Protecting pollinators from pesticides
CANOLA

POLLINATOR PARTNERSHIP CANADA

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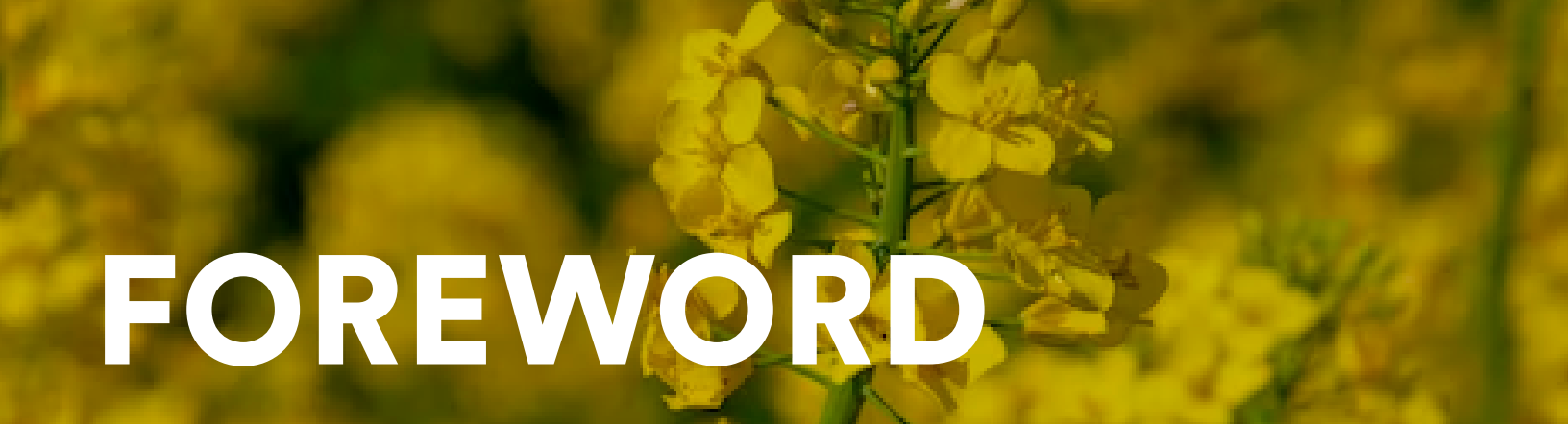
POLLINATOR PARTNERSHIP CANADA

TABLE OF CONTENTS



FOREWORD

Insect pollinators, especially bees, play a crucial role in the pollination of seed and add benefit for commodity canola across Canada. Pollinator health is important to the long-term sustainability of canola production as well as to the broader environment—especially as pollinator populations are known to be in decline globally. Keeping managed bees and wild pollinators such as bees, butterflies, beetles, flies, and moths healthy requires involvement from all who participate in canola production, from growers to beekeepers, agronomists, crop consultants, and pesticide applicators.

The focus of this guide is to minimize the impacts of pesticides and other management measures on pollinators, and it is meant for all those involved in canola production. There are many factors that impact pollinator health in addition to pesticide exposure, including habitat loss, parasites and diseases, and climate change. By reducing pollinators' exposure to pesticides and taking other steps to support healthy populations, everyone can help pollinators to be more robust and healthier in the face of multiple stressors.

This guide can be used as a quick reference on individual topics or can be read in its entirety for a deeper dive into the subject. We acknowledge that the farmers who have known and lived on their land for generations know the nuances of their land and can develop best practices that are catered and specific to place. This guide is intended to provide guidance on how to minimize the impacts of pesticides on the pollinators (primarily native bee species) found on canola crops through informed decision-making, best management practices, and by maintaining good communication between growers, applicators, and beekeepers.

The **first section** of this guide covers the relationship between managed and wild pollinators, and canola crops. The **second section** covers important practices that help minimize the impacts of pesticides on pollinators: integrated pest management, including the use of beneficial insects, communication, habitat, and pesticide product selection and use. The **third section** distills the information contained in sections 1 and 2 into action-oriented recommendations for growers, applicators, and beekeepers. The **fourth section** includes resources with more detailed information on the impacts of pesticides on bees and how to identify and report suspected bee poisoning.

In addition to this guide, readers can consult the supplemental document which outlines pollinator precaution levels for products registered for use in canola production, including further information on the pesticide risk characterization framework used by the Pest Management Regulatory Agency (PMRA) to designate precaution levels.

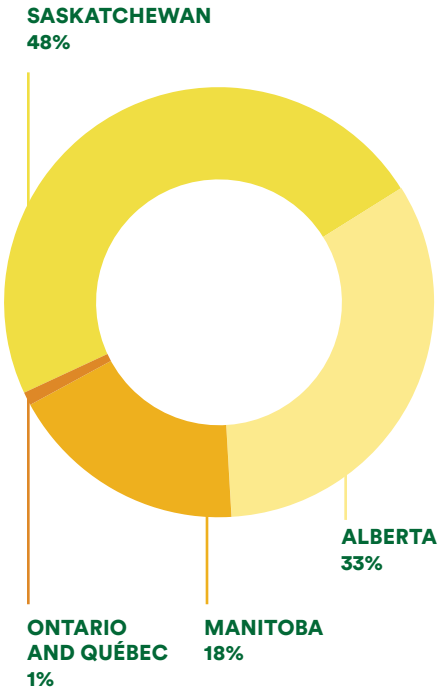
This guide focuses on seed and production canola. We recognize the vast world of canola and intend for this guide to help those involved in canola production learn more about the pollinators of this important crop, including how we can maintain productive and healthy canola growing systems while protecting pollinators within those systems.

1 CANOLA POLLINATION

CANOLA PRODUCTION IN CANADA

Canola (created from the term, "CANadian Oil Low Acid") is a type of rapeseed that was first developed by plant breeders in Saskatchewan and Manitoba during the 1960s and 70s. The high-oil, low acid and low sulphur profile of canola seeds make it ideal for the manufacture of food-grade oil. By the 1980s, due to the market success of canola oil, production of the crop overtook all other rapeseed farming in Canada[1]. As of 2022, Canada is the world's largest producer of canola (approximately 20 million tonnes/year), with over 90 percent of the crop being exported to foreign markets[2, 3].

In Canada as of 2020, canola processing contributed nearly $6 billion to the economy annually, along with over 7,000 jobs[4]. The pollination services of bees, wild and managed, contribute to this value. Most canola production in Canada occurs in Saskatchewan (48%), followed by Alberta (33%) and Manitoba (18%), with Ontario and Québec producing the remaining 1%[5].

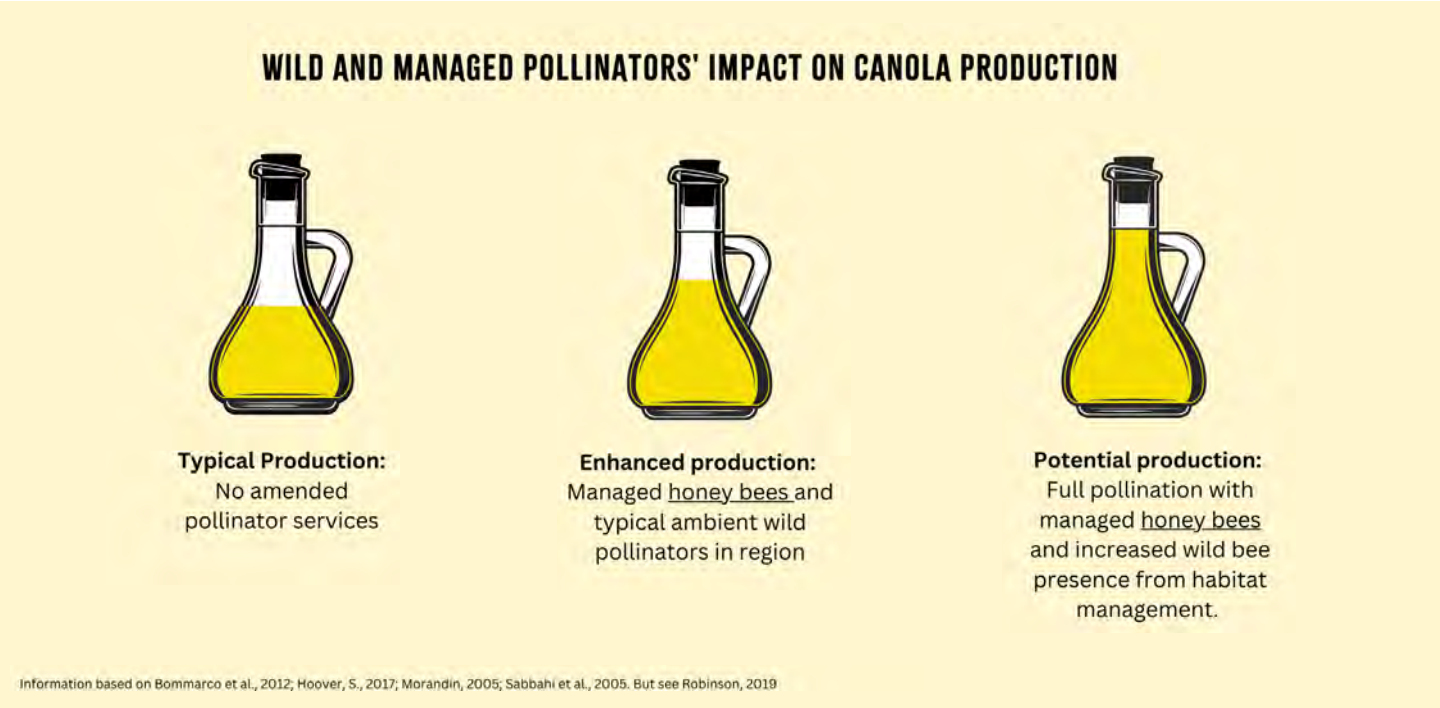


Canola production can be split into two categories – production for seed to plant commodity canola and commodity canola; the seed of which is crushed to produce oil and meal. Seed canola production is managed by seed-production companies with the goal of developing new varieties with desirable agricultural traits. The seed produced from these varieties is purchased by farmers and growers to produce commodity canola. Seed canola production takes up a fraction of land compared to commodity canola (~20,000 ha and 20 million ha respectively, as of 2016) and is largely restricted to irrigation districts in southern Alberta[2, 6]. It is important that seed developers and producers, and commodity growers can produce a marketable product, which requires consideration of pest control, pollination requirements, as well as other factors.

CANOLA POLLINATION SYSTEMS

Canola is a complex of three species of rapeseed; *Brassica rapa* (Polish canola), *B. napus* (Argentine canola), and *B. juncea* (brown mustard). Though *B. napus* is the most grown variety, all three species readily hybridize, and various hybrids, biotypes, and cultivars of the crop are created each year. There are many differences in growing characteristics and seed yield between cultivars that growers must consider, in addition to local growing conditions, to determine the best seed to grow. While many cultivars can self-fertilize, pollinators play a crucial role in the sustainability of this crop. Canola is highly attractive to bees, due to its clustered, bright-yellow flowers that bloom for relatively long periods of time. The flowers are a great source of nectar, and their plentiful pollen provides a good source of protein and fats for bees[7]. There are many economic benefits to encouraging native pollinator species on your land. Consider how increased quality, yield, and timeliness of seed setting benefits your bottom line. By supporting these natural systems, you gain access to thousands of tiny 'farmhands', who are working daily to help you make the most of your growing season.

Studies on *B. napus* have shown an increase in the yield, weight and market value of canola seeds grown in areas with higher pollinator abundance[8-10]. Other benefits of pollinators in canola fields include lower pollen-deficit within flowers, and heavier fruit sets[11]. Not only do farmers benefit economically from pollinators through increased seed quality and quantity, but in the face of changing climatic conditions, the presence of early season pollinators can also help the crop reach seed maturity sooner, reducing the risk of economic losses from dramatic weather events[8]. Work by Robinson[6] indicates that these benefits may be more dramatic in seed canola than in commodity canola. Anecdotal evidence, such as in the Steppler Farms case study show that there can be noticeable differences when native pollinators are supported. Overall, the presence of managed and wild pollinators on canola crops helps mitigate the inherent risks involved in farming, without a substantial added cost to the farmer.



Canola farming is an inherently risky activity, compounded by changing cycles of climate, soil nutrition, moisture, pests, and more. Each year, any one or more of these factors can negatively affect crop yield, and farmers spend a lot of time and money on mitigating these risks.

Supporting managed and wild pollinators on your land is a low-cost way to help mitigate the impacts of these risks through improved seed weight, early-season seed setting, reduced risks of pod shatter, and more.

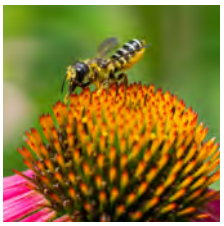
In the production of canola seed, crossbreeding must take place between two different canola varieties. Male and female plants of desired varieties are planted in parallel bays, and fields are stocked with European honey bees (*Apis mellifera*; also known as the Western honey bee) and Alfalfa leafcutting bees (*Megachile rotundata*; also an introduced European species) to ensure adequate pollen transfer between the male and female flowers[12, 6]. Once these hybrid seeds are produced, they are usually treated with pesticides such as imidacloprid, clothianidin, and thiamethoxam, which then arrive onto farm fields across Canada to produce commodity canola[13]. In the absence of these pollinators, large-scale hybrid seed production would not be possible.

The average cost of canola seed has increased to record highs as of 2022, making the most sought-after varieties of hybrid canola harder to access[14]. The most desirable seed varieties are those with the greatest potential to effectively self-pollinate. With increasing demand and pricing for these varieties, the potential economic benefits provided by pollinators to less desired seed varieties must be heavily considered (improved seed weight, reduced pod-shatter, earlier fruit set).

POLLINATOR AND BENEFICIAL INSECT IDENTIFICATION IN CANOLA

HONEY BEES

Honey bees (*Apis mellifera*) are not native to Canada; rather they are livestock managed for the creation of honey, other hive products, and increasingly for agricultural pollination services. Honey bees are utilized in two ways within the canola agri-system. We have discussed their role in the production of seed canola, but they are also an integral component of commodity canola as beekeepers value canola for honey production, and many farmers host honey bees on their land for honey production. Canola produces an incredible density of attractive yellow flowers that provide a large nectar and pollen resource for honey bees, while the bees provide pollination services to the crop/farmer. This relationship in turn provides the market with a light, pleasant tasting honey that is highly marketable and favored by consumers. Honey bees travel greater distances than native bees in search of pollen and nectar, and can typically be housed along the edges of fields to reduce any conflict of space in actively farmed fields. **This ability to travel further also means that during pesticide application, honey bee colonies may be impacted from transfer of pesticides onto individual bees during foraging, and into the colony, even from fields treated 2-3 km away from honey bee colonies**. Refer to the "Action Guide" section for communication guidelines around pesticide applications to reduce the possibility of negative impact. Honey bees forage at lower temperatures compared to leafcutting bees and some other wild bees.



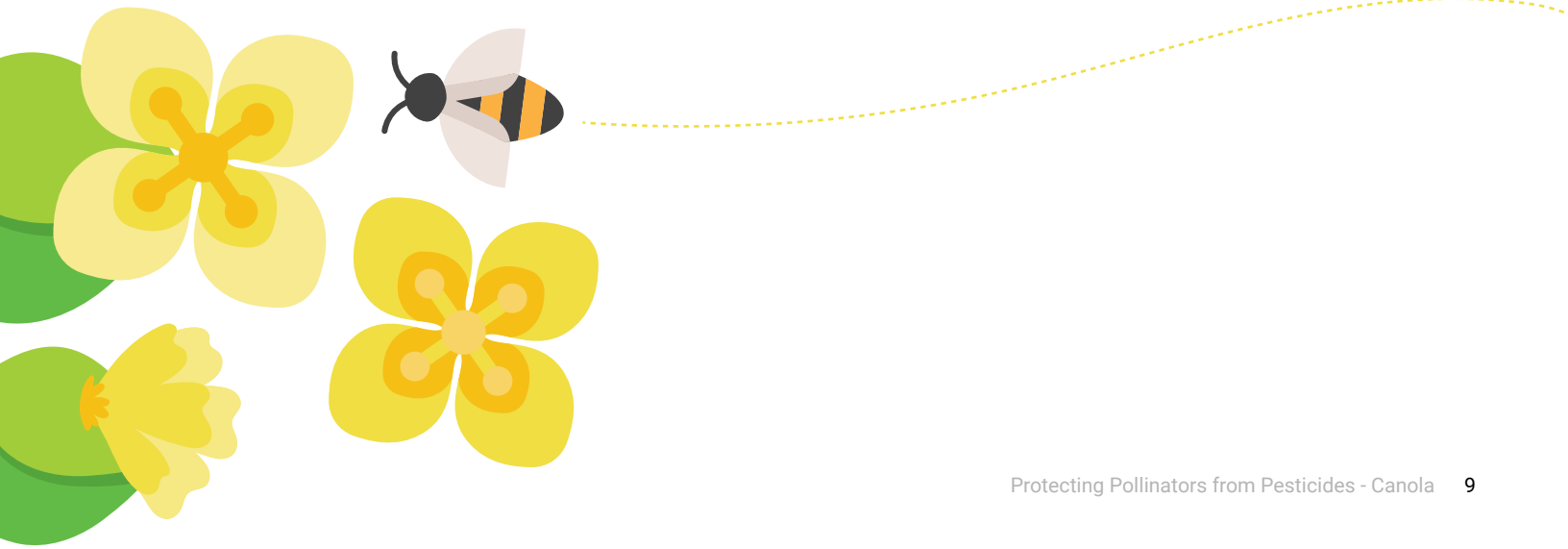
LEAFCUTTING BEES

Alfalfa leafcutting bees (*Megachile rotundata*) are not native to Canada, though they are closely related to native leafcutting bees. Their life history is quite different from honey bees. While honey bees live in large colonies, usually with one queen bee and many thousands of worker bees, leafcutting bees are gregarious. This means that every female reproduces, each creating their own small nest, and provisioning each one of their eggs individually. Being gregarious, they nest in relatively high densities in proximity to one another. Their natural nesting material is pithy or hollow plant stems, in addition to beetle and other insect tunnels in wood. Their nesting requirements (pre-existing tunnels) allows humans to provide concentrated artificial nest sites, and harvest their cocoons, making them ideal as a managed crop pollinator. As this species does not travel as far as honey bees, nest sites of these bees (referred to as 'tents' or 'shelters') are spread throughout a seed field in the female bays. ***M. rotundata* are more effective pollinators of canola than honey bees**. Whereas honey bees wet the pollen they collect so that it can better stick to their legs (corbicula), female leafcutting bees carry dry pollen loosely packed into their abdominal scopae, or hairs. The difference between this wet and dry pollen strategy means that honey bees transport much of the pollen they collect back to their colony whereas leafcutting bees shed more of their collected pollen to each flower they visit.

WILD BEES

Managed honey bees and leafcutting bees are the most considered species in canola farms, though there are over 800 species of wild bees in Canada, many of whom occur freely within canola landscapes. Wild pollinators are your on-site natural allies known to support a variety of crops in increasing production yield and quality, while simultaneously providing crop resiliency in the face of climate change. Even in the presence of high densities of honey bees, having wild bees present improves crop pollination[15, 16] including in canola[9-11, 17, 18]. Canola flowers are also visited by other types of wild solitary bees, hover flies, flies, and butterflies. These species help canola farmers by reducing crop risks on farms and increasing general quality of food production[11, 19, 20]. Growers can improve pollination by maintaining natural areas and by creating wild pollinator habitat along field margins or within large fields, as well as using managed pollinators[21-25].

Wild bees exist in and around fields year-round, either as adults that can be seen foraging, or as eggs, larvae, or pupae that are less visible but are nonetheless present in nests in the ground, in twigs, or in cavities. In fact, many ground-nesting bees such as bumble bees, long-horned bees, mining bees, and sweat bees construct their nests on crop edges or in fields. Below are some native pollinators that you may see in or around canola fields.



WILD POLLINATORS OF CANOLA

These are some native pollinators that you may see in or around canola fields. They are docile and rarely sting people. All those shown here are known to visit canola crops. Use the iNaturalist App to help identify species on your land.

BUMBLE BEES

(genus *Bombus*) Bumble bees are excellent pollinators when they are present. They live in small colonies (~40-400 individuals) in the ground or above ground in cavities. They can fly in cool and inclement weather. There are about 40 different types of bumble bees across Canada and while it is easy to tell a bumble bee from most other bees, it can be tricky to know what species of bumble bee you are looking at in the field.

BEEFLIES AND HOVER FLIES

(order Diptera) Beeflies and hover flies often mimic bees and wasps in their coloration. This is an evolutionary defense mechanism, since they do not have the stingers that honey bees and wasps do. These species are underestimated pollinators, as well as pest control agents. While the adults visit flowers to gain nutrition, larval stages of these species are predatory, and actively feed on aphids and sapsuckers.

SWEAT BEES

(family Halictidae) Sweat bees can be as tiny as 4 mm like the one on the left, or up to about 11 mm. Some are metallic, others bright green, and some have stripes. They are solitary and nest in the ground. Some species might land on you and lick your sweat in the summer! The most common group you are likely to see on canola are small sweat bees in the genus *Lasioglossum*.

LEAFCUTTER BEES

(family Megachilidae) Unlike the sweat bees, leafcutter bees nest in pithy stems. Each emerging female in the spring will create and provide for her own nest with multiple young. They utilize leaf material to construct cylindrical shaped cells, within which they place a small ball of pollen, and lay an individual egg. They range in size from 7 mm to 18 mm. They are common pollinators of canola crops, look for them nesting within stems of old berry bushes and flower stalks. Like all solitary bees, they are very docile and rarely sting people.

2 PRACTICES TO PROTECT POLLINATORS

75% OF CROPS REQUIRE OR BENEFIT FROM INSECT POLLINATION

Growing crops in a productive and cost-effective manner that also factors in planning for—and mitigation of— the effects of climate change, is crucial for the success of future generations of farmers and citizens. Keeping a variety of wild pollinator species healthy relates to the larger global issues of weather unpredictability and climate change because of the systems they help to support. Pollinators and agriculture are intimately tied together, as 75% of global crops require or benefit from insect pollination[27, 28]. Balancing the need for crop protection with pollinator health calls for employing several practices that together result in resilient and productive agricultural systems.

This guide covers **four important practices** that can help all stakeholders protect pollinators while maintaining production:

- Integrated pest management
- Communication between beekeepers and farmers
- Supporting pollinators through habitat
- Using pesticide products

INTEGRATED PEST MANAGEMENT (IPM)

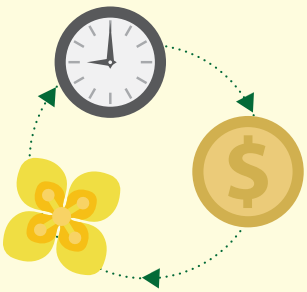
Using Integrated Pest Management (IPM) and an IPM consultant will help you save money and time, reduce pesticide use, reduce impacts to wild pollinators, and enhance crop pollination. IPM is a strategy based on ecosystem function and long-term prevention of pest damage. It combines techniques such as habitat manipulation and conservation, use of pest-resistant plant varieties, a range of cultural practices, biological control, and as a last step, pesticides to keep pest populations below an economic threshold. Setting up and adapting your IPM plan each year before the season begins helps you to create a well-considered methodology that can be tinkered with and adapted throughout the years (see Steppler Farms case study).

Pest management materials are selected and applied in a manner that minimizes risks to human health, beneficial and nontarget organisms, and the environment[29]. For example, pesticides are used only when monitoring indicates they are needed according to established guidelines, and treatments are made with the goal of removing only the target organism. IPM plans help growers meet their production and crop protection goals and protect pollinators, while minimizing impacts to the environment. Targeted and planned applications will greatly reduce economic costs associated with standard reactionary or preventative pesticide applications.

IPM PRINCIPLES:

- A multi-faceted approach that combines chemical, physical, biological, and cultural pest control methods.
- Prevention of infestations.
- Monitoring and identifying pests at frequent intervals throughout the growing season.
- Decision-making based on monitoring and thresholds.
- Selection of pest control products that are the least toxic to non-target, beneficial insects.
- On-going evaluation and improvement of management strategies.

Careful consideration of pollinator health should be taken in each of these steps to support pollinators without limiting the effectiveness of pest management.



AN IPM CONSULTANT CAN HELP YOU SAVE MONEY AND TIME, REDUCE PESTICIDE USE, REDUCE IMPACTS TO WILD POLLINATORS, AND ENHANCE CROP POLLINATION.

Planning to integrate various strategies for pest and disease management must happen before the land is worked on and doing this in the winter months can provide a time and space for thorough consideration that considers the real, lived experiences of farmers, researchers, and crop planners. You do not need to do it alone and there are many resources to help! Consider hiring an Agronomist who has knowledge, or specializes in IPM to support you in farm planning, treatment applications and utilizing beneficial insects.

IPM strategies sometimes require more initial thought and investment, but they have large and long-term payoffs that include cost savings from using fewer inputs, less crop damage from a reduced need for equipment in fields, and better yields from healthier and larger pollinator and beneficial insect populations. Growers can learn about IPM and implement IPM strategies themselves, or create contracts with local IPM specialists.

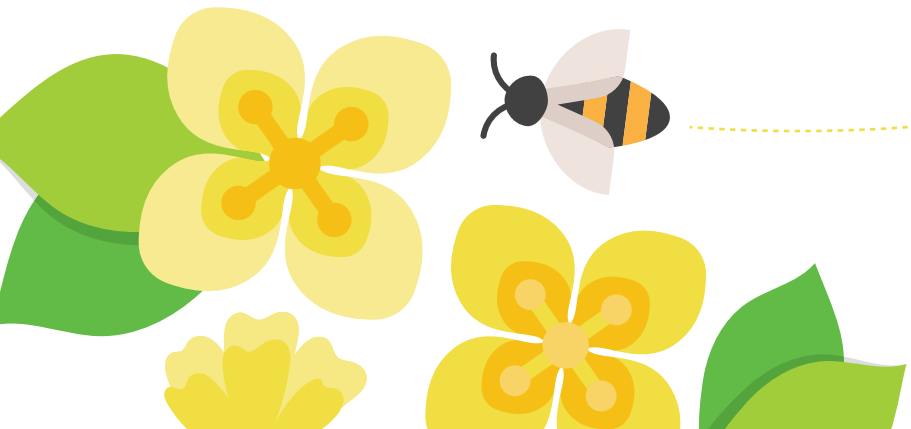
Avoid the use of broad-spectrum insecticides when you see any pollinator species on your crop and do not use preventative applications. If you must spray, consider treating the land during 'off-peak' times, when insects are less likely to be out foraging. For honey bees and some native bees, this is during the cooler parts of the day, during the evening and night. Spraying overnight can help ensure the product dries overnight, and has less impact on pollinators the following day. Save money while encouraging beneficial insects to stay on your land by preserving vegetation in areas that are less managed and not sprayed, such as field margins and ditches (see Steppler Farms case study). Consider utilizing inexpensive plants rich in nectar, such as sweet clover, and yarrow as well as native plants that will support nutrition and habitat needs for a diversity of species. Most research in agricultural landscapes shows that the creation and preservation of native wildflower habitat helps attract additional pollinators to a crop from surrounding areas[24, 30, 31].

For examples and guides of IPM in canola, See our Useful Links (page 41)

UTILIZING CROP ROTATION

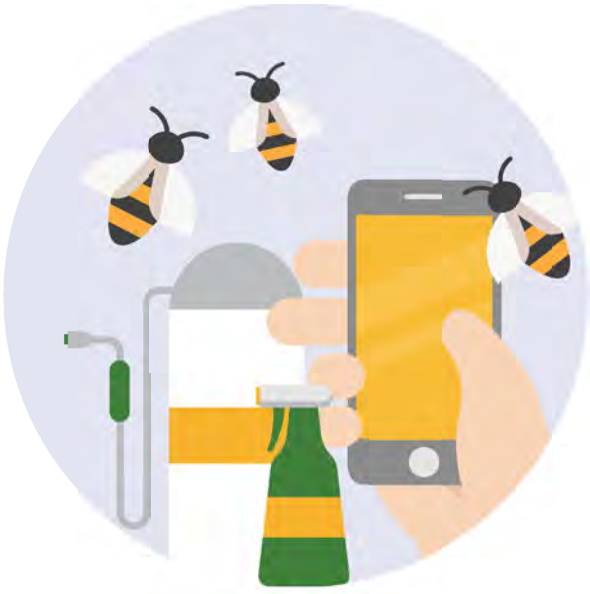
A study conducted by Agriculture and Agri-Food Canada in 2016 showed that even with varied cultivars grown each year, canola yield was highest when crops were rotated every three years. Best results were found with pea-wheat-canola and wheat-wheat-canola rotations[26]. The time in between plantings allows for the decomposition of any crop residue that may be infected with pathogens. Planting canola in back-to-back years increases the probability of pathogen spread throughout the crop.

Pesticides should always be selected and applied in a manner that minimizes risks to human health, beneficial and nontarget organisms, and the environment. For example, pesticides are used only when field monitoring indicates that pest insect populations are exceeding pre-established economic thresholds. These thresholds change each year, based on the value of the crop and cost of pesticide application. To determine population thresholds for spraying, visit the Canola Council's Thresholds for major canola insects. Treatments are made with the goal of reducing populations of the target pests without harming other organisms



MAINTAINING CLEAR COMMUNICATIONS

Regardless of using IPM, the need for communication and cooperation between beekeepers and growers is the most effective way to reduce honey bee and native pollinator species' pesticide exposure risk. Both beekeepers and growers benefit from developing positive working relationships and familiarizing themselves with each other's management practices. **However, communication between beekeepers and growers does not fully overcome exposure issues for wild bees, as many species live in the soil and flowers overnight**. See the Selecting and Using Pesticides section for more information on how to protect wild bee populations.



DISCUSSIONS AND CONTRACTS* BETWEEN GROWERS AND BEEKEEPERS SHOULD INCLUDE:

- ✓ Coordination of crop timing with dates of apiary arrival and departure.
- ✓ Details of the beekeeper's responsibility to provide strong and effective colonies for crop pollination.
- ✓ Details of the grower's responsibility to safeguard bees from poisoning.
- ✓ A clear designation of responsibility for providing supplemental water and feed.
- ✓ A description of pest management practices in the cropping system before colonies are delivered.
- ✓ A description of pesticides to be used on a crop while bee colonies are present.
- ✓ A description of buffers to be placed between treated areas and apiaries.
- ✓ A communication plan for informing neighbouring growers and applicators of apiary locations.
- ✓ A description of possible pesticide use in adjacent crops.
- ✓ A diagram showing the location of honey bee colonies.
- ✓ Reference to provincial and regional information on crop pests and spraying schedule where available.

*Due to the changing nature of farming, the creation of formal contracts may not be feasible for all parties. In some cases, formal agreements can be a hindrance for farmers looking to allow honey bees on their properties. Despite this, a discussion and agreement between all parties is valuable in maintaining honey bee and wild pollinator health.

COMMUNICATION

- Give minimum 48 hours notice to beekeepers when applications are necessary so that safety measures to protect the hives can be taken.

- Though not mandatory, it is strongly recommended to write and agree to a contract in advance that defines expectations and responsibilities between beekeeper and grower/applicator, including minimum advance notification time for land treatments, protocol for suspected pesticide incidents involving pollinators, and anything else that may come up for either party.

- Establish a chain of communication between all parties, including coworkers, crop consultants, and applicators.

- Outline a pest management plan that specifies which systemic products have been applied, which contact pesticides may be used during bloom, and methods to protect bees during application. This will be helpful for future crop planning, and fine-tuning practices over time.

SUPPORTING POLLINATORS THROUGH HABITAT

Creating habitat in canola fields can be as simple as utilizing brushpiles and wildflowers on strips of seasonally unusable land.

Maintaining or creating habitat on your farm is inexpensive and can go a long way toward supporting healthy honey bees, increasing the abundance and variety of wild bees, and improving their resilience to other stressors. There is an abundance of evidence showing that leaving non-invasive weeds, wildflowers, and other habitat patches around pollinator-dependent crops increases pollination and crop production[17, 25, 32, 33]. This also saves you money, time, and resources.

ENHANCING AGRICULTURAL HABITAT FOR POLLINATORS

Loss of habitat in agricultural lands threatens pollination in crops such as canola. Actions taken to increase habitat, large and small, can make a significant impact on pollinator populations.

Key actions that a farmer can take

- Increase flower diversity
- Reduce impact of mowing
- Provide nest sites
- Communicate with beekeepers about pesticide applications
- Reduce pesticides

Consider incorporating some of these actions on your farm. Keep an eye out for wild bees to see the positive impact you are having.

Providing buffer strips or habitat near the farms can improve crop yield in pollinator-dependent crops.

Provide additional pollinator habitat near your home.

Plant roadside with flowers or flowering trees to provide food for pollinators.

Maintain riparian buffers that provide pollinator habitat.

Create pollinator habitat on marginal lands and around field edges.

Avoid insecticides when crop, cover crop, or marginal lands are in bloom and use integrated pest management.

Retain some dead branches or logs for nesting sites.

Retain native flowers, plants, and trees that provide bloom all season.

Leave some areas of bare ground for ground nesting bees.

Minimize mowing of roadsides, marginal lands, and lawns to retain flowers.

Nest blocks provide habitat for cavity nesting bees. Make sure to clean and maintain artificial nest boxes.

RESEARCH HIGHLIGHT

THE IMPORTANCE AND BENEFITS OF HABITAT PATCHES IN CANOLA-GROWING REGIONS

The area known as the Prairie Pothole Region spans the prairie provinces, and is defined by its unique patchwork of small wetlands left behind by receding glaciers. Research conducted in south-central Alberta showed a crucial relationship between these wetland margins in canola fields, and pollinator diversity and abundance. Researchers found that the diversity of pollinator species, and the number of individuals found for each species, were highest closest to wetland margins. These numbers decreased with sampling further into canola fields.

The team conducted pollinator sampling via trapping in 21 quarter sections (a quarter section is 160 ac or 65 ha) that included canola, barley, and perennial grassland landscapes. Three sampling stations were placed within each field, located at the 0.25 and 75 m mark from wetland margins into the crop or grassland. Results showed highest pollinator abundance and diversity within collections closest to the wetland margins, with both decreasing further into canola and barley fields. The same was not true for grassland landscapes, where the number of pollinator species increased further from wetland margins[48].

These results highlight the importance of habitat patches within canola fields for pollinator abundance and diversity. Though wetland habitats are not typically ideal for bees, with lots of water and saturated soils that they cannot utilize, these places act as a haven within canola fields. In grasslands, where opportunities for nesting within stems and soils are more abundant, a greater diversity of species can inhabit these regions. Low-cost implementation of small habitat patches within canola fields could act as other landing spaces for all these species, increasing pollinator populations and diversity across a cropland.

Further research is underway to quantify the economic benefits provided by the pollination services of these habitat patches to canola growers.

There can be concern that non-crop floral resources will 'pull' honey bees or other bees away from the crop. However, research shows that non-crop floral resources help honey bees by providing a diversity of pollen sources needed to maintain health. These areas attract and enhance bee populations rather than taking them away from the crops[24, 30- 32].

Having habitat to support honey bees and wild bees can be as simple as reducing unnecessary vegetation control. As such, it can involve no extra work and even some labour savings:

- Selective weed control to increase pollinator friendly species.
- Keeping 'scrubby' areas rather than farming every bit of land: this can lead to more 'intensive' production; that is, more yield on less land due to the enhanced pollination from wild bees and healthier honey bees.
- Identify areas that are lower production and 'marginal'. Keep these as habitat for beneficial insects rather than cultivating these sections. This can save money and enhance production.

Vickruck, J. L., Best, L. R., Gavin, M. P., Devries, J. H., & Galpern, P. (2019). Pothole wetlands provide reservoir habitat for native bees in prairie croplands. Biological Conservation, 232, 43–50. https://doi.org/10.1016/j.biocon.2019.01.015

Proactively enhancing and creating pollinator habitat can also help attract and sustain pollinator populations on your farm and help enhance your crop yield through improved pollination:

- Create floral strips or hedgerows, which can take little or no land out of production, on field edges and other areas of your farm[24].

Ideal habitat for bees includes the following elements. Keep in mind that creating habitat with just some of these elements can significantly improve bee and pollinator health and abundance:

- Flowering plants (native plants, cover crops, non-invasive weeds, shrubs, trees, or ornamental plants) that, in combination, bloom from early spring to fall to support honey bees and wild bees such as bumble bees that need forage all season.
- Undisturbed soil, including lawns, piles of debris such as sticks, dead leaves or compost, standing plant material, or old logs provide nesting sites for ground nesting, twig (tunnel) nesting, and cavity nesting bees in addition to overwintering sites for bumble bee queens. Leave them in place, or set aside spots for these habitats, remembering to be mindful of these homes during spring crop planning and preparation.
- Protection from pesticide application and drift can occur through pesticide-free buffers and thoughtful management, especially around native bee nesting aggregations. Consider planting tall "hedges" of sunflowers, Jerusalem artichokes, or other tall flowers to provide natural pesticide buffers during the summer and fall months.

See the Honey Bee Health Coalition (HBHC) Best Management Practices (BMPs) for Pollinator Protection in Canola Fields for an in depth resource guide that will help you ensure you are keeping safe while encouraging pollinators and other beneficial insects on your farm.

OTHER BENEFITS OF POLLINATOR HABITAT

Erosion Control

Accelerated erosion is a growing concern in all Canadian agricultural regions, though the causes vary across the country. Although erosion caused by excess water is most common outside of the Prairies, water erosion can still occur in these provinces due to excess snowmelt and severe summer thunderstorms. There are different types of water erosion, with varying levels of soil damage. Sheet damage is caused by the impact of rain, and rill erosion occurs when runoff accumulates in large amounts forming small channels. Enough rills can combine to form gullies, which can reoccur in the same location each season unless tilled and re-graded. Even so, wind is the most prevalent cause of erosion impacting canola crops in Canada. Wind erosion can occur once wind speeds reach 25 to 50 kilometres per hour 30 centimetres above the soil surface. In all circumstances, valuable topsoil is lost and the possibilities of land-use reduce. The creation and maintenance of pollinator habitat including grasses and forbes around crop margins is known to reduce particulate movement out of fields, while increasing the site's capacity to absorb excess irrigation and stormwater[57].

Carbon Benefits

The average root depth of the most typical lawn grass, Kentucky bluegrass (*Poa pratensis*), is between 7 and 16 centimeters. Compare this to the root depths of native grasses such as little bluestem (*Schizachyrium scoparium*), which can reach depths of 1 to 3 meters. Although the carbon capture abilities of trees have been well researched, in an environment like the Prairies, where a majority of canola is grown, the implementation of prairie grassland species is a more ecologically sound option. Increased rates of wildfires due to drought, fire suppression and climate change, on Canada's West coast has made historically carbon absorbing old growth forests into carbon sources. Unlike trees, who store most of their carbon in their wood and leaves, grassland species sequester most of their carbon underground. When fires go through a forest, their absorbed carbon is released back into the atmosphere, but when grasslands burn, the carbon tends to stay in the roots and soil. With the current path of increasing carbon loads globally, grasslands are the most viable carbon dioxide sinks for large semi-arid landscapes like the Canadian Prairies[57].

CASE STUDY
STEPPLER FARMS, MANITOBA

Steppler Farms has always been conservation-minded since its inception over 100 years ago (est. 1921). What started as a commodity operation diversified to a 1416 ha (3500 acre) canola and grain farm, Charolais and Angus cattle rearing, and a 1500-hive honey bee apiary. Ian Steppler manages the apiary operations and has a well-experienced perspective on the interplay of pollinators and canola crop yield.

"Farmers spend a lot of money on practices that will help improve [canola] yield by as little as 2 to 3 percent. [Supporting wild and managed pollinators] by creating habitat in remnant pockets where canola cannot be grown can do the same thing, without adding any extra cost. The benefits to yield can range from 1 to 5 percent, depending on the seasonal conditions."

BMP'S FOR FARMERS

- Reduced application of herbicides and pesticides in ditches and fallow land to help support wild populations of flowers for pollinator provision.
- Plan to make pollinator habitat in the areas that aren't used for production in a given year, like wet areas, or places missed by machinery.
- Pay attention to early season cues for pest management. If timed correctly, the use of targeted soil-based control products for grasshoppers can effectively control these pest populations.

As a beekeeper, Ian further understands the needs of pollinators in relation to crop management by the use of pesticides and herbicides. Creating and managing pollinator habitat, along with engaging in key best management practices can help protect pollinators from these management techniques.

"Focus on nutrition to make a healthier insect [to help them] handle the low-doses of pesticides"

BMPS FOR BEEKEEPERS

- Supply honey bees with late-season protein supplement products that provide generalized amino acids.
- Ensure good populations of late-season blooms such as sunflower, aster, and goldenrod to help bees stock up with good nutrition for overwintering.

IAN STEPPLER, STEPPLER FARMS

SELECTING AND USING PESTICIDE PRODUCTS

Pesticides have become an integral part of most canola crop and farm management systems. Although a helpful tool, it is important to recognize the short and long-term risks to pollinators and agroeconomics. Exposure to pesticides can kill bees, though exposure is more likely to cause effects that do not kill them right away, but negatively impact foraging, learning, reproduction, and/or the long-term health of native and cultivated bee populations[34]. If insecticide treatments are needed to control insect pests in canola crops, growers should rotate between pesticide class treatments (a) from year to year in the same crop to avoid the development of pest resistance and (b) in the same location, even if a different crop is grown, to avoid accumulation of pesticide residues in the soil[35].

POTENTIAL PESTICIDE IMPACTS ON BEES

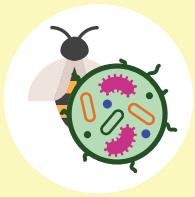
Bees can be impacted lethally or sublethally by pesticides. For more information, see Recognizing and Reporting a Bee Poisoning in the Resources section on page 36.

Lethal

increased bee death

Sublethal

increased susceptibility to pests and diseases



alteration of gut microbiome

decreased reproduction

learning and memory impairment

impaired orientation

reduced foraging

It is important to remember that wild bees will be visiting the canola crop flowers even if honey bees have been moved during pesticide application. Spraying anything on a blooming crop (even fungicides) can affect the ability of bees and pollinators to detoxify other pesticides, such as systemic neonicotinoids. Good practice to protect these native pollinators is to avoid applying crop treatments during bloom time, or at least aim for applications in the evenings when bees are less active. Keep in mind that some bees such as bumble bees are early morning foragers, so pesticides should not be applied during that time. The following practices outline ways to control exposure to pesticides, so the risk is acceptable to pollinators while maintaining crop production and quality.

By using pesticides within an IPM framework, following label directions, and selecting products that have low toxicity to bees, healthy bee populations can be maintained. This benefits us all, as they contribute to canola pollination and yield, including pollinating other crops and natural ecosystems. Health Canada's Pest Management Regulatory Agency (PMRA) uses a risk assessment framework to help eliminate unacceptable risks from pesticides. To learn more about this framework, see the supplemental document.

SELECTING LEAST TOXIC PESTICIDE PRODUCTS

UNDERSTANDING PESTICIDE RISKS

Native and honey bee poisonings are related to exposure amount, exposure time, and the toxicity of a pesticide. The term, 'pesticide' refers to all substances that are meant to control pests, including insecticides, fungicides, nematicides, miticides, and herbicides. The highest risk to bees is from pesticide products that are highly toxic, have residual toxicity longer than 8 hours, can be found as residues in pollen, nectar, or soil where bees can be exposed to them, or are sprayed on the crop during bloom when bees are present. **Risks are reduced by following pesticide labels closely and paying attention to changes in use restrictions.**

Insecticides are generally more toxic to non-target insects than other types of pesticides (e.g. fungicides, herbicides) because they are formulated specifically to kill insects. Though herbicides and fungicides are generally less toxic than insecticides, they also present risks. However, herbicides can also be useful and necessary for the creation and management of pollinator habitat, and fungicides and other pesticide applications are necessary components of seed canola production.

Some of the active ingredients in the following chemical families used in canola crops have residual toxicity longer than 8 hours. None can be applied to the crop during bloom. Read labels carefully.

- Organophosphates such as malathion.
- N-methyl carbamates such as carbaryl.
- Neonicotinoids such as imidacloprid, clothianidin, thiamethoxam.

FUNGICIDES

Fungicides are sometimes necessary for canola production. However, there is evidence that some fungicides can negatively impact bees on their own[53] and in synergy with insecticides[49-54]. Following label directions, avoiding applying fungicides directly on or near honey bee colonies, and applying them when wild bees are not active, can help safeguard bee health.

INSECTICIDES

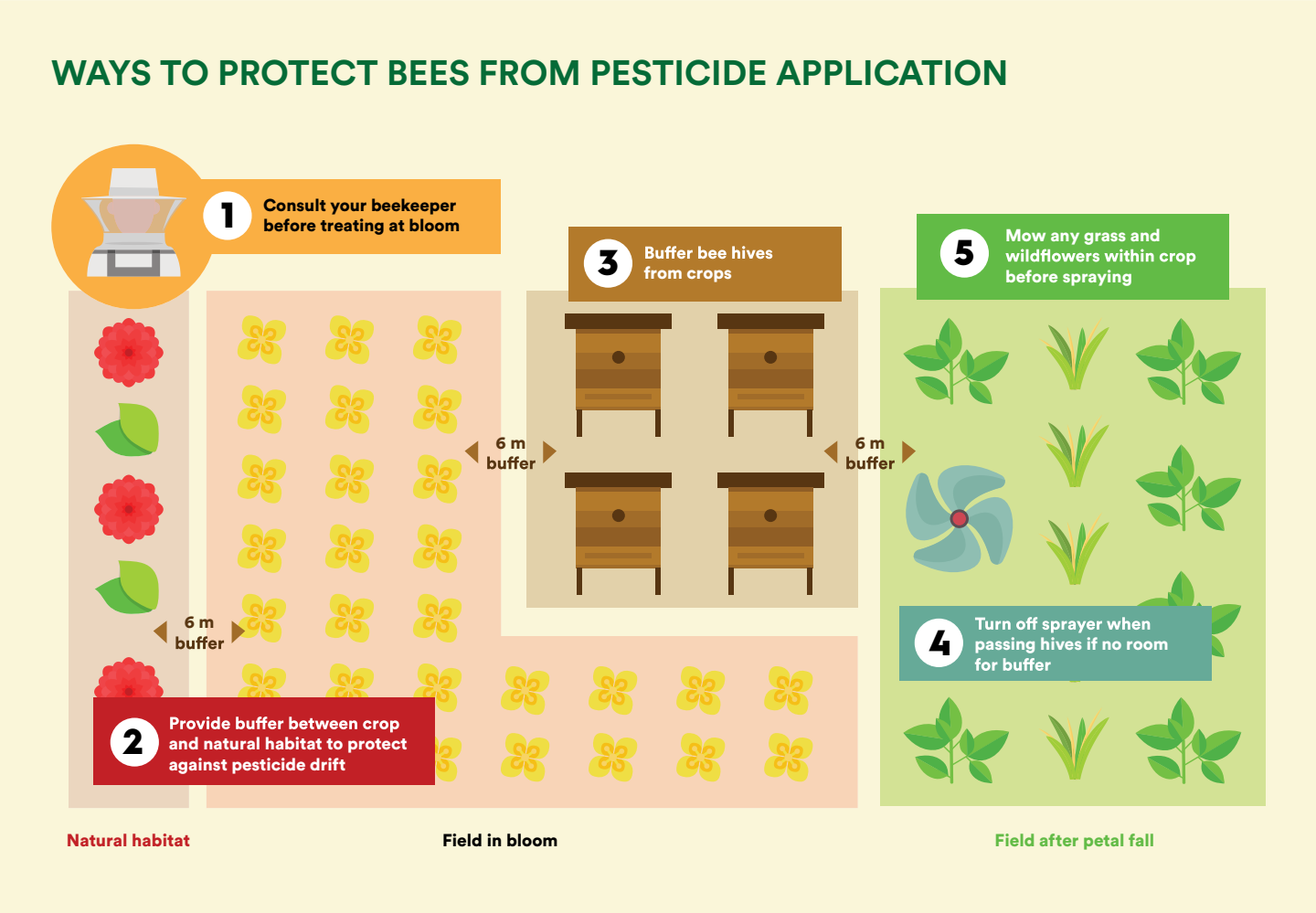
Insecticides are designed to kill insects and therefore present a higher risk to managed and wild bees than other pesticides. Insecticides are considered a major factor contributing to agricultural productivity, yet if they are used incorrectly, they can be toxic to humans and/or animals. If they are used repeatedly in the same location, some insecticides can accumulate in the environment[36]. Use of insecticides within an Integrated Pest Management framework (see page 12) and following label directions for application to canola will help minimize risk to bees and other beneficial insects.

SYNERGIES

Some products can have synergistic effects in the field, that is, they are more toxic in combination than individually. For example, the fungicides myclobutanil and propiconazole have each been found to synergize with some pyrethroids and neonicotinoids[48-52]. Follow label instructions.

Growers can compare the toxicity of pesticides by using the tables in the supplemental document to choose those that are least toxic to pollinators while still being effective against target pests. Use Supplemental Table 2: Pesticide Toxicity to help you choose the lowest risk products. However, it is also important to use pesticides with different modes of action to avoid developing chemical resistance in pest insects or pathogens. **This means that only using the lowest toxicity product may not always be recommended**. See page 36 for resources on mode of action.

Direct application of neonicotinoids to soil and chemigation in field crops are not permitted in Canada[36]. Because neonicotinoids are systemic, residues can travel from the point of application to other parts of the plant, including nectar and pollen where foraging bees can be exposed[37, 38]. In soil, neonicotinoid residues can persist for long periods of time[35].



Best management practices beekeepers and growers can use to reduce bee exposure to pesticides by creating buffers between treated fields, colonies, and bee forage areas. Diagram adapted from Iris Kormann, Oregon State University.

FOLLOW LABEL DIRECTIONS

Pesticide labels are legal documents. Product registration, toxicity testing, and product regulation are in place to protect honey bees and other pollinators from the negative effects of pesticides. **It is illegal to use a pesticide in any way other than for the purpose and in the manner stated on the label**. Properly following pesticide labels is important from an economic perspective for the canola grower, from a human health perspective for the user, by-standers, and consumers, as well as from an environmental perspective for bees and other beneficial insects. Applying too much of one pesticide, applying it repeatedly in the same place, or applying it outside of label use because of inattention to label details could cost the grower more money and could increase the risk of the product to visiting bees and humans.

For the most current information on label restrictions, use the PMRA online label search or download the PMRA pesticide label app.

The Environmental Precautions/Hazards section of the pesticide label contains information designed to protect bees.

- Review the entire label for precautionary and advisory statements such as “toxic to bees”.
- Crop-specific precautions may also be listed on the label.
- Although the bee precautions are mainly based on toxicity to honey bees, they are also relevant to other species of bees. Where differences in toxicity to other bee species are known, they are noted in Table 2 in the supplemental document.
- Residual toxicity to bees can vary greatly between insecticides. When using insecticides with extended residual toxicity, it is imperative that applicators carefully consider potential exposures to wild and managed bees and avoid applying insecticides to blooming plants (crops or weeds)[39, 40].
- More PMRA information on pollinator protection can be found at: www.canada.ca/pollinator

ROUTES OF PESTICIDE EXPOSURE TO BEES

Directly sprayed on or through contact with recently sprayed leaves and flowers

Consumption of contaminated pollen and nectar

Contact with contaminated nesting materials

Effects on larvae through contaminated nectar, pollen, and cell materials

Contact with contaminated soil

Ways bees can be exposed to pesticide contaminants. Diagram adapted from Iris Kormann, Oregon State University.

Mow wildflower areas adjacent to canola before applying pesticides that are toxic to bees.

Bee exposure to pesticides can occur when:

- Beekeepers and growers do not adequately communicate.
- Pesticides are applied when bees are actively foraging.
- Pesticides are applied to canola crops, weeds in the field or field margins during bloom, or to neighbouring fields.
- Pesticides drift onto blooming plants adjacent to the canola crop.
- Systemic insecticides (like neonicotinoids) are translocated into the nectar and pollen of crop and non-crop flowering plants because of their movement through soil and water.
- Bees collect insecticide-contaminated nesting materials, such as leaf pieces collected by leafcutting bees, or they are exposed to soil contaminated with pesticide residues as they build their ground nests.
- Honey bees collect insecticide-contaminated water in or near treated fields.
- Wild bees develop or overwinter in soil contaminated with pesticides.

REDUCING BEE EXPOSURE TO PESTICIDES

When using pesticides, in addition to following label directions and maintaining clear communications with beekeepers and other stakeholders (see pages 30-31), other ways of minimizing managed and wild bee exposure include:

- Ensuring that pesticide drift is minimized to reduce contact with adjacent habitat. Consider applying pesticides on low or no-wind days.
- Avoiding applying pesticides during warm evenings when honey bees are clustered on the outside of their hives.
- Avoiding applying pesticides (especially insecticides that have toxicity to bees) to any blooming flowers, even weeds; bees may be using these resources.
- Being aware that pesticides can be absorbed in soil, potentially impacting ground nesting bees or taken up by non-crop plants that bees forage on[41].
- Looking for bees on crops, (see wild bees page 9) and for ground and foliage nests of solitary bees like leafcutting bees, long-horned bees, sweat bees, and mining bees within fields. Protect nesting areas from any exposure to insecticides wherever possible.
- Remembering that some bees, including the important leaf-cutter bee and bumble bees, forage in the early morning.

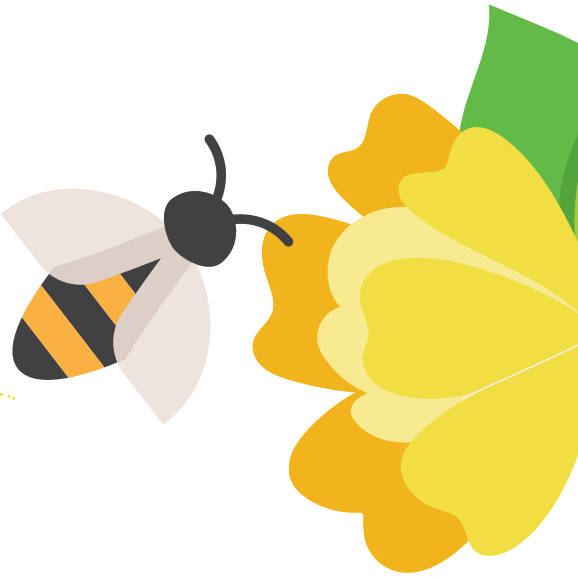
Notes may be found in Table 2 of the supplemental document if it is currently known that greater precautions are needed for bumble bees or solitary bees than for honey bees.

OTHER CONSIDERATIONS

Canada has a robust and comprehensive pesticide risk characterization protocol which informs pollinator precautions and use restrictions. These risk characterizations and label restrictions help prevent harm to bees. Tests are mainly conducted on honey bees which are generally a good proxy for testing oral and contact toxicity for all bees.

It is however recognized that other bees may be exposed in different ways than honey bees and toxicity may be different among types of bees; testing on other types of bees is being increasingly conducted and recommended[41, 42].

- Some products can interact in the field and increase toxicity synergistically[43-45]. These interactions are sometimes captured in label guidelines.
- Colonies may be exposed to one pesticide, moved to a new cropping system, and then exposed to a second pesticide. More research is needed to understand potential additive, synergistic, chronic, or delayed effects from repeated exposure.
- Reducing overall pesticide use through IPM can reduce chronic exposure.



3 ACTION GUIDE

Working together and in harmony with the land and one another works for people, pollinators and your plants! It pays in many ways to plan ahead by establishing IPM strategies, and keeping records of your observational, and seed/spray/growth documentation from previous years. Strongly recommended though not mandatory, writing and agreeing to a contract or plan usually helps everybody involved work together in a good way. Remember! Occasional check-ins with all parties are important and adaptations to agreements can always be evaluated and adjusted.

GROWERS AND PESTICIDE APPLICATORS

A relationship between beekeepers and farmers is based on **good communication, planning, dialogue, consistency, and timely responses**. Connect and plan for scenarios with one another ahead of time so there are protocols in place that are economical and efficient.

The most important takeaway when it comes to applying any pesticides is to notify any neighboring beekeepers, and that timing your application(s) is crucial (at night is usually when bees are inactive). Some products are safer than others for wild and managed bees, so always read the labels and check for toxicity information.

Though honey bees are not the only species of valuable pollinators on your land, consciously supporting the safety of this managed pollinator species will enhance the quality of life on your land for all pollinators!

COMMUNICATION

- Agree to a contract that defines expectations and responsibilities between beekeeper and grower, including protocol for suspected pesticide incidents involving pollinators. Though not necessary, a written contract is recommended as best practice for both parties to maintain fairness and safety of all parties involved.
- Establish a chain of communication between all parties, including crop consultants and applicators.
- Outline a pest management plan that specifies which products may be used during bloom and methods to protect bees during application.
- Give 48 hours notice to beekeepers when applications are necessary so that safety measures to protect the hives can be taken if needed.

HIVE LOCATION

When hosting hives on your property, it is important to provide a safe location that is out of the range of pesticide applications, including no-spray buffer zones. Planting perennial meadows, or sunflower barriers can double as a buffer zone and wild insect refuge/habitat. Allowing for less-managed land on hedgerows to be planted with native pollinator plants will help with natural weed suppression, as well as soil and water retention. Best Management Practices from the Canola Council of Canada[46] suggest allowing for a 50m buffer area around beehives to reduce exposure to pesticides through wind and drift. Many beekeepers prefer to situate hives where there is easier roadside access. Utilize this preference to integrate hedgerows and wild pollinator species habitat around those spaces, to help protect any hives that may be housed on or around your property.

BE AWARE!
There likely are more honey bee colonies than you are currently aware of in your area. Honey bees have a foraging range of a few kilometers. Check with your Regional and Provincial Ministry/Department of Agriculture for hives that might be located in your area and consider using the BeeConnected app.

PRODUCT SELECTION AND USE

Preferred timing for all crop spraying is after dusk, when bees are inactive. **Always notify beekeepers with a minimum of 48 hours, and remember to read the labels**. Some products are safer for bees and wild pollinators than others. Follow Best Management Practices (BMPs) for all pesticide applications. The Canola Council of Canada has their own canola-specific BMP guide for bees.

- Always read and follow pesticide label directions.
- Select pesticides that have the lowest pollinator precaution levels using the Table in the supplemental document.
- Be careful to only apply pesticides to target crops and avoid spray drift onto hives, other blooming crops, or flowering weeds nearby, whether or not the pesticide has a bee caution on the label. Since fine droplets tend to drift farther, apply spray at lower pressures or choose low-drift nozzles that produce medium to coarse droplet size. Turn off sprayers near water sources (ponds, irrigation ditches, or leaking irrigation pipes), when making turns, and at the ends of fields.
- Do not spray in windy conditions to minimize drift. Visit the Canola Council's Tips for Spraying in the Wind if necessary.
- Less drift occurs during ground application than aerial application. During aerial application, do not turn the aircraft or transport materials back and forth across hives, blooming fields, or water sources.
- Never spray crop products onto hives, including low toxicity products such as herbicides and fungicides.
- Apply pesticides with residual toxicity when bees are inactive or not present. Bees generally forage during daylight hours and when temperatures exceed 13°C for some wild bees and 17°C for honey bees. When abnormally high temperatures result in foraging activity earlier or later in the day than normal, adjust application times accordingly to avoid bee exposure.
- Inspect chemigation systems to verify that bees cannot access chemigation water.

PLANNING AND SCHEDULING

Plan your pesticide applications to occur well before or after blooming, if possible. Recognizing that certain pest species need control during canola flowering, it is vital that you avoid spraying during the middle of the day and plan to apply pesticides at night, when most pollinators are no longer foraging for food. Some products lose efficiency at higher daytime temperatures, so this is mutually beneficial. Best Management Practices include planning applications when hives are not on location or are placed in buffer zones, and at minimum, when managed and wild bees are not active on the crop.

Review Canola Council of Canada's video on PRE-HARVEST SCOUTING

- Learn when the bees in your farm are most active, as regional temperature variations can vary bee activity.
- Keep track of weather patterns, including wind, precipitation, humidity, and daily temperatures to avoid any unintentional pesticide drift to nearby bee foraging areas.

PEST AND WEED CONTROL

There will always be some weeds and unwanted pests present in your crop. Spraying preventatively is discouraged by the Canola Council of Canada, as it will kill beneficial insect species, and could inadvertently poison pollinators who reside in the soil or are using spring-flowering plants (such as dandelion and mustard) for nutrition. Utilizing a variety of trap methods to scout for problem insects can include things like sweep nets, pitfall traps, or a tent. Above all else, your eyes and experiential knowledge, including previous years' observations are the most valuable tools to determine economic thresholds for pest and weed control. Having an IPM strategy in place will reduce the need and frequency in which you apply products, saving you money and time. There are many resources to help you determine what pest or disease threshold makes it economically viable to invest in pesticide treatments.

During canolaPALOOZA 2017, Kevin Floate, an expert in Agriculture at Agri-Food Canada with a focus on pest monitoring education said that the most important element of pest monitoring is "your eyes. Eyes on the ground, on your knees in the field. Moving aside the soil [to look for things causing crop damage]."[47]

Key tips:

- Scout for pest insects often, and use economic thresholds for treatment decisions; you can learn and refer to the pests and beneficial insects and treatment thresholds yourself (visit the Canola Council's resource on Scouting for Flea Beetles in Canola), or hire an Integrated Pest Management consultant that will help save you valuable resources of time and money by reducing unnecessary pesticide application.
- If necessary, control blooming weeds such as dandelions within fields before applying insecticides that have a long residual toxicity to bees. This is especially important in early spring when bees will fly several kilometers to obtain pollen and nectar from even a few blooms of dandelions or wild mustard.

Focusing your efforts on controlling weeds during the 2-4 leaf stage is most valuable. Canola plants are extremely competitive against weeds once the plants grow tall enough to form a canopy.

CONSIDERATIONS

- Consider non-chemical pest control, such as beneficial insects and other cultural practices, for long-term control of insect pests. Details of integrated pest management (IPM) practices can be found at https://ipmcouncilcanada.org, https://fieldheroes.ca/ and http://www.agr.gc.ca/eng/?id=1288805416537
- Explore programs such as Operation Pollinator or Bees Matter that support planting habitat areas on your farm for honey bees, other pollinators, and other beneficial insects, or build your own bee habitat using Pollinator Partnership's Ecoregional Planting Guides or the Canadian Honey Bee Forage Guide.

BEEKEEPERS

COMMUNICATION AND REGISTRATION

- Write and agree to a contract that defines expectations and responsibilities between beekeeper and grower, including protocol for suspected pesticide incidents involving pollinators. See page 15 for caveats.
- Do not leave unmarked colonies near fields. Post the beekeeper's name, address, and phone number on apiaries, large enough to be read at a distance.
- Register your colonies with your Provincial Ministry/Department of Agriculture. You can notify pesticide applicators of the location of your apiaries using the BeeConnected app. Encourage others to also use the app.
- Communicate clearly to the grower and/or applicator where your colonies are located, when they will arrive, and when you will remove them.
- Ask the grower what pesticides, if any, will be applied while bees are in the field, when they will be applied, and whether the label includes precautionary statements for bees. Ask them to contact you if they decide on any new applications.
- Request 48 hours' notice from growers when applications are necessary so that safety measures to protect the hives can be taken.

PEST MANAGEMENT

- Learn about the major pest problems in canola, and associated management programs to develop mutually beneficial agreements with growers concerning pollination services and prudent use of insecticides. Seek information on major crop pests and treatment options for your region (see resource section for provincial links).
- Miticides, such as those used in hives for varroa control, are pesticides too. Use care when managing pests in and around bee hives, apiaries, and beekeeping storage facilities. Use pesticides for their intended use and follow all label directions carefully. Regularly replace brood comb to reduce exposure to residual miticides.

PROTECTING HONEY BEES FROM EXPOSURE

- Work with growers to find a location for beehives that is at least 6 m away from the crop, including no-spray buffers.
- Do not return colonies to fields treated with insecticides that are highly toxic to bees until at least 48 to 72 hours after application. Bee deaths are most likely to occur during the first 24 hours following application.
- If practical, isolate apiaries from intensive insecticide applications and protect them from chemical drift. Establish holding yards at least 4 km from crops so that honey bee colonies can be moved to those yards when crops are being treated with insecticides that are highly toxic to bees.
- Place colonies on ridge tops rather than in depressions. Insecticides drift down into low-lying areas and flow with morning wind currents. Inversion conditions are particularly hazardous.
- Verify that a clean source of water is available for bees, and if there is not one available, provide one.
- Feed bees when nectar is scarce to prevent long-distance foraging to treated crops. This is especially important when stocking bee colonies for the fall. Evidence suggests that proper stocking can lead to lower colony losses in subsequent years.
- In pesticide risk-prone areas, inspect bees often to recognize problems early.

RESOURCES

RECOGNIZING AND REPORTING BEE POISONING

Because of guidelines and regulation on product use, large-scale honey bee deaths are uncommon in developed countries, especially in recent years. Nevertheless, incidents where large quantities of bees are killed by pesticides do occur and suggest a misuse of a product, system, or management protocol, or a possible result of a lack of communication.

Bee poisonings can be either lethal or sublethal. An example of lethal poisoning is when pesticide drift comes into direct contact with foraging honey bees, leading to large numbers of dead workers within or around the crop, or outside the hive entrance. In contrast, sublethal exposure does not kill bees outright but rather can lead to poor bee and hive health; reduced capacity to forage, orient, and learn; and many other symptoms. Lethal and sublethal poisonings are harder to casually observe in wild bees than in managed honey bees but are nevertheless a risk. Without a marked hive or nesting site, they can easily go unobserved. Known sublethal impacts on wild bees include reduced longevity, development, body mass, learning, colony size, reproduction, navigation, and increased susceptibility to pests and pathogens.

If you see more than one dead bumble bee in a location, this may be an indication that there has been lethal exposure to a toxic substance. The signs and symptoms listed below can be the result of pesticide exposure, but some can also be a result of viruses or other diseases. Careful observation of individual honey bee and colony behaviour, as well as preserving samples for testing (see instructions on page 39), can help determine the underlying causes. In some cases, pesticide poisoning can be exacerbated when hive health is initially poor, emphasizing the importance of nutrition, water supply, and proper management practices by beekeepers to maintain the health of their colonies and native bees.

IDENTIFYING HONEY BEE POISONING

- Excessive numbers of dead and dying honey bees in front of hives.
- Severe colony imbalance, large brood size with few bees.
- Lack of foraging bees on normally attractive blooming crops.
- Stupefaction, paralysis, and abnormal jerky, wobbly, or rapid movements; spinning on the back.
- Forager disorientation and reduced foraging efficiency.
- Immobile, lethargic bees unable to leave flowers.
- Regurgitation of honey stomach contents and tongue extension.
- The appearance of “crawlers” (bees unable to fly). Bees move slowly as though they have been chilled.
- Dead brood, dead newly emerged workers, or abnormal queen behaviour, such as egg laying in a poor pattern.
- Queenless hives.
- Poor queen development in colonies used to produce queens, with adult worker bees unaffected.

HONEY BEE RECOVERY FROM PESTICIDE POISONING

If a honey bee colony has lost many of its foragers but has sufficient brood and adequate stores of uncontaminated pollen and honey, it may recover without any intervention. Best practices include moving bees to a pesticide-free foraging area, if possible. If sufficient forage is unavailable, feed them with sugar syrup and pollen substitute, and provide clean water to aid their recovery. Protect them from extremes of heat and cold, and if needed combine weak colonies.

If pollen or nectar stores are contaminated, brood and workers may continue to die until the colony is lost. Additionally, pesticides applied by beekeepers can accumulate in colonies. If there is a possibility that pesticides have transferred into the hive beeswax, consider replacing the comb with a new foundation, using comb from unaffected colonies, or shaking the bees into a new hive and destroying the old comb and woodenware. Replacing brood comb on a regular schedule (typically 2 to 5 years) may prevent pesticide accumulation in brood comb wax and is also good practice for managing disease accumulation in comb.

PESTICIDE POISONING IS NOT ALWAYS OBVIOUS AND MAY BE CONFUSED WITH OTHER FACTORS:

- Delayed and chronic effects, such as poor brood development, are difficult to link to specific agrochemicals, but are possible when stored pollen, nectar, or wax comb become contaminated with pesticides. Severely weakened or queenless colonies may not survive the winter.
- Poisonous plants, such as death camas (*Zigadenus venenosus*), corn-lily (*Veratrum viride*), and spotted locoweed (*Astragalus lentiginosus*), can injure and occasionally kill bee colonies.
- Viral paralysis disease, starvation, winter kill, and chilled brood can cause symptoms that may be confused with bee poisoning. Beekeepers may request a laboratory analysis of dead bees to determine the cause of an incident. Health Canada and provincial Departments of Agriculture or of the Environment (depending on the province) investigate suspected bee poisoning incidents (see page 40 for contact information).

REPORT A BEE INCIDENT TO HEALTH CANADA

Bee incidents can also be reported by contacting Health Canada's PMRA at 1-800-267-6315. If you know which product may have caused the bee poisoning, you can also notify the pesticide company, which is required by law to report adverse effects to Health Canada. See the Useful Links section below (page 41) for a link to report a bee incident to Health Canada.

HOW TO REPORT A SUSPECTED BEE POISONING

If you suspect a bee poisoning incident, or have a question or concern regarding an incident, contact the appropriate federal or provincial authority (see contact information on page 40). Describe why you suspect the bees may have been exposed. Provide photos or videos of the incident, list pesticide treatments you have applied to the hives and any notes describing the previous health of the colony, prevailing winds, registrant name on the product label, product name, or active ingredients (from the pesticide label or PMRA's pesticide label search app), including any other pertinent details. Growers and beekeepers should work together to compile this information.

Preserve at least 56 grams (1/4 cup) of adult bees, brood, pollen, honey/nectar, or wax by immediately freezing in clearly labelled, clean containers. Ensure the samples stay dry and protected from light, which can lead to the degradation of pesticides. This may be helpful if the incident is later determined to warrant laboratory analysis. It is also a good idea to have a sample of the affected bees as well as a sample from an unaffected apiary. In the event of enforcement action, some provinces will need to collect their own samples. Do not disturb the hives or site until the representative from your province's lead office has finished collecting information.

It also is important that, if you suspect a bee poisoning incident, you communicate with nearby growers and/or beekeepers, and act quickly so that the cause can be determined and prevented in the future.

PROVINCIAL RULES AND RESOURCES TO PROTECT POLLINATORS

The federal government is responsible for the registration of pest control products, and all three levels of government (federal, provincial/territorial, and municipal) play a role in regulating their sale and use. Ministries of certain provinces provide rules intended to reduce the hazard of pesticide applications to bees, as well as guidance on bee management.

ALBERTA (MINISTRY OF AGRICULTURE AND RURAL DEVELOPMENT)

https://open.alberta.ca/publications/how-to-reduce-bee-poisonings-from-pesticides

780-415-2314

BRITISH COLUMBIA (MINISTRY OF AGRICULTURE)

https://www2.gov.bc.ca/gov/content/industry/agriculture-seafood/animals-and-crops/animal-production/bees/beekeeping-bulletins

604-556-3129

MANITOBA (MINISTRY OF AGRICULTURE)

https://web2.gov.mb.ca/laws/statutes/ccsm/b015.php?lang=en

604-556-3129

NEW BRUNSWICK (DEPARTMENT OF AGRICULTURE, AQUACULTURE AND FISHERIES)

https://www2.gnb.ca/content/gnb/en/departments/10/agriculture/content/bees.html

506-453-2108

NEWFOUNDLAND AND LABRADOR (DEPARTMENT OF NATURAL RESOURCES)

http://www.nlbeekeeping.ca/beekeepers-corner/research/

709-637-2662

NOVA SCOTIA (DEPARTMENT OF AGRICULTURE)

https://novascotia.ca/agri/programs-and-services/farm-animal-welfare/

902-679-8998

ONTARIO (ONTARIO MINISTRY OF FOOD AND RURAL AFFAIRS)

http://www.omafra.gov.on.ca/english/food/inspection/bees/apicultu.html

1-877-424-1300

SASKATCHEWAN (MINISTRY OF AGRICULTURE)

http://www.agriculture.gov.sk.ca/

306-953-2304

PRINCE EDWARD ISLAND (DEPARTMENT OF AGRICULTURE AND FORESTRY)

https://www.princeedwardisland.ca/sites/default/files/legislation/A%2611-1-2-Animal%20Health%20and%20Protection%20Act%20Bee%20Health%20Regulations.pdf

902-314-0816

QUÉBEC (MINISTÈRE DE L'AGRICULTURE, DES PÊCHERIES ET DE L'ALIMENTATION)

http://legisquebec.gouv.qc.ca/en/ShowDoc/cs/A-1

(1-844-264-6289) 1-844-ANIMAUX

REPORT A BEE INCIDENT TO HEALTH CANADA

Bee incidents can also be reported by contacting Health Canada's PMRA at 1-800-267-6315. If you know which product may have caused the bee poisoning, you can also notify the pesticide company, which is required by law to report adverse effects to Health Canada. See the Useful Links section below (page 41) for a link to report a bee incident to Health Canada.

USEFUL LINKS

CANOLA COUNCIL OF CANADA (CCC) BEE BEST MANAGEMENT STRATEGIES

https://www.canolacouncil.org/canola-watch/2014/07/03/bee-bmps/

HONEY BEE HEALTH COALITION BEE BEST MANAGEMENT PRACTICES

https://honeybeehealthcoalition.org/resources/canola-best-management practices/

PRAIRIE PEST MONITORING NETWORK

https://prairiepest.ca/

SASKATCHEWAN CANOLA DEVELOPMENT COMMISSION (SASKCANOLA)

https://www.saskcanola.com/

CANOLA DIGEST (UP-TO-DATE NEWS ON CANOLA DEVELOPMENTS)

https://canoladigest.ca/

BEECONNECTED APP FOR FARMERS

http://www.beeconnected.ca/

CCC PRE-HARVEST PEST SCOUTING

https://www.youtube.com/watch?v=meacgEo9fVI

MANAGEMENT OF PESTICIDE AND SPRAY DRIFT

https://www.canada.ca/en/health-canada/services/consumer-product-safety/pesticides-pest-management/growers-commercial-users/drift-mitigation/management-pesticide-spray-drift.html

iNATURALIST APP

https://www.inaturalist.org/

INSECTICIDE RESISTANCE ACTION COMMITTEE: THE IRAC MODE OF ACTION CLASSIFICATION

https://irac-online.org/mode-of-action/

HEALTH CANADA'S PEST MANAGEMENT RESGULATORY AGENCY (PMRA) PESTICIDE LABEL SEARCH

https://escrop.com/factsheets/

POLLINATOR PARTNERSHIP CANADA: POLLINATOR GUIDES

https://pollinatorpartnership.ca/en/ecoregional-planting-guides

REPORT A BEE INCIDENT TO HEALTH CANADA

https://www.canada.ca/en/health-canada/services/consumerproduct-safety/pesticides-pest-management/public/protecting-yourhealth-environment/report-pesticide-incident.html

POLLINATOR PARTNERSHIP: TECHNICAL GUIDE FOR PRESERVING AND CREATING HABITAT FOR POLLINATORS ON ONTARIO'S FARMS

https://pollinatorpartnership.ca/en/ecoregional-planting-guides

REFERENCES

1. Casséus, L. (2009, April 9). Canola: a Canadian success story. Canadian Agriculture at a Glance, No. 96-325-X200700010778. Statistics Canada. https://www150.statcan.gc.ca/n1/pub/96-325-x/2007000/article/10778-eng.htm
2. Canola Council of Canada. (2022, February 11). Canola production statistics. The Canola Council of Canada. https://www.canolacouncil.org/markets-stats/production/
3. Pines, L. (2022, February 11). Canola: Versatile Cooking Oil, but Does That Make It Valuable? History, Production, and Price Drivers. Commodity.Com. https://commodity.com/soft-agricultural/canola/
4. Canola Council of Canada. (2022, February 11).Markets & Statistics: Canola industry: at a glance. The Canola Council of Canada. https://www.canolacouncil.org/markets-stats/
5. Canola Council of Canada. (n.d.) Industry Overview: Grown on Canadian farms, consumed around the world. The Canola Council of Canada. https://www.canolacouncil.org/about-canola/industry/
6. Robinson, S. V. J. (2019). Central-place foraging, crop yield, and population change in bees: A study in canola agroecosystems (Unpublished doctoral thesis]. University of Calgary, Calgary, AB. https://doi.org/10.11575/PRISM/37186
7. U.S. Canola Association. (2019, March 1). Best Management Practises (BMPS) for pollinator protection in canola fields. Honey Bee Health Coalition. https://honeybeehealthcoalition.org/wp-content/uploads/2019/03/HBHC_Canola_030119.pdf
8. Adamidis, G. C., Cartar, R. V., Melathopoulos, A. P., Pernal, S. F., & Hoover, S. E. (2019). Pollinators enhance crop yield and shorten the growing season by modulating plant functional characteristics: A comparison of 23 canola varieties. Scientific Reports, 9(14208). https://doi.org/10.1038/s41598-019-50811-y
9. Bommarco, R., Marini, L., & Vaissière, B. E. (2012). Insect pollination enhances seed yield, quality, and market value in oilseed rape. Oecologia, 169(4), 1025–1032. https://doi.org/10.1007/s00442-012-2271-6
10. Sabbahi, R., DeOliveira, D., & Marceau, J. (2005). Influence of honey bee (Hymenoptera: Apidae) density on the production of canola (Crucifera: Brassicacae). Journal of Economic Entomology, 98(2), 367–372. https://doi.org/10.1093/jee/98.2.367
11. Morandin, L. A., & Winston, M. L. (2005). Wild bee abundance and seed production in conventional, organic, and genetically modified canola. Ecological Applications, 15(3), 871–881. https://doi.org/10.1890/03-5271
12. Clay, H. (2009, August). Pollinating hybrid canola: the southern Alberta experience. Hivelights, 22, 14-16. https://www.honeycouncil.ca/documents/CanolaSthAB2009.pdf
13. Sekulic, G., & Rempel, C. B. (2016). Evaluating the role of seed treatments in canola/oilseed rape production: integrated pest management, pollinator health, and biodiversity. Plants, 5(3), 32. https://doi.org/10.3390/plants5030032
14. Furtas, R. (2022, August 15). 2022 Alberta canola seed costs. Government of Alberta. https://www.alberta.ca/agri-news-2022-alberta-canola-seed-costs.aspx
15. Button, L., & Elle, E. (2014). Wild bumble bees reduce pollination deficits in a crop mostly visited by managed honey bees. Agriculture, Ecosystems & Environment, 197, 255–263. https://doi.org/10.1016/j.agee.2014.08.004
16. Winfree, R., Williams, N. M., Dushoff, J., & Kremen, C. (2007). Native bees provide insurance against ongoing honey bee losses. Ecology Letters, 10(11), 1105–1113. https://doi.org/10.1111/j.1461-0248.2007.01110.x
17. Garibaldi, L. A., Carvalheiro, L. G., Leonhardt, S. D., Aizen, M. A., Blaauw, B. R., Isaacs, R., Kuhlmann, M., Kleijn, D., Klein, A. M., Kremen, C., Morandin, L., Scheper, J., & Winfree, R. (2014). From research to action: Enhancing crop yield through wild pollinators. Frontiers in Ecology and the Environment, 12(8), 439–447. https://doi.org/10.1890/130330
18. Hoehn, P., Tscharntke, T., Tylianakis, J. M., & Steffan-Dewenter, I. (2008). Functional group diversity of bee pollinators increases crop yield. Proceedings of the Royal Society B: Biological Sciences, 275(1648), 2283–2291. https://doi.org/10.1098/rspb.2008.0405
19. Mazzei, M. P., Vesprini, J. L., & Galetto, L. (2021). Seminatural habitats and their proximity to the crop enhances canola (Brassica napus) pollination and reproductive parameters in Argentina. Crop Science, 61(4), 2713–2721. https://doi.org/10.1002/csc2.20450
20. Morandin, L. A., & Winston, M. L. (2006). Pollinators provide economic incentive to preserve natural land in agroecosystems. Agriculture, Ecosystems & Environment, 116(3-4), 289-292. https://doi.org/10.1016/j.agee.2006.02.012
21. Albrecht, M., Kleijn, D., Williams, N. M., Tschumi, M., Blaauw, B. R., Bommarco, R., Campbell, A. J., Dainese, M., Drummond, F. A., Entling, M. H., Ganser, D., Arjen de Groot, G., Goulson, D., Grab, H., Hamilton, H., Herzog, F., Isaacs, R., Jacot, K., Jeanneret, P., … Sutter, L. (2020). The effectiveness of flower strips and hedgerows on pest control, pollination services and crop yield: A quantitative synthesis. Ecology Letters, 23(10), 1488–1498. https://doi.org/10.1111/ele.13576
22. Kremen, C., Williams, N. M., Bugg, R. L., Fay, J. P., & Thorp, R. W. (2004). The area requirements of an ecosystem service: crop pollination by native bee communities in California. Ecology Letters, 7(11), 1109–1119. https://doi.org/10.1111/j.1461-0248.2004.00662.x
23. Kremen, C., Williams, N. M., & Thorp, R. W. (2002). Crop pollination from native bees at risk from agricultural intensification. Proceedings of the National Academy of Sciences, 99(26), 16812–16816. https://doi.org/10.1073/pnas.262413599
24. Morandin, L. A., & Kremen, C. (2013). Hedgerow restoration promotes pollinator populations and exports native bees to adjacent fields. Ecological Applications, 23(4), 829–839. https://doi.org/10.1890/12-1051.1
25. Morandin, L. A., Long, R. F., & Kremen, C. (2016). Pest control and pollination cost–benefit analysis of hedgerow restoration in a simplified agricultural landscape. Journal of Economic Entomology, 109(3), 1020–1027. https://doi.org/10.1093/jee/tow086
26. Narduzzi, D. (2016, January 27). You should reconsider before seeding back-to-back to canola ('Canola and snow' is not profitable). Grainews. https://www.grainews.ca/features/canola-and-snow-is-not-profitable/
27. Klein, A-M., Vaissière, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., & Tscharntke, T. (2006). Importance of pollinators in changing landscapes for world crops. Proceedings of the Royal Society B: Biological Sciences, 274(1608), 303–313. https://doi.org/10.1098/rspb.2006.3721
28. Rader, R., Bartomeus, I., Garibaldi, L. A., Garratt, M. P. D., Howlett, B. G., Winfree, R., Cunningham, S. A., Mayfield, M. M., Arthur, A. D., Andersson, G. K. S., Bommarco, R., Brittain, C., Carvalheiro, L. G., Chacoff, N. P., Entling, M. H., Foully, B., Freitas, B. M., Gemmill-Herren, B., Ghazoul, J., … Woyciechowski, M. (2016). Non-bee insects are important contributors to global crop pollination. Proceedings of the National Academy of Sciences, 113(1), 146–151. https://doi.org/10.1073/pnas.1517092112
29. Statewide Integrated Pest Management Program. (2020). What Is Integrated Pest Management (IPM)? University of California Agriculture and Natural Resources. Retrieved February 26, 2021 https://www2.ipm.ucanr.edu/What-is-IPM/
30. Blitzer, E. J., Dormann, C. F., Holzschuh, A., Klein, A.-M., Rand, T. A., & Tscharntke, T. (2012). Spillover of functionally important organisms between managed and natural habitats. Agriculture, Ecosystems & Environment, 146(1), 34–43. https://doi.org/10.1016/j.agee.2011.09.005

31. Williams, N. M., Ward, K. L., Pope, N., Isaacs, R., Wilson, J., May, E. A., Ellis, J., Daniels, J., Pence, A., Ullmann, K., & Peters, J. (2015). Native wildflower plantings support wild bee abundance and diversity in agricultural landscapes across the United States. Ecological Applications, 25(8), 2119–2131. https://doi.org/10.1890/14-1748.1
32. Blaauw, B. R., & Isaacs, R. (2014). Flower plantings increase wild bee abundance and the pollination services provided to a pollination-dependent crop. Journal of Applied Ecology, 51(4), 890–898. https://doi.org/10.1111/1365-2664.12257
33. Park, M. G., Blitzer, E. J., Gibbs, J., Losey, J. E., & Danforth, B. N. (2015). Negative effects of pesticides on wild bee communities can be buffered by landscape context. Proceedings of the Royal Society B: Biological Sciences, 282(1809), 20150299. https://doi.org/10.1098/rspb.2015.0299
34. Desneux, N., Decourtye, A., & Delpuech, J-M. (2007). The sublethal effects of pesticides on beneficial arthropods. Annual Review of Entomology, 52(1), 81–106. https://doi.org/10.1146/annurev.ento.52.110405.091440
35. Bonmatin, J-M., Giorio, C., Girolami, V., Goulson, D., Kreutzweiser, D. P., Krupke, C., Liess, M., Long, E., Marzaro, M., Mitchell, E. A. D., Noome, D. A., Simon-Delso, N., & Tapparo, A. (2015). Environmental fate and exposure; neonicotinoids and fipronil. Environmental Science and Pollution Research, 22(1), 35–67. https://doi.org/10.1007/s11356-014-3332-7
36. Pest Management Regulatory Agency (2021, June 29). Proposed special review decision PSRD 2021-02, Special Reviews: Potential environmental risk related to squash bee (Peponapis pruinosa) exposure to Clothianidin, Thiamethoxam and Imidacloprid used on cucurbits. Government of Canada. ISSN: 2561-636 https://www.canada.ca/en/health-canada/services/consumer-product-safety/pesticides-pest-management/public/consultations/proposed-special-review-decision/2021/environmental-risk-related-to-squash-bee/document.html
37. Dively, G. P., & Kamel, A. (2012). Insecticide residues in pollen and nectar of a cucurbit crop and their potential exposure to pollinators. Journal of Agricultural and Food Chemistry, 60(18), 4449–4456. https://doi.org/10.1021/jf205393x
38. Stoner, K. A., & Eitzer, B. D. (2012). Movement of soil-applied Imidacloprid and Thiamethoxam into nectar and pollen of squash (Cucurbita pepo). PLOS ONE, 7(6), e39114. https://doi.org/10.1371/journal.pone.0039114
39. Botías, C., David, A., Horwood, J., Abdul-Sada, A., Nicholls, E., Hill, E., & Goulson, D. (2015). Neonicotinoid residues in wildflowers, a potential route of chronic exposure for bees. Environmental Science & Technology, 49(21), 12731–12740. https://doi.org/10.1021/acs.est.5b03459
40. David, A., Botías, C., Abdul-Sada, A., Nicholls, E., Rotheray, E. L., Hill, E. M., & Goulson, D. (2016). Widespread contamination of wildflower and bee-collected pollen with complex mixtures of neonicotinoids and fungicides commonly applied to crops. Environment International, 88, 169–178. https://doi.org/10.1016/j.envint.2015.12.011
41. Boyle, N. K., Pitts-Singer, T. L., Abbott, J., Alix, A., Cox-Foster, D. L., Hinarejos, S., Lehmann, D. M., Morandin, L., O'Neill, B., Raine, N. E., Singh, R., Thompson, H. M., Williams, N. M., & Steeger, T. (2019). Workshop on pesticide exposure assessment paradigm for non-Apis bees: foundation and summaries. Environmental Entomology, 48(1), 4–11. https://doi.org/10.1093/ee/nvy103
42. Cresswell, J., & Goulson, D. (2015). In response: current evidence and implications--an academic perspective. Environmental Toxicology and Chemistry, 34(7), 1454–1456. https://doi.org/10.1002/etc.2987
43. Iverson, A., Hale, C., Richardson, L., Miller, O., & McArt, S. (2019). Synergistic effects of three sterol biosynthesis inhibiting fungicides on the toxicity of a pyrethroid and neonicotinoid insecticide to bumble bees. Apidologie, 50, 733–744. https://doi.org/10.1007/s13592-019-00681-0
44. Thompson, H. M., Fryday, S. L., Harkin, S., & Milner, S. (2014). Potential impacts of synergism in honeybees (Apis mellifera) of exposure to neonicotinoids and sprayed fungicides in crops. Apidologie, 45, 545–553. https://doi.org/10.1007/s13592-014-0273-6
45. Wade, A., Lin, C-H., Kurkul, C., Regan, E. R., & Johnson, R. M. (2019). Combined toxicity of insecticides and fungicides applied to California almond orchards to honey bee larvae and adults. Insects, 10(1), 20. https://doi.org/10.3390/insects10010020
46. Canola Council of Canada. (2014, July 3). Bee BMPs. The Canola Council of Canada. https://www.canolacouncil.org/canola-watch/2014/07/03/bee-bmps/
47. Floate, K. [albertacanola]. (2017, August 14). canolaPALOOZA 2017 – Lacombe, Alberta. [Video]. YouTube. https://www.youtube.com/watch?v=3b-KF0Dr8Tzw&t=42s
48. Vickruck, J. L., Best, L. R., Gavin, M. P., Devries, J. H., & Galpern, P. (2019). Pothole wetlands provide reservoir habitat for native bees in prairie croplands. Biological Conservation, 232, 43–50. https://doi.org/10.1016/j.biocon.2019.01.015
49. May, E., Isaacs, R., Ullmann, K., Wilson, J., Brokaw, J., Foltz Jordan, S., Gibbs, J., Hopwood, J., Rothwell, N., Vaughan, M., Ward, K., & Williams, N. (2017). Establishing wildflower habitat to support pollinators in Michigan fruit crops. Michigan State University Extension Bulletin E-3360: 1–18. https://www.canr.msu.edu/uploads/resources/pdfs/establishing_wildflower_habitat_to_support_pollinators_of_michigan_fruit_crops_-_e3360.pdf
50. Desneux, N., Decourtye, A., & Delpuech, J.-M. (2007). The sublethal effects of pesticides on beneficial arthropods. Annual Review of Entomology, 52, 81–106. https://www.annualreviews.org/doi/10.1146/annurev.ento.52.110405.091440
51. Bonmatin, J. -M., Giorio, C., Girolami, V., Goulson, D., Kreutzweiser, D. P., Krupke, C., Liess, M., Long, E., Marzaro, M., Mitchell, E. A., Noome, D. A., Simon-Delso, N., & Tapparo, A. (2015). Environmental fate and exposure; neonicotinoids and fipronil. Environmental Science and Pollution Research International, 22, 35–67. https://doi.org/10.1007/s11356-014-3332-7
52. Carneiro, L. S., Martínez, L. C., Gonçalves, W. G., Santana, L. M., & Serrão, J. E. (2020). The fungicide iprodione affects midgut cells of non-target honey bee Apis mellifera workers. Ecotoxicology and Environmental Safety, 189, 109991. https://doi.org/10.1016/j.ecoenv.2019.109991
53. Iverson, A., Hale, C., Richardson, L., Miller, O., & McArt., S. (2019). Synergistic effects of three sterol biosynthesis inhibiting fungicides on the toxicity of a pyrethroid and neonicotinoid insecticide to bumble bees. Apidologie, 50, 733–744. https://doi.org/10.1007/s13592-019-00681-0
54. Helmers, M. J., Eisenhauer, D. E., Dosskey, M. G., Franti, T. G., Brothers, J. M., & McCullough, M. C. (2005). Flow pathways and sediment trapping in a field-scale vegetative filter. Transactions of the ASAE, 48(3), 955-968. doi: 10.13031/2013.18508
55. Dass, P., Houlton, B. Z., Wang, Y., & Warlind, D. (2018). Grasslands may be more reliable carbon sinks than forests in California. Environmental Research Letters, 13(7), 074027. doi: 10.1088/1748-9326/aacb39
56. Wade, A., Lin, C. H., Kurkul, C., Regan, E. R., & Johnson, R. M. (2019). Combined toxicity of insecticides and fungicides applied to California almond orchards to honey bee larvae and adults. Insects 10, 20. https://doi.org/10.3390/insects10010020
57. Thompson, H. M., Fryday, S. L., Harkin, S., & Milner, S. (2014). Potential impacts of synergism in honeybees (Apis mellifera) of exposure to neonicotinoids and sprayed fungicides in crops. Apidologie 45, 545–553. https://doi.org/10.1007/s13592-014-0273-6

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