrior	Pyrethroid	3A	0.038	High	1
malathion	Malathion	Organophosphate	1B	0.2	High	1
methidathion	Supracide	Organophosphate	1B	0.236	High	1
methomyl	Lannate	Carbamate	1A	0.16	High	1
methoxyfenozide	Intrepid	Diacylhydrazine	18	100	Very low	1
novaluron	Rimon	Benzoylurea	15	100	Very low	1
oxamyl	Vydate	Carbamate	1A	0.094	High	1
paraffinic oil	JMS Stylet Oil	Not classified	NA	NA	Very low	1,2
permethrin	Ambush, Pounce	Pyrethroid	3A	0.024	High	1
phosmet	Imidan	Organophosphate	1B	1.06	High	1
pyrethrin + piperonyl butoxide	Evergreen	Pyrethroid	3A	0.022, 11	High	1
pyrethrum	Pyganic	Pyrethrins	3A	0.022	High	1
pyridaben	Nexter	METI	21A	0.024	High	1
pyriproxyfen	Esteem	Juvenile hormone mimic	7C	100	Very low	1
spinetoram	Delegate, Radiant	Spinosyn	5	0.24	High	3
spinosad	Entrust, SpinTor, GF-120	Spinosyn	5	0.0029	High	1
spirodiclofen	Envidor	Tetronic acid derivative	23	>100	Very low	10
spiromesifen	Oberon	Tetronic acid derivative	23	200	Very low	1
spirotetramat	Movento	Tetramic acid derivative	23	>100	Very low	4
tebufenozide	Confirm	Diacylhydrazine	18	234	Very low	1

Table 1. Insecticide and miticide toxicity to bees (continued).

Active ingredient	Trade name(s)	Chemical group	Mode of action*	LD_{50} (µg/ bee)	Risk ranking	Reference
thiacloprid	Calypso	Neonicotinoid	4A	17.32	Low	1
thiamethoxam	Actara, Platinum	Neonicotinoid	4A	0.0005	High	1
thiamethoxam + pyrazole	Voliam Flexi	Neonicotinoid	4A, 28	0.0005	High	1
tolfenpyrad	Apta	METI	21A	Not listed	High	3
zeta-cypermethrin	Mustang MAX	Pyrethroid	3A	0.181	High	5

*IRAC (Insecticide Resistance Action Committee, **www.irac-online.org**) or FRAC (Fungicide Resistance Action Committee, **www.frac.info**) classification code for the mode of action for each chemical. Chemical groups should be rotated for resistance management.

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Table 2. Fungicide toxicity to bees. Risk rankings are based on EPA toxicity classifications derived from the contact LD_{50} for honey bees. Not all products in this table are labeled for use in all north central region states — check with your state pesticide regulatory agency to determine whether a product is registered for use in your state.

Active ingredient	Trade name(s)	Chemical group	Mode of action*	LD_{50} (µg/bee)	Risk ranking	Reference
azoxystrobin	Abound	Quinone outside inhibitor	11	200	Very low	1
Bacillus pumilus	Sonata	Biological	Bio	NA	Very low	1
Bacillus subtilis	Serenade Max	Biological	Bio	NA	Very low	1
boscalid	Endura	Carboxamide	7	166	Very low	1
captan	Captan, Captec	Phthalimide	M4	10	Moderate	1,6
chlorothalonil	Bravo WeatherStik, Equus, Quali-pro	Chloronitrile	M5	181.29	Very low	1
copper hydroxide	Champ, ChampFormula, Kocide 101	Inorganic	M1	44.5	Low	2
copper sulfate	Copper Sulfate, Cuprofix Disperss	Inorganic	M1	>23.5	Low	2
cymoxanil + famoxadone	Tanos	Cyanoacetamide-oxime/ Quinone outside inhibitor	27, 11	25	Low	1
cyprodinil	Vangard	Anilino-pyrimidine	9	784	Very low	1
cyprodinil + fludioxonil	Switch	Anilino-pyrimidine/ Phenylpyrrole	9, 12	784, 25	Low	1
dicloran	Botran	Aromatic hydrocarbon	14	0.2	High	1
difenoconazole	Inspire Super	Demethylation inhibitor	3	100	Very low	1
dodine	Syllit FL	Guanidine	M7	12.1	Low	1
fenarimol	Rubigan, Vintage	Demethylation inhibitor	3	10	Moderate	1
fenbuconazole	Indar	Demethylation inhibitor	3	292	Very low	1
fenhexamid	Elevate	Hydroxyanilide	17	215	Very low	1
fenhexamid + captan	CaptEvate	Hydroxyanilide/ Phthalimide	17, M4	215, 10	Moderate	1
ferbam	Ferbam Granuflo	Dithiocarbamate	M3	12.1	Low	1
fludioxonil	Scholar	Phenylpyrrole	12	25	Low	1
fluopicolide	Presidio	Pyridinylmethyl-benzamide	43	>100	Very low	2
fosetyl-al	Aliette	Phosphonate	33	100	Very low	1
hydrogen dioxide	Oxidate	Not classified	NA	Not listed	High	7
iprodione	Iprodione, Nevado, Rovral	Dicarboximide	2	>120	Very low	4,6

Table 2. Fungicide toxicity to bees (continued).

Active ingredient	Trade name(s)	Chemical group	Mode of action*	LD_{50} (µg/ bee)	Risk ranking	Reference
kresoxim-methyl	Sovran	Quinone outside inhibitor	11	25	Low	1
lime sulfur	Sulforix	Inorganic	M2	NA	Very low	1,2
mancozeb	Dithane, Penncozeb	Dithiocarbamate	M3	178.9	Very low	1
mancozeb + copper hydroxide	ManKocide	Dithiocarbamate/ inorganic	M3, M1	178.9, 44.5	Low	1
mancozeb + zoxamide	Gavel	Dithiocarbamate/ Benzamide	M3, 22	178.9, >100	Low	1
mandipropamid	Revus	Carboxylic acid amide	40	>200	Very low	4
metalaxyl-M	Ridomil Gold	Phenyl amide	4	100	Very low	1
metalaxyl-M/copper	Ridomil Gold/Copper	Phenyl amide /inorganic	4, M1	100	Low	1
metalaxyl-M/ mancozeb	Ridomil Gold MZ	PhenylAmide / Dithiocarbamate	4, M3	100, 178.9	Low	1
metconazole	Quash	Demethylation inhibitor	3	>90	Low	1
metiram	Polyram	Dithiocarbamate	M3	437	Very low	1
myclobutanil	Eagle, Rally	Demethylation inhibitor	3	>362	Very low	4
neem oil	Trilogy	Not classified	NA	NA	Very low	6
oxytetracycline	Mycoshield Ag Terramycin	Tetracycline antibiotic	41	100	Very low	1
petroleum distillates	Purespray Green	Not classified	NA	25	Low	1
phosphoric acid	Phostrol	Not classified	NA	>11	Low	5
potassium bicarbonate	Armicarb	Not classified	NA	>24	Low	2
potassium phosphate	AgriFos	Phosphonate	33	>145	Very low	2
potassium salts	Fosphite, ProPhyt	Phosphonate	33	>25	Low	3
propiconazole	Bumper, Orbit, PropiMax	Triazole	3	25	Low	1,6
pyraclostrobin	Cabrio	Quinone outside inhibitor	11	100	Very low	1
pyraclostrobin + boscalid	Pristine	Quinone outside inhibitor/ Carboxamide	11, 7	100, 166	Low	1
pyrimethanil	Scala	Anilinopyrimidine	9	100	Very low	1
quinoxyfen	Quintec	Quinoline	13	100	Very low	1
Streptomyces lydicus	Actinovate, ActinoGrow	Glucopyranosyl antibiotic	25	NA	Very low	1
streptomycin	Agri-Mycin	Glucopyranosyl antibiotic	25	100	Very low	1

Table 2. Fungicide toxicity to bees (continued).

Active ingredient	Trade name(s)	Chemical group	Mode of action*	LD_{50} (µg/bee)	Risk ranking	Reference
sulfur	Kumulus, Microthiol Disperss	Inorganic	M2	>100	Very low	1
tebuconazole	Elite, Orius, Tebuzol	Demethylation Inhibitor	3	>200	Very low	1
thiabendazole	Mertect	Methyl benzimidazole carbamate	1	>200	Very low	4
thiophanate-methyl	Topsin-M	Methyl benzimidazole carbamate	1	100	Very low	1
thiram	Thiram Granuflo	Dithiocarbamate	M3	74	Low	1
triadimefon	Bayleton	Demethylation inhibitor	3	25	Low	1
Trichoderma harzianum	RootShield	Biological	Bio	NA	Very low	3
trifloxystrobin	Flint, Gem	Quinone outside inhibitor	11	>200	Very low	3
triflumizole	Procure	Demethylation inhibitor	3	160	Very low	1
ziram	Ziram	Dithiocarbamate	M3	46.6	Low	1

* FRAC (Fungicide Resistance Action Committee, **www.frac.info**) code for the mode of action of each chemical.

Fungicides should be rotated for resistance management.

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