Organic Pesticides

MINIMIZING RISKS TO POLLINATORS AND BENEFICIAL INSECTS

XERCES SOCIETY
for Invertebrate Conservation

The Xerces Society for Invertebrate Conservation is a nonprofit organization that protects wildlife through the conservation of invertebrates and their habitat. Established in 1971, the Society is at the forefront of invertebrate protection, harnessing the knowledge of scientists and enthusiasm of citizens to implement conservation programs worldwide. The Society uses advocacy, education, and applied research to promote invertebrate conservation.

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Photographs & artwork

Front cover: left—yellow-faced bumble bee (*Bombus vosnesenskii*) buzz-pollinating a tomato flower (*Solanum lycopersicum*); top right—Large Foliage Ground Beetle (*Lebia grandis*) eating Colorado potato beetle (*Leptinotarsa decemlineata*) eggs; bottom right—two-spotted longhorn bee (*Melissodes bimaculata*) pollinating a watermelon flower (*Citrullus lanatus*). We are grateful to the photographers and artists for allowing us to use their wonderful works. Photographs and artwork remain under the copyright of the creator. None of the photographs or graphics may be reproduced without permission. See *Additional Acknowledgments* on page 19 for more information.

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This document is provided only as a guide. It offers science-based information to help you make informed decisions to reduce the risk of pest management efforts to pollinators and other beneficial insects. It may also contain specific pest management suggestions, including pesticide uses, but does not guarantee the efficacy of these uses. While based on guidance, advice, research literature, or other documentation, these recommendations are just that: recommendations for applicators and land managers to consider when developing or refining a specific pest management plan.

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Introduction

There are about 3,600 species of bees native to the United States. These wild insects provide pollination to wild plants in natural ecosystems as well as to many different fruit, nut, and vegetable crops. For some crops such as tomatoes (*Solanum lycopersicum*) and blueberries (*Vaccinium* spp.), only our native bees provide the sonication (a.k.a. buzz pollination) required for the most effective pollination.

For more than a decade, managed non-native European honey bees (*Apis mellifera*) have suffered high annual colony losses due to diseases, parasitic mites, and other factors. This makes native bees, which contribute more than $3 billion worth of crop pollination annually to the U.S. economy, more important than ever. Wild native bees are of particular importance to organic farming. They are an important component of the on-farm wildlife and natural resources that organic certified farms are required to maintain and, unlike honey bees, native bee populations can be supported without the use of antibiotics and other chemical inputs.

Organic agriculture generally supports higher biodiversity than conventional management (Tuck et al. 2013), and organic farms can play an important role in protecting and supporting bees and other beneficial insects in agricultural landscapes. Many organic operations already have good numbers of wild bees, as well as predators and parasitoids that attack crop pests. These beneficial species may provide most or all necessary crop pollination and pest control services when adequate habitat is available and preventive non-chemical pest management practices are implemented. For information about supporting desirable species, see the Xerces Society publications, *Organic Farming Practices: Reducing Harm to Pollinators from Farming*, *Farming for Bees*, and *Farming with Native Beneficial Insects* (see *References & Resources* on page 16 for details).

Unfortunately, however, even pesticides allowed for use in organic agriculture can cause harm to bees and other beneficial insects. There are many considerations when choosing between different pesticide options, including efficacy, specificity, cost, and risks to human health and the environment. This guide provides a brief overview of how to select and apply pesticides for organic farm operations while minimizing pollinator mortality. Many of the practices outlined here for protecting pollinators also can help to protect beneficial insects such as parasitoid wasps and flies; predaceous wasps, flies, and beetles; ambush and assassin bugs; lacewings; and others. The presence of these insects can further reduce pest pressure and the need for chemical treatments.

Figure 1: Hundreds of species of native bees pollinate blueberries and other fruit, nut, and vegetable crop flowers across North America. Protecting these insects from pesticides is important for maintaining good crop pollination and yields.

1 Pesticides: A Concern for Pollinators and Beneficial Insects

Pesticides are increasingly recognized as a factor in the decline of bees and other beneficial insects. Bees can be poisoned when they absorb pesticides through their exoskeleton; consume contaminated nectar, pollen, or water; or when pesticidal dusts become trapped in their pollen-collecting hairs. These non-target poisonings may occur immediately in the field when pesticides are applied, but harm also can occur days and even months after an application when toxic residues persist.

What determines the risk of a pesticide to non-target organisms? The amount of exposure an insect receives is as important as the toxicity of the pesticide (see *Toxicity*, next page)—or in other words, the dose makes the poison. A large dose of a low-toxicity pesticide might pose the same level of risk as a small exposure to a highly toxic pesticide. Both of these factors are important when considering strategies for minimizing risk to non-target organisms.

In general, insecticides permitted for use on organic farms are less toxic to beneficial insects and less persistent than those used in conventional systems (Edwards-Jones and Howell, 2001; Roubos et al., 2014). Many organic insecticides (e.g., pyrethrins, *Bacillus thuringiensis*) are sensitive to degradation in sunlight and UV light and break down more quickly in the environment than common conventional insecticides, including most organophosphates, pyrethroids, and neonicotinoids.

Bees and other beneficial insects can be exposed to pesticides in different ways as they move through the landscape. In addition to direct exposure while adult bees are out collecting pollen and nectar or seeking mates and nesting sites, pesticides may be carried back to nests in contaminated pollen or nectar and fed to developing brood (larvae). Leafcutter bees (*Megachile* spp.) gather leaf pieces and mason bees (*Osmia* spp.) collect mud to construct brood cells within their nests. Where this brood food or nest material is contaminated, bee larvae can be harmed.

Exposure to pesticides can kill non-target organisms outright at lethal doses, but even at lower levels of exposure bees and other beneficial insects can experience a variety of negative (a.k.a. "sublethal") effects, such as disorientation, disruption of movement, reduced reproduction, and paralysis. Pesticides may also disproportionably affect native bees, many of which are solitary (see sidebar, *Solitary Insects*), have smaller bodies than honey bees, and are more likely to be exposed to pesticides in nesting materials (Boyle et al. 2018). Unfortunately, most label guidelines only reflect toxicity to honey bees and do not mention impacts to native bees or other beneficial insects at all.

Solitary Insects: More Vulnerable to Pesticides

Figure 2: Most native bees are solitary, meaning all of the nest construction, foraging for pollen and nectar, and egg laying is carried out by a single adult female. The death of a solitary female from exposure to a pesticide ends reproduction and provisioning for her nest.

Excluding a few groups like bumble bees (*Bombus* spp.) and social wasps (*Polistes* spp., *Vespula* spp., etc.), most native bees and other beneficial insects are solitary species.

Among bees and wasps, this means that each female constructs and provisions her own nest, which is usually a small tunnel or cavity that contains a few brood cells provisioned with pollen and nectar stores or live prey. These females live only a few weeks as adults and usually die after completing their nests. Because solitary species are entirely self-reliant, with no daughters to help collect pollen and nectar or care for brood, they often have small nests with less than half a dozen offspring.

For this reason, pesticides are likely to have more population-level effects on solitary bees and wasps, as the death of a solitary female ends reproductive output for that nest. By contrast, the loss of foraging honey bees is buffered by other surviving members of the colony.

Pesticide Toxicity: Standardized Testing and Its Limitations

Pesticide toxicity to bees is complex and difficult to measure. Effects of pesticides range from immediate mortality, the easiest to measure, to sublethal effects such as changes in reproduction, foraging, navigation, and memory. The toxicity ratings in the Table of *Common Organic-Allowed Pesticides* (page 14) are based on acute lethality, the most readily available toxicity data for bees. Lethality of different pesticides is typically determined by testing different rates of an active ingredient (a.i.) on adult honey bees (*Apis mellifera*) to determine the dose that kills half of the tested bees (this dose is termed the "LD_{50}" because it is the amount that is lethal to 50% of a test population). The smaller the LD_{50}, the more acutely toxic the active ingredient is to honey bees. Lethal doses range from the highly toxic spinosad and pyrethrins, which can kill 50% of tested bees with less than 0.01 microgram of active ingredient per bee, to the practically nontoxic *Cydia pomonella* granulovirus, which has an LD_{50} of over 10 trillion micrograms per bee, an amount that would not be reached with real-world exposures.

Toxicity rankings in the table at the end of this document are based on the LD_{50} of those pesticides to honey bees, where available. Many organic pesticides lack even this standardized acute toxicity testing data for honey bees, let alone information on toxicity to native bees and other non-target organisms. In general, toxicity to honey bees can serve as a rough representation of the toxicity of different pesticides to native bees and other beneficial insects, with some exceptions. Some native bee species can be more vulnerable than honey bees to pesticides due to smaller body size and other physiological and behavioral differences. Additionally, some pesticides are toxic only to certain insect orders. For example, *Bacillus thuringiensis* ssp. *kurstaki* has little to no toxicity to bees but can be toxic to non-target butterflies and moths. Where available, we considered other peer-reviewed research studies to help infer toxicity ratings for active ingredients that lack an LD_{50}. In most cases, a lack of information meant we were unable to assess the subtler effects of pesticides on bees and other beneficial insects, such as changes to foraging behavior or reproduction.

It's important to note that toxicity is not the only indicator of whether a pesticide will pose a problem for pollinators. Pesticide risk is a function of both the toxicity of a pesticide as well as the level of exposure, or dose, that the insect receives. Repeated or high rate applications of a low-toxicity pesticide (e.g., a fungicide applied to a blooming crop in pounds per acre) might have a similar level of risk to bees as a low-rate application of a highly toxic pesticide (e.g., an insecticide applied outside of bloom in ounces per acre). In addition, there is still much we don't know about the indirect effects of pesticides, such as how pesticides can interact with other stressors to affect bee health. Recent research, for example, suggests that exposure to certain pesticides can make bees more vulnerable to a variety of pathogens.

In response to the unknown risks, the Xerces Society takes a cautionary approach to the use of pesticides. While many of the organic pesticides listed in the table are low risk to bees and other beneficial insects, we do not include a "non-toxic" category, as all pesticides carry some level of risk to one or more non-target species. We encourage the use of preventive pest management practices, such as crop rotation or floating row covers, which help reduce the need for and reliance on pesticides. We also recognize that pesticides are part of organic production and at times other management techniques are either not feasible or effective. That is why this guidance document includes recommended mitigation methods, such as applying short-lived pesticides at night, to reduce harmful effects to bees when pesticides are employed.

Figure 3: Bees visiting crop flowers or flowering weeds in crop fields can be exposed directly to harmful pesticide applications. Avoid applying pesticides directly to or allowing them to drift onto flowering plants visited by bees. Most native bees, like large carpenter bees (*Xylocopa* spp., left), lay each of their eggs on a ball of pollen and nectar (right). If pollen and nectar resources are contaminated with pesticide residues, the developing larvae may receive long-term (chronic) exposure to low doses of pesticides, which may result in lethal or sublethal effects.

2 Supporting Bees While Managing Pests

Figure 4: Careful scouting and monitoring for insect pests and diseases is critical for making informed management decisions. Pesticides should be applied only when scouting and monitoring indicate that pest populations have exceeded pre-determined economic thresholds.

Figure 5: Reduced pesticide use combined with increased application accuracy can help limit the negative impacts of pesticides on non-target species that nest in or around crop fields—such as native bees and wasps that nest in the pithy stems of plants like blackberries.

Prevention Is the Key

Preventive pest management is the foundation for whole-farm reductions in pesticide risk to pollinators and other beneficial insects. An integrated pest management (IPM) approach that minimizes pesticide use by monitoring crop pests and applying a variety of cultural, biological, and physical pest management techniques before resorting to chemical interventions can help support populations of bees and other beneficial insects. However, even with an integrated approach, pesticides may still sometimes be used to ensure pests do not cause economic damage. If pesticides are used, steps should be taken to reduce both the toxicity and level of exposure of these chemical interventions to bees and other beneficial insects.

Product Selection

To help reduce harm to pollinators and other beneficial insects when using pesticides, choose the least-toxic option. In the next section, *Common Organic Pesticides*, we review the toxicity to bees of many different types of pesticides allowed for organic crop production.

Off-Site Movement and Drift Protection

In addition to product selection, application method and timing can be adjusted to reduce risk. The best application method is the one that keeps the pesticide on target. Minimize drift, or the movement of spray droplets to adjacent non-target areas, by properly calibrating equipment. Also adjust nozzles to spray as close to the crop canopy as possible and produce droplet sizes that reduce offsite movement and maximize on target coverage.

Flowering plants around the farm can help support bees and other beneficial insects by providing important food resources. It is critical to protect

Figure 6: Non-attractive vegetative barriers, such as coniferous windbreaks and non-attractive filter strips, can help reduce pesticide drift onto and soil leaching/movement into wildflower habitat. Wherever possible, site habitat safely away from fields receiving pesticide applications. This coniferous windbreak in Minnesota helps mitigate drift from crop fields (left) onto nearby pollinator habitat (right).

flowering habitat from pesticide contamination. Protect permanent flowering habitat near crop fields by leaving a spatial buffer between habitat and pesticide applications, or by planting a vegetative drift barrier of plants that are not attractive to floral visitors (e.g., one or more rows of small-needled evergreen trees planted so that they will have 40–60% density at maturity between the habitat and treated areas [Adamson et al 2012]). Pay attention to wind speed and direction, and avoid applications when pesticides are likely to drift onto nearby flowering habitat.

Avoid or Limit Direct Exposure

To avoid direct exposure of foraging bees, do not apply pesticides when crops (or immediately adjacent flowering weeds and cover crops) are in bloom. In addition, mow or otherwise remove flowering vegetation (e.g., clovers and other flowering ground covers or weeds) in the understory or row middles of crop fields and orchard blocks before applying bee-toxic pesticides in those areas. Consider spot-treatments instead of whole-field applications to reduce the chance of exposure.

When other management methods are not feasible and you choose to use a pesticide on or near blooming plants, apply after dusk when bees are not actively foraging. Keep in mind that pesticide residues may persist longer on wet foliage, so dewy conditions should be avoided. Applying pesticides in the late evening or at night can help reduce exposure for bees and other day-active beneficial insects, like lady beetles and syrphid flies. However, night applications can increase risk for night-active beneficial insects, such as ground beetles and lacewings. For more information on minimizing the risk of pesticides to bees and other beneficial insects, see *Farming for Bees: Guidelines for Providing Native Bee Habitat on Farms* and *Farming with Native Beneficial Insects*.

Figure 7: Mow flowering vegetation (including weeds like dandelions and clover) in orchards or between crop rows before applying bee-toxic pesticides to avoid harming pollinators. If mowing is not an option, apply pesticides later in the day or in the evening when bees are less active.

3 Common Organic Pesticides

INSECTICIDES, REPELLENTS, AND PEST BARRIERS

Azadirachtin and neem oil: Azadirachtin and neem oil (clarified hydrophobic extract of neem oil) are botanical extracts from the tropical tree *Azadirachta indica*. Azadirachtin and other neem derivatives are insect growth regulators that prevent maturation of immature insects by disrupting their hormonal system. Both azadirachtin and neem oil are considered moderately toxic to bees and parasitoid wasps (Lowery and Isman 1995; Tasei 2001). Toxicity of azadirachtin and neem oil to bees increases when mixed with soap; avoid mixing with detergents when pollinators may be present.

FIGURE 8: Bt ssp. *kurstaki* is targeted at lepidopteran pest species like the cabbage white (*Pieris rapae*), but has little to no toxicity to bees. Avoid spraying this lepidopteran-specific pesticide on habitat near crop fields where butterflies could be harmed.

FIGURE 9: Spray drift can threaten bees and other pollinators foraging in habitats near crop fields. Here, a technician adjusts the calibration of nozzles to reduce drift and maintain accurate application on the target crop.

***Bacillus thuringiensis* (Bt):** Bt is a naturally occurring soil-dwelling bacterium that produces crystal proteins that function as an insect stomach poison upon ingestion. There are many subspecies of Bt that target relatively specific groups of insects (e.g., moths and butterflies, flies, and beetles). While many Bt subspecies (e.g., ssp. *kurstaki*, *israelensis*, and *tenebrionis*) have little to no toxicity to bees, the Bt subspecies *aizawai* was found to be highly toxic to honey bees (*Apis mellifera*) when fed at high doses over two weeks (EPA 1991; Hanley et al. 2003). The common Bt subspecies *kurstaki* (used in brand-name products such as DiPel) can be applied at label rates with low likelihood of harm to bees, but can pose a risk to non-target butterflies and moths if it drifts onto caterpillar host plants outside of farm fields (Johnson et al. 1995).

Beauveria bassiana: This naturally occurring insect pathogenic fungus has been reported to be extremely virulent to alfalfa leafcutter bees (*Megachile rotundata*), resulting in >87% mortality after 10 days (James et al. 2012). Mortality impacts are delayed, as it takes about a week for the fungus to germinate and develop after making contact with an insect's exoskeleton. The fungus also has been found to harm bumble bees (*Bombus* spp.) and likely has the potential to harm a variety of bees and beneficial insects when applied in liquid formulations at label rates (Vandenbergi 1990; Butt et al. 1993; Mommaerts et al. 2009; Karise et al. 2014). Dry formulations appear to have much less pathogenicity to bees.

Boric acid/borax: Boric acid (sodium tetraborohydrate decahydrate) is a mild acid and abrasive registered for use when not in contact with food or crops. It is low in toxicity to adult bees and beneficial insects and—because use is targeted for structural pests like ants and cockroaches—there is little danger that it will affect beneficial insects. However, some boron fertilizers are produced from boric acid and have the potential to pose risks to bees if applied to blooming crops; take steps to minimize bee exposure if applying boric acid-based foliar fertilizers.

Burkholderia **spp. strain A396:** A naturally occurring soil bacterium that interferes with insect cuticle development and molting. The bacterium has low acute (short term) contact toxicity to bees, but the potential for pathogenicity and long-term effects, particularly if ingested by larvae via contaminated pollen or nectar, is unknown. Products containing this strain of *Burkholderia* currently include advisory statements on the label to minimize potential exposure to bees and other pollinating insects; use caution and follow all label language.

Cedar oil: This oil, extracted from various species of cedar (*Cedrus* spp.), cypress (*Cupressus* spp.), or juniper (*Juniperus* spp.), is most commonly used as a mosquito or tick repellent, with some products used on lawns and gardens. Very little is known about the toxicity of this oil to bees, but product labels recommend not applying when bees are active, suggesting it may have some contact toxicity or other negative effects on bees and other beneficial insects. Use caution if applying cedar oil during or near bloom, as its repellent properties may reduce flower visitation and pollination by bees.

***Chromobacterium subtsugae*:** This naturally occurring soil bacterium produces metabolites with insecticidal activity to a variety of insects upon ingestion. Dietary toxicity testing indicated that this bacterium can be highly toxic to honey bees across a range of concentrations when bees were fed contaminated food over one to two weeks, but laboratory and field studies have not found evidence for increased bee mortality at field-relevant doses (NYSDEC 2012).

Cinnamaldehyde: This phenolic compound, the primary constituent of cinnamon oil, is typically used as a fungicide for mildews, botrytis, and rots. It is toxic to some soft-bodied insects, mites, and nematodes, but has low toxicity to honey bees (Gende et al. 2009; Brasesco et al. 2017).

Cydia pomonella **granulovirus (CpGV/CYD-X):** CpGV is a virus that infects and kills codling moth (*Cydia pomonella*) larvae (a pest of various fruit

Microbial Pesticides

Microbial pesticides contain one or more microorganisms (e.g., a species or strain of bacteria, fungi, virus, or protozoan) or their byproducts as the active ingredient. The best-known example of a microbial pesticide is *Bacillus thuringiensis* (Bt), which is a soil bacterium that produces crystalline proteins that puncture insect stomachs upon ingestion. Over the past decade, microbial pesticides have proliferated in the market.

Some of the microorganisms used as pesticides have unique risks to bees and other insects that differ from traditional synthetic or organic pesticides. Entomopathogens are microorganisms that parasitize, or live off the nutrients provided by host insects, mites, and/or ticks. The toxicity of entomopathogenic fungi, bacteria, and viruses to bees and beneficial insects can be difficult to measure and is often not captured well by standard acute toxicity testing for honey bees, which is conducted over a 24- to 48-hour observation period. Fungi like *Beauveria bassiana* and *Isaria fumosorosea* can take a week or more to germinate and develop inside an insect after first contact, meaning that a two-day toxicity test would fail to capture the effects of these pathogens on infected insects. The pathogenicity of these microorganisms may also vary based on environmental conditions, such as temperature and humidity.

Ongoing research and farmer observation of the effects of these microbial products in the field will help build our understanding of the risks these pesticides pose to pollinators and natural enemies.

Figure 10: Traditional acute toxicity tests may not accurately gauge the long-term effects of microbial pesticides on pollinators and beneficial insects, due to the lengthy germination time of some microbial species—it took over a week for *B. bassiana* to kill European corn borers (*Ostrinia nubilalis*) in this field test.

trees). It is specific to insects in the *Cydia* genus and is unlikely to have any toxicity to honey bees and other beneficial insects (Arthurs et al. 2007; Mommaerts et al. 2009).

Diatomaceous earth (DE): DE is a silica powder that damages the waxy outer layer of insect exoskeletons (cuticle), causing them to dehydrate and die (Korunic 1998). It is a universal insecticide that can kill pollinators and beneficial insects along with pest species, although different types of insects vary in their susceptibility (Losic and Korunic 2017). DE is less effective in high humidity or when mixed with water. If bees or beneficial insects are seen crawling on leaf or stem surfaces with recently applied DE, spray clean water to wash away the DE. Take care to avoid creating clouds of DE dust during application.

Garlic, cottonseed, or clove oil: These pungent plant extracts are typically used as deterrents for insects and small mammals. There is some evidence that these oils—particularly garlic oil—can be repellent to foraging honey bees and toxic to honey bee workers and larvae (Xavier et al. 2015). Be aware that if applying during or close to bloom time, these repellents may reduce flower visitation and pollination by bees.

Horticultural oil/narrow range oil: Horticultural oils, consisting of light-weight petroleum or vegetable oils, are used to smother pest insects and are only harmful to bees upon direct contact. Apply at night to minimize risk to bees.

Insecticidal soap: Potassium fatty acid soaps only work when directly applied to pest insects. The soap disrupts cell membrane permeability, causing cell contents to leak, leading to death. Mortality may occur if directly applied to foraging bees and other beneficial insects; apply at night to minimize risk to bees.

Isaria fumosorosea: This fungus acts as a parasite to some invertebrates and is used as an insecticide and miticide. Spores of the fungus attach to and penetrate insect cuticle (the waxy outer layer of an insect's exoskeleton), then grow inside the insect, causing its death. The fungus emerges from the dead insect to release spores to infect other insects. *Isaria fumosorosea* infection resulted in slightly increased mortality in three stingless bee species (Toledo-Hernández et al. 2016). Like other fungal pathogens, *I. fumosorosea* has low acute toxicity to bees (Sterk et al. 2003), but may have longer term mortality effects, as it takes about a week to germinate and develop within an insect after infection.

Kaolin/kaolin clay: This pest barrier consists of finely ground kaolin particles mixed into a liquid slurry, which forms a barrier film that discourages insect feeding. It has low toxicity to bees but may affect some beneficial insects by disrupting movement and feeding ability and reducing oviposition (Porcel et al. 2011). Kaolin application can disrupt bee foraging; apply at night to minimize exposure to foraging bees.

Figure 11: Applying short-lived pesticides and those that are toxic only upon direct contact (e.g., 'smothering' pesticides like horticultural oil) in the evening or at night can reduce exposure risk for bees and day-active beneficial insects.

Figure 12: Kaolin clay has low toxicity to bees, but acts as a barrier to beneficial insects along with pests and can disrupt flying bees at the time of application. Apply at night to minimize exposure to bees.

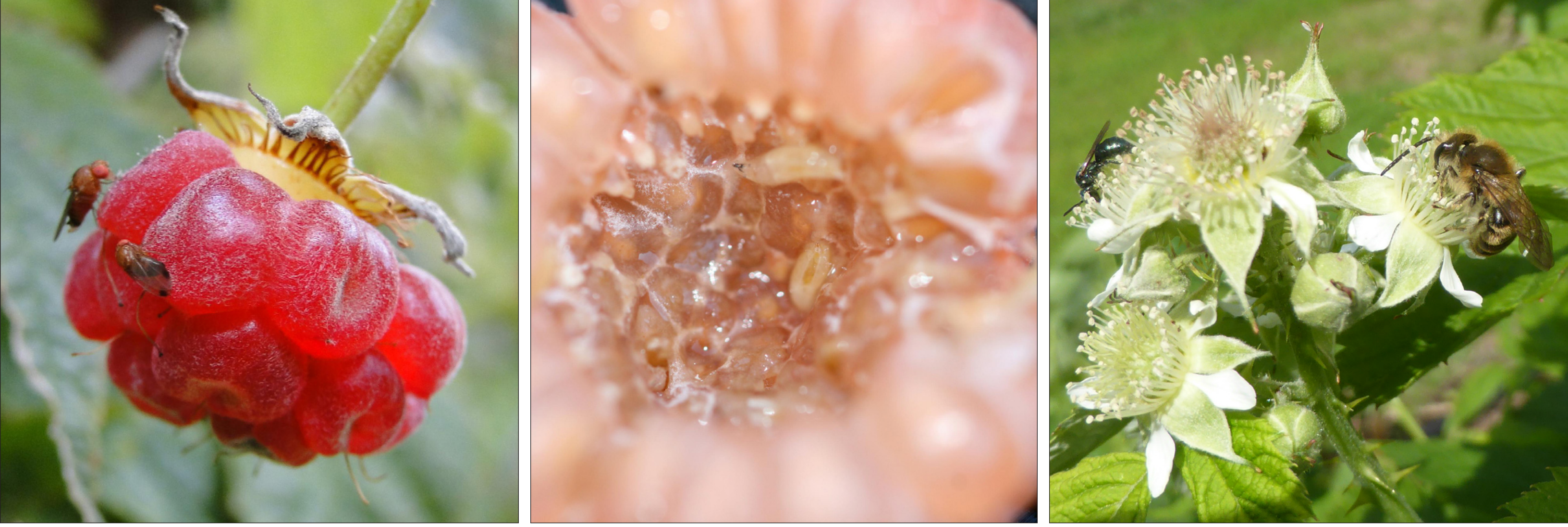

Figure 13: Spinosad and pyrethrins are two broad-spectrum organic-approved insecticides commonly used for control of challenging pests like spotted-wing drosophila (*Drosophila suzukii*—adults, left; larvae, center). However, both are highly toxic to bees and other beneficial insects, including to the many species of wild bees that pollinate our fruit and vegetable crops (such as small carpenter bees [*Ceratina* spp.] and mining bees [*Andrena* spp.], right). Wherever possible, take steps to reduce use of and mitigate risk to bees from applications of these pesticides.

Limonene/D-limonene: Limonene is a botanical extract from citrus peel used as a repellent and insecticide, sometimes in combination with other products. Direct contact at recommended doses is low in toxicity to bees and beneficial insects, but inhalation of aerosolized limonene, such as when applied as an in-hive fumigant, can be toxic to honey bees (Ellis et al. 1997).

Pyrethrins: These products are fast-acting derivatives from plants in the genus *Chrysanthemum* and have been used as broad-spectrum insecticides for centuries. Pyrethrum is the crude flower dust, while pyrethrins are the insecticidal compounds extracted from the dried flower heads. Pyrethrins are highly toxic to bees and moderately to highly toxic to other beneficial insects, particularly parasitoid wasps (Wilkinson et al. 1975; Simmonds et al. 2002). Relative to other organic pesticides, extremely low levels of pyrethrins can be toxic to bees. However, pyrethrins degrade rapidly when exposed to sunlight and air (Antonious 2004; Gunasekara 2005). Applying these relatively short-lived products at night can help minimize risk to bees.

Rotenone: This broad-spectrum dust, derived from the roots of a tropical legume, disrupts cellular processes by inhibiting oxygen uptake. **Rotenone is now prohibited for use in U.S. organic agriculture.** Various sources report residual effects of rotenone persisting anywhere from two hours to 42 days after application. Rotenone is moderately to highly toxic to bees and other beneficial insects, though lab studies have shown mixed results (Obrycki et al. 1986; Gregorc and Škerl 2007; Xavier et al. 2015).

Ryania/Ryanodine: The active ingredient of this botanical insecticide, the alkaloid ryanodine, is extracted from the ground stems of *Ryania speciosa*. Ryanodine fell out of general use by the end of the 20th century, and **ryanodine pesticides are no longer registered for any uses in the United States.**

Sabadilla: Sabadilla is an alkaloid compound derived from the seeds of the sabadilla lily (*Schoenocaulon officinale*), which acts as a stomach and nerve poison. It is used for control of thrips in citrus (*Citrus* spp.), mango (*Mangifera indica*), and avocado (*Persea americana*), and is only registered in a limited number of states. It is moderately toxic to many insects, including bees and other beneficial insects (Anderson and Atkins 1958). It can be slow to degrade, meaning that its residues can remain toxic for a day or more (Rosen and Zang 2006). If applying during bloom, spray at night to minimize bee exposure. Note, however, that its slow degradation means that bees are likely to receive some exposure, even when applied at night.

Spinosad: A nerve and stomach poison derived from the bacterium *Saccharopolyspora spinosa*, this product is highly toxic to bees and other beneficial insects (Mayes et al. 2003; Arthurs et al. 2007; Tomé et al. 2014). Relative to other organic pesticides, low levels of spinosad can be toxic to bees. Spinosad is much less toxic after spray residues have dried (Mayes et al. 2003). Applying at night, when conditions allow for residues to dry, can help reduce bee exposure.

Bacillus amyloliquefaciens: *B. amyloliquefaciens* is a naturally occurring non-pathogenic soil rhizobacterium that competes with and reduces abundance of plant fungal diseases. This species is commonly found in the honey bee gut microbiome and in honey; and it has also been used to treat chalkbrood in hives. No toxic effects were found for adult honey bees in a 17-day feeding trial (Health Canada PMRA 2015). It has not been tested for toxicity to other beneficials.

Bacillus subtilis: *B. subtilis* is a naturally occurring soil bacterium that functions as a fungicide and plant growth aid. While short-duration toxicity tests indicate *B. subtilis* has little to no toxicity to bees and a variety of beneficial insects, two longer-duration studies found mortality and sublethal effects in bumble bees when *B. subtilis* was applied at the maximum field recommended concentration (Mommaerts et al. 2009; Ramanaidu and Cutler 2013). Dry formulations may be less toxic to bees than wet formulations (Mommaerts et al. 2009). Avoid repeated applications.

Bicarbonates: Sodium bicarbonate (baking soda) and potassium bicarbonate are salts that can be used as contact fungicides. Baking soda mixed with various oils has been used for powdery mildew and other plant diseases since the 1930s. No acute toxicity testing has been conducted for bicarbonates. One study found no treatment-related effects of potassium bicarbonate fed to bumble bees in contaminated pollen (Gradish et al. 2009).

Copper: Copper-based pesticide formulations (e.g., copper hydroxide, copper oxychloride, copper oxide, and copper salts) are highly caustic. Impacts vary greatly for bees and beneficial insects. Copper oxychloride was documented to have contact toxicity to the larvae of an *Osmia* (mason bee) species (Tesoriero et al. 2003). Avoid applying copper products for 2–4 days after an application of *Beauveria bassiana* when bees are likely to be present, as coppers can synergize the insecticidal activity of the fungal pathogen (Kouassi et al. 2003). Because copper is a heavy metal that does not degrade in the environment, repeated uses of copper products can result in accumulation of copper in the soil, which can have negative impacts on soil ecology and fauna.

Copper sulfate: Copper sulfate, Bordeaux mixture (copper sulfate + lime), and other water-based copper fungicides have been reported to be moderately toxic to bees and beneficial insects for more than a day after application. Copper sulfate was found to have contact and oral toxicity to a stingless bee species in the tropics (Rodrigues et al. 2016). Bordeaux mixture is strongly repellent to bees and other beneficial insects and, as a result, may reduce densities of these insects in orchards receiving repeated sprays (Lo 2004).

Gliocladium catenulatum: This naturally occurring soil fungus inhibits the growth of other fungi. Like other fungal pathogens, *G. catenulatum* has little to no acute (short term) toxicity to bees. An 11-day feeding trial at the maximum field recommended concentration found no lethal or sublethal effects of the fungus on bumble bees (Mommaerts et al. 2009). Bumble bees exposed to high doses of *G. catenulatum* over several weeks experienced high mortality after about three weeks, but no lethal effects were observed at field-relevant doses (Mommaerts et al. 2012).

Hydrogen peroxide: This weak acid can be used as a bactericide and fungicide. No quantitative toxicity information is available. Product labels for hydrogen-peroxide-based formulations include a bee hazard statement with precautionary language, indicating that these products may be harmful to bees and other non-target arthropods.

Lime sulfur: This caustic fungicide is strongly repellent to bees and other insects. This repellent effect, which can persist for >7 days, has been known for decades (Butler et al. 1943). The fungicide is generally considered to have low toxicity to bees at field doses but can be more toxic at higher doses (Kim et al. 2008; Efrom et al. 2012).

Pythium oligandrum: This naturally occurring fungus-like soil microorganism is a parasite of other fungi. *Pythium oligandrum* has little to no acute (short term) toxicity to bees, but the potential for pathogenicity and long-term effects is unknown.

***Reynoutria sachalinensis* extract:** This extract of giant knotweed (*Fallopia sachalinensis*) activates internal plant defenses against fungal and bacterial diseases. No quantitative toxicity information is available, but *R. sachalinensis* extract is not likely to be toxic to bees and other beneficial insects.

***Streptomyces* spp.:** These naturally occurring filamentous soil bacteria produce antibiotic substances and are used as a fungicide in greenhouses and for ornamental plants. Acute toxicity testing indicates low toxicity to honey bees.

Sulfur: This fungicide has been reported to have low toxicity to bees (Anderson and Atkins 1958; Fell et al. 1983), but is more toxic to some other beneficial insects, including parasitoid wasps (Thomson et al. 2000). Toxic residuals or repellent effects may persist for several days after application.

Tea tree/melaleuca oil: This essential oil derived from the tea tree (*Melaleuca alternifolia*) is used as a fungicide in several crops. Acute toxicity testing indicates low toxicity to bees, but it can be toxic to aquatic invertebrates.

***Trichoderma* spp.:** These naturally occurring soil fungi compete with, and reduce abundance of, plant pathogenic fungi. Acute toxicity testing indicated low toxicity to bumble bees, and a field study did not find increased mortality to honey bees after a 30-day exposure (Brownold et al. 1997; Sterk et al. 2003).

HERBICIDES, PLANT GROWTH REGULATORS (PGRS), AND ADJUVANTS

Acetic acid (vinegar): While little toxicity information is available for horticultural vinegar, highly caustic products containing 10% acetic acid or higher are likely to pose risks to honey bees and non-target arthropods (EFSA 2013). Follow label directions and any additional advisory language; use caution if applying highly concentrated solutions. Spot applications will reduce the likelihood of exposing non-target species.

Corn gluten: This powdery byproduct of the corn milling process is used as a pre-emergent herbicide for lawn and turf, and more broadly as a fertilizer. No quantitative toxicity information is available, but its use on organic farms is unlikely to affect bees or beneficial insects. Avoid uses that could cause nitrate contamination of groundwater.

Gibberellic acid: This plant growth regulator is low to moderately toxic to honey bees (EFSA 2012); but it is highly toxic to the parasitoid wasp *Aphidius colemani*, which is widely used as a biological control agent.

FIGURE 14: Spot-spraying is an effective way to target the application of pesticides to pest-affected plants or problem weeds, reducing the risk to pollinators and beneficials nesting or foraging in the area.

Adjuvants

Adjuvants are substances meant to improve pesticide performance, typically bought separately from pesticide products and added to them. Adjuvants can improve the ability of the active ingredient to spread or stick, stimulate insect feeding, and/or change other physical properties of the mixture, such as droplet size. Most organic adjuvants have little to no information available on toxicity to bees and other agriculturally beneficial species. A few adjuvants have been documented to have toxicity to honey bees, including organosilicone surfactants (Mullin et al. 2016), some of which are approved for use in organic agriculture. In addition, there are many "inert" ingredients in pesticide formulations. Most of these ingredients also lack information about potential harm to non-target species. Formulated products can be either more or less toxic than the active ingredient alone, suggesting that the risk of adjuvants varies, with some adjuvants increasing concern and others reducing the potential for harm to pollinators. In general, with adjuvants of unknown toxicity, the Xerces Society recommends using caution and to avoid applying them when bees are foraging.

4 Common Organic Pesticides in Agriculture

The table below provides a comparative overview of pesticides commonly permitted (or referrenced) for U.S. organic agriculture. Use this table to determine which pesticide(s) is most appropriate for your situation.

ACTIVE INGREDIENT (A.I.)	TYPE*							EXAMPLE PRODUCT NAMES	BEE TOXICITY
Acetic acid (vinegar)				H		A		Weed Pharm	MEDIUM
Azadirachtin / neem oil	I	M						Neemix, Trilogy, Azatrol, Debug, Neem Pro	MEDIUM
Bacillus amyloliquefaciens			F					Stargus	LOW
Bacillus subtilis			F					Serenade	MEDIUM
Bacillus thuringiensis ssp. *aizawai*	I							Xentari, Agree	MEDIUM–HIGH
Bacillus thuringiensis ssp. *kurstaki / israelensis*	I							DiPel, Javelin, Biobit	LOW
Beauveria bassiana	I							BotaniGard	MEDIUM–HIGH[W]
Bicarbonates (sodium / potassium)			F					Armicarb, Kaligreen, Remedy	LOW
Boric acid	I							Boric acid, Borax	LOW
Burkholderia spp. strain A396	I	M						Venerate, Majestene	LOW–MEDIUM
Cedar oil	I	M			R			CedarCide	LOW–MEDIUM
Chromobacterium subtsugae	I	M						Grandevo	LOW–MEDIUM
Cinnemaldehyde	I	M	F					Cinnacure, Cinnerate, Bravado	LOW
Citrus oil (Limonene / D-limonene)	I			H				GreenMatch, Orange Guard, Avenger	LOW
Coppers			F					Badge, Champ, Nu-Cop, Cuprocaffaro	LOW–MEDIUM
↳ Copper sulfate ($CuSO_4$)			F					Copper sulfate, $CuSO_4$	LOW–MEDIUM
↳ Copper sulfate + lime (Bordeaux mixture)			F					Bordeaux	MEDIUM
Corn gluten				H				Corn gluten	LOW
Cydia pomonella granulovirus	I							Cyd-X	LOW
Diatomaceous earth	I	M						Diatomaceous earth	MEDIUM
Garlic, cottonseed, or clove oil	I	M	F		R			GC-Mite, Matratec, Scary Garlic Plus	LOW–MEDIUM
Gibberellic acid							P	ProGibb	LOW–MEDIUM
Gliocladium catenulatum			F					Prestop	LOW
Horticultural oil / narrow range oil	I	M	F					JMS Stylet Oil, Ecotrol, Leaf Life Gavicide Green	MEDIUM
Hydrogen dioxide, peroxyacetic acid			F					Oxidate 2.0	HIGH
Insecticidal soap	I	M	F					M-Pede	LOW–MEDIUM
Isaria fumosorosea	I	M						Preferal, NoFly	LOW–MEDIUM
Kaolin clay	I	M						Surround	LOW
Lime sulfur	I	M	F					Lime sulfur, Sulforix	LOW–MEDIUM
Pyrethrins	I	M						PyGanic, Azera	HIGH
Pythium oligandrum			F					Polyversum	LOW
Reynoutria sachalinensis extract			F					Regalia	LOW
Rotenone	I	M						**PROHIBITED FOR USE IN U.S. ORGANIC AGRICULTURE**	MEDIUM–HIGH
Ryania/Ryanodine	I							**CANCELLED**	LOW–MEDIUM
Sabadilla (*Schoenocaulon officinale*)	I							Veratran-D	MEDIUM
Spinosad	I	M						Entrust, Success, Regard	HIGH
Streptomyces spp.			F					Actinovate, MycoStop	LOW
Sulfur	I	M	F					Sulfur, Microthiol	LOW
Tea tree oil			F					Timorex	LOW
Trichoderma spp.			F					Bio-Tam 2.0	LOW

NOTES

* **TYPE**—insecticide (I); miticide (M); fungicide (F); herbicide (H); repellent (R); adjuvant (A); plant growth regulator (P)

DO NOT APPLY directly to, or allow to drift onto, flowering plants

† **MOA**—Mode of action (e.g., how a pesticide works, or the mechanism by which it causes physiological disruption at its target site[s])

	NOTES & SPECIAL PRECAUTIONS
✘	Applications made with concentrations of acetic acid over 10% likely to be toxic to bees and other beneficials
✘	Mixing with soap increases toxicity to bees
✘	SLOW-ACTING MOA†—Impacts on bees likely to be delayed
✘	SLOW-ACTING MOA†—Impacts on bees likely to be delayed
	Toxic to butterflies and other beneficials (Diptera)
✘	SLOW-ACTING MOA†—Impacts on bees likely to be delayed; ⚠ (see Coppers below); W—wet formulation
	Uses for structural pest control are unlikely to affect bees; use caution if applying fertilizers that contain boric acid
✘	MOA† suggests that impacts could be delayed, but no data currently available
✘	Repellent to bees and may disrupt pollination
✘	SLOW-ACTING MOA†—Impacts on bees likely to be delayed; repellent to bees and may disrupt pollination for up to a week
✘	Toxic to other beneficials (ground beetles, mites, nematodes)
✘	Repellent to bees and may disrupt pollination
✘	Avoid heavy repeated use—copper can accumulate in soils and contaminated soils are difficult to remediate
✘	
✘	⚠ **Do not apply copper(s) within one week of *Beauveria* application**
✘	SLOW-ACTING MOA†—Impacts on bees likely to be delayed
✘	
✘	
✘	MOA† suggests that impacts could be delayed, but no data currently available
✘	Only toxic to bees upon direct contact; *if applying during bloom*, apply at night to minimize risk to bees
✘	
✘	
✘	SLOW-ACTING MOA†—Impacts on bees likely to be delayed
✘	Can disrupt foraging bees at time of application; *if applying during bloom*, apply at night
✘	Repellent to bees and may disrupt pollination
✘	
✘	MOA† suggests that impacts could be delayed, but no data currently available
	Highly toxic to honey bee larvae
	SLOW-ACTING MOA†—Impacts on bees likely to be delayed
✘	
✘	Granular spinosad bait products generally have a much lower exposure risk for bees
	Only registered for greenhouses / ornamentals
✘	Repellent to bees and may disrupt pollination; may reduce pollen viability for some crops
✘	SLOW-ACTING MOA†—Impacts on bees likely to be delayed

Resources & References

Pesticides Approved for Organic Use

USDA National Organic Program

SYNTHETIC substances allowed for use in organic crop production
http://bit.ly/crops601

NONSYNTHETIC substances prohibited for use in organic crop production
http://bit.ly/crops602

Organic Materials Review Institute

OMRI Listed Products
www.omri.org

Pesticide Environmental Reviews & Toxicity Ratings

Bee Precaution Pesticide Ratings

University of California Statewide IPM Program
http://ipm.ucanr.edu/beeprecaution/

BPDB: A to Z List of Active Ingredients

University of Hertfordshire Bio-Pesticides DataBase
http://sitem.herts.ac.uk/aeru/bpdb/atoz.htm

UC Pest Management Guidelines

University of California Statewide IPM Program
http://ipm.ucanr.edu/GENERAL/pesticides.html

PPDB: A to Z List of Pesticide Active Ingredients

University of Hertfordshire Pesticide Properties DataBase
http://sitem.herts.ac.uk/aeru/ppdb/en/atoz.htm

Pesticide Risk Reduction

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Organic farms can support diverse and abundant bee populations that include specialist pollinators like these squash bees (*Peponapis pruinosa*). Protecting pollinators and other beneficial insects from pesticides is important to sustain their populations and the ecological services they provide.

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