BEES AND BERRIES

Photo by Rufus Isaacs

Photo by Salena Helmreich

Blossoming Success:

BEST PRACTICES FOR NORTHERN HIGHBUSH BLUEBERRY POLLINATION

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Objective

This document describes northern highbush blueberry (*Vaccinium corymbosum;* hereafter referred to as "blueberry") pollination and factors that promote pollination success in open-field and protected culture (i.e., greenhouses, polytunnels, etc.). We will review how managed and wild pollinators contribute to pollination and how to aid their activity and health. Attention will also be given to future outlooks on pollination technologies and decision-support tools.

Defining pollination

Pollination is the movement of pollen between the reproductive parts of a flowering plant, which results in fertilization, production of seeds, and fruit development. In pollination-dependent crops, this pollen movement is facilitated by insects, mainly bees. In blueberry, insect visitation to flowers increases fruit set, berry size, and marketability. Bees, both managed and wild, are well known pollinators of blueberry; however flies and birds may also be minor contributors to the overall pollination success of blueberry. Most blueberry growers bring in managed hives of Western honey bees (*Apis mellifera*) to promote successful crop pollination. Some growers choose to supplement their honey bee pollination with other commercially available bumble bees (*Bombus* spp.), mason bees (*Osmia* spp.), or leafcutter bees (*Megachile* spp.). They may also promote wild bee populations locally in the landscape for increased pollination services.

Integrated Crop Pollination

Integrated crop pollination (ICP) is when multiple kinds of bees and management strategies are considered together to achieve consistent pollination through the entire bloom period (Isaacs et al., 2017; DeVetter et al. 2022). The pillars of ICP include the use of managed pollinator species, pesticide stewardship, habitat enhancement, and horticultural practices. This document is structured around the pillars of ICP and highlights factors that promote pollination and identifies where knowledge gaps remain (Figure 1). However, an understanding of blueberry pollination requirements and flowering biology is necessary before delving into the pillars of ICP.

Globally, the supply of honey bee colonies has not kept up with the increased demand for pollination services in flowering crops over the past several decades (Breeze et al., 2014). Anecdotal reports also suggest honey bees are at a higher risk of diseases such as European Foulbrood (*Melissococcus plutonius*) after foraging in blueberry fields. There is heavy reliance on rented honey bee colonies for blueberry pollination. The hive density is often set at a certain number of hives per acre and is not adjusted for how much pollination is coming from wild bees, the flower density, the pollination needs of varying cultivars, the trends in climate, and pest management problems encountered on the farm. As a consequence, growers may not be utilizing their pollination resources efficiently if these other factors are not being considered and addressed.

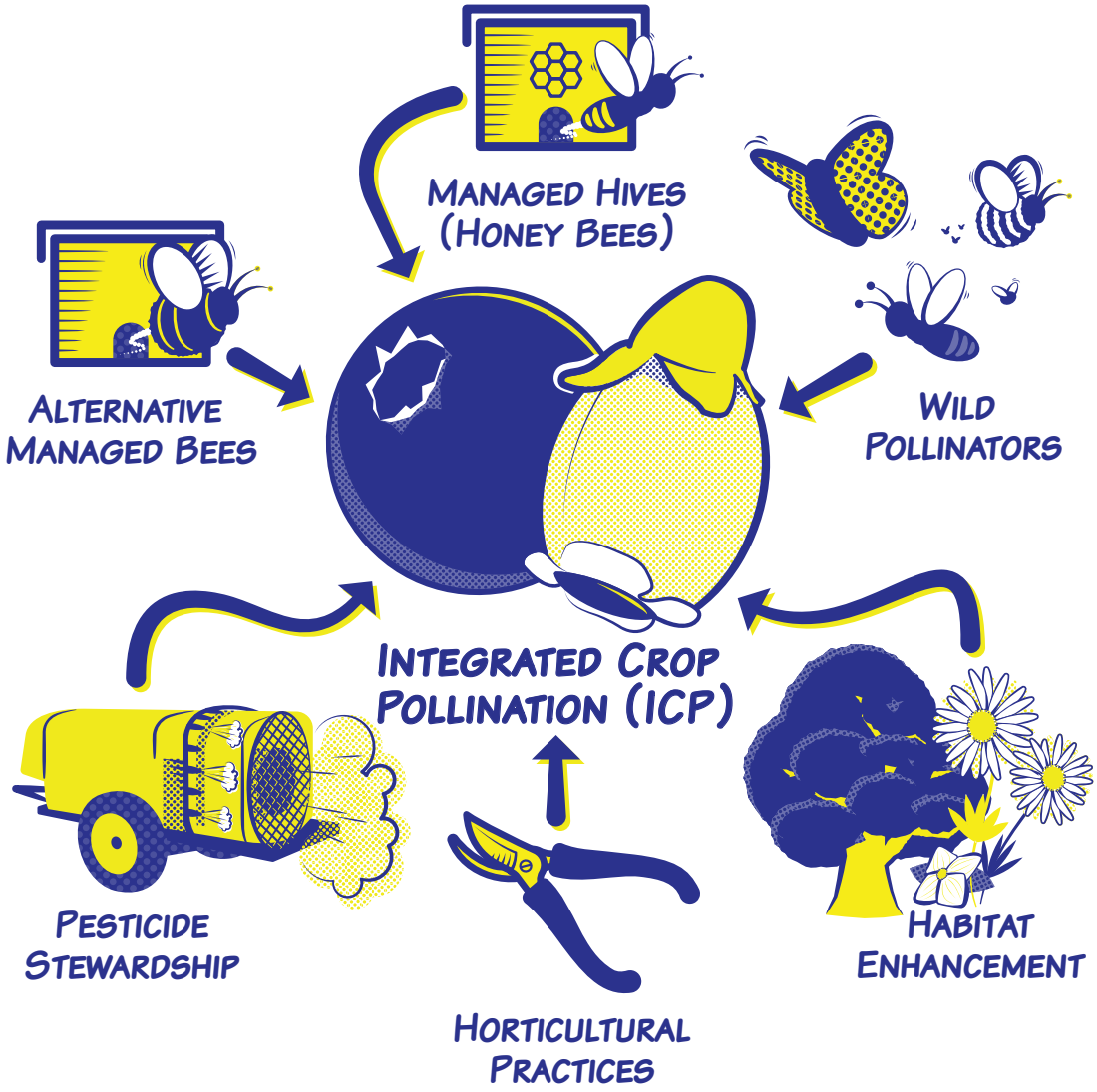


Figure 1. Integrated crop pollination (ICP) integrates management practices such as pesticide stewardship, horticultural practices, and habitat enhancements with pollination strategies that include honey bees, alternative managed bees, and other wild pollinators. Ideally, this can be used to achieve consistent pollination throughout the entire bloom period of every growing season. Image by Andrew Mack.

Pollination requirements

A key measure of pollination success is the number of flowers that are ultimately pollinated and become fruit (fruit set). There is potential for 100% fruit set from flowers in blueberry when there are sufficient pollinators and resources available (Ehlenfeldt, 2001; Kumarihami et al., 2021). Insects are crucial for blueberry pollination and numerous studies have shown that as low as 20-40% fruit set occurs when insects are not allowed access to blueberry blossoms. This results in reduced fruit set and berry development, limiting yield.

Plant species and cultivars (i.e., "varieties") vary in their pollination requirements. Blueberry has some degree of self-fertility whereby fruits can develop from flowers when pollinated by self-pollen. Self-pollen may be derived from pollen on the same plant or from other plants of the same cultivar. However, blueberry is only partially self-fertile. Partial self-fertility results in partial embryo abortion following self-pollination, and thus reduces fruit set and berry size. Because of this, blueberry often benefits from cross-pollination with increased fruit set and berry size compared to self-pollination.

What is self-pollination?

Self-pollination occurs when pollen from the same plant, flower, or cultivar lands on the pollen-receiving organ in a flower and leads to self-fertilization (Figure 2). Blueberry has both “male” (stamen) and “female” (pistil) reproductive organs inside the same flower, so pollen can be transferred from stamen to pistil in an individual flower and still induce successful pollination if timed correctly. Successful self-pollination may be limited, however, due to the partial self-fertility of blueberries described above.

What is cross pollination?

Cross pollination is the transfer of pollen from one plant to the stigma within a flower of another plant of another cultivar or genotype within the same species (Figure 2). In other words, cross pollination occurs when pollen is transferred between different cultivars. Although blueberry is capable of self-pollination, cross pollination can increase fruit yield as well as aspects of fruit quality such as time to ripen (Table 1). However, due to the partial self-fertility of blueberries, growers often plant single-cultivar blocks. In other cropping systems of plants that are highly self-infertile, such as fruit trees like apple and sweet cherry (*Malus domestica* and *Prunus avium*, respectively), it is common to incorporate pollinizer cultivars or species within the orchard that can cross-pollinate the focal cultivars.

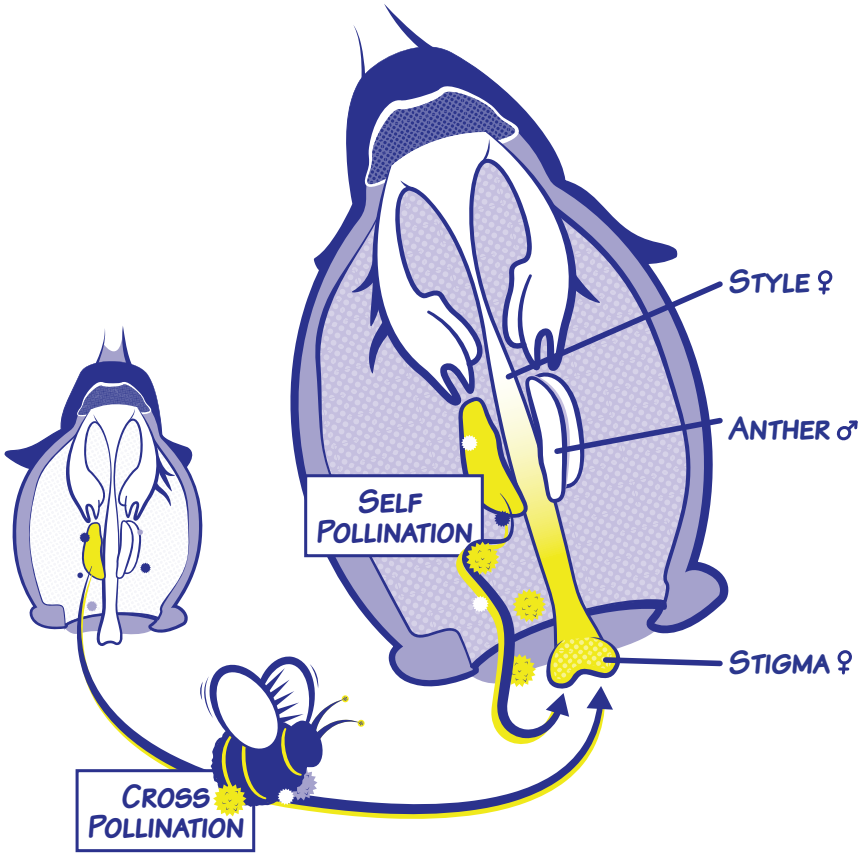


Figure 2. Self- vs. cross-pollination. Blueberry flowers are hermaphroditic, meaning they have both male and female reproductive parts. Self-pollination can happen when pollen from the same flower is shaken from the anthers and lands on the stigma, where fertilization will occur. Cross pollination happens when pollen from one blueberry flower is transferred to the stigma of another blueberry flower, usually by insects such as bees. Image by Andrew Mack.

Table 1. Cultivar response to cross pollination with select cultivars.

Cultivar	Crossed with	Fruit Mass	Firmness	Fruit Set	Ripening Time
Aurora	**Draper**	+	+	=	No change
Aurora	**Legacy**	+	+	=	A few days faster
Aurora	**Duke**	+	=	=	No change
Bluecrop	**Draper**	+	+	=	No change
Bluecrop	**Legacy**	+	=	=	Slower
Bluecrop	**Duke**	+	=	=	No change
Calypso	**Draper**	+	+	=	About 1 week faster
Calypso	**Duke**	+	+	=	About 1 week faster
Calypso	**Legacy**	+	+	=	No change
Draper	**Duke**	+	+	=	Up to 1 week faster
Draper	**Legacy**	+	+	=	Up to 1 week faster
Draper	**Nelson**	+	+	=	Up to 1 week faster
Duke	**Draper**	+	=	+	No change
Duke	**Legacy**	+	=	+	No change
Duke	**Nelson**	=	=	+	No change
Elliott	**Draper**	+	+	+	No change
Elliott	**Duke**	+	=	+	No change
Elliott	**Legacy**	+	=	+	No change
Last Call	**Bluecrop**	+	=	=	About 1 week faster
Last Call	**Draper**	+	+	=	About 1 week faster
Last Call	**Duke**	+	+	=	About 1 week faster
Last Call	**Legacy**	+	+	=	About 1 week faster
Liberty	**Draper**	+	+	+	Up to 2 weeks faster
Liberty	**Duke**	+	+	+	Up to 2 weeks faster
Liberty	**Legacy**	+	+	+	Up to 2 weeks faster
Sensation	**Draper**	+	+	=	Up to 1 week faster
Sensation	**Duke**	*Unknown*	*Unknown*	=	Incomplete data
Sensation	**Legacy**	+	+	=	Up to 1 week faster
Legacy	**Bluecrop**	–	–	=	No change
Legacy	**Draper**	–	=	=	No change
Legacy	**Nelson**	–	=	=	No change
Nelson	**Bluecrop**	=	+	+	No change
Nelson	**Draper**	=	=	+	No change
Nelson	**Legacy**	+	=	+	No change

Data comes from Chabert and Mallinger at the University of Florida. It is based on greenhouse experiments in optimum conditions, i.e., without plant maternal resource limitation, and may not be directly transferable to the field. "Cultivar" indicates the pollen recipient plant used in the greenhouse experiment and "Crossed with" indicates the pollen donor used to cross-pollinate by hand. (+) indicates positive effects resulting from cross-pollination, (–) indicates negative effects, and (=) indicates very little or no change.

Early-acting inbreeding depression after pollination

Early-acting inbreeding depression (EID) found in blueberries results in the partial abortion of embryos following self-pollination, and thus a decrease of mature seeds. Berries with fewer mature seeds are generally smaller and take longer to ripen. The number of developing seeds reaching maturity may also affect pectin content in mature fruits, therefore affecting firmness. As a rule, the more a cultivar is inbred, the more it will benefit from cross-pollination for pollination outcomes (e.g., fruit set, fruit size, firmness, time to ripen). In these cases, using co-blooming pollen donors more distantly related to the recipient cultivar can increase the benefits of cross-pollination. In general, blueberry benefits from cross-pollination for both fruit size and time to ripen, but effects vary in magnitude depending on the recipient cultivar and pollen donor (see preliminary data in Table 1). For example, in greenhouse experiments, fruit mass per berry of 'Bluecrop' was increased by 16% following cross-pollination with 'Legacy', while it was increased by 34% following cross-pollination with 'Draper'.

Further research needs to be done with both southern and northern highbush cultivars to determine if planting designs should be modified to optimize the benefits of cross-pollination in commercial production field contexts and to further assess the cost-benefits of this practice.

Flower reproductive biology and interactions with the environment

Anthesis is the time of flowering beginning when the flower opens. Pollen is produced in pollen sacs within the anthers (green) before the flower opens (Figure 3.1). Thousands of pollen grains are produced in each anther. The pollen (orange) remains in the anthers until the flower is stimulated by insect interaction, including buzz pollination, which triggers the release of pollen through the through the pore at the tip (blue) (Figure 3.2).Wind or other means of agitation can also trigger pollen release. In blueberries, pollen is released from the stamen through a beveled opening called a "pore". The pore opening faces the style, which is the long column-shaped organ at the center of the flower which has the stigma (purple) at the tip that receives pollen. It has a sticky surface that pollen can attach to and germinate on. When insects visit the flowers, their pollen-covered bodies deposit pollen onto the stigma. Following pollination, pollen tubes grow along the style, reach the ovary, and fertilize the ovules of the flower within hours (Figure 3.3).

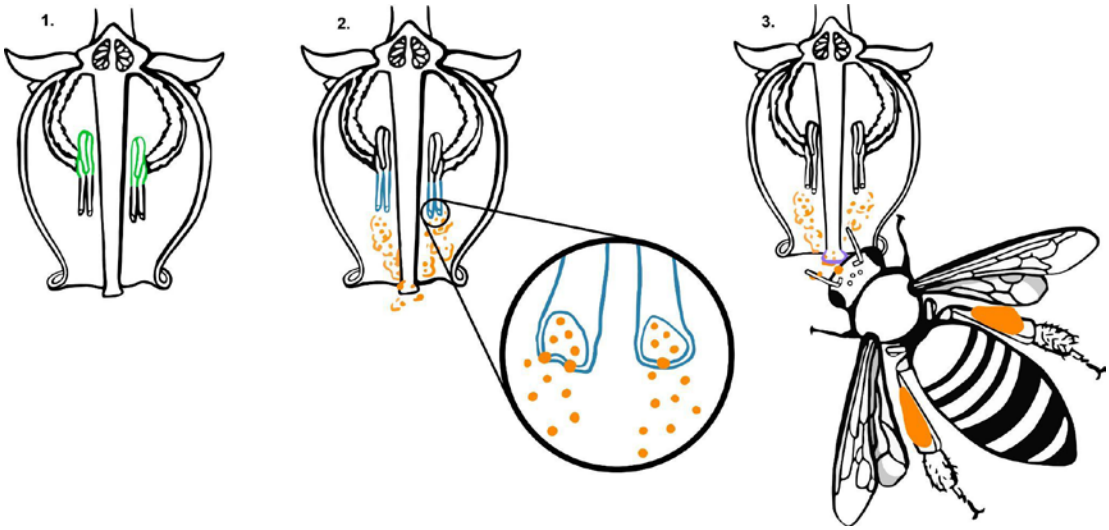


Figure 3. (1) Pollen production occurs in the anthers of the flower. (2) Pollen grains are released when the flower is stimulated by an insect, buzz pollination, wind, or other movement. (3) Pollination in blueberry usually occurs through transfer of pollen produced from the stamen to the stigma by bees. Image by Zoe Little.

Does temperature affect pollination?

There are optimal temperatures for blueberry pollen germination and growth ranging between 68-86°F (20-30°C) (Walters and Isaacs, 2023). However, exposure to temperatures above 90°F (32°C) can compromise pollen germination and reduce pollination success. Plant temperatures are generally warmer than air temperatures and early research at Michigan State University suggests running sprinklers for evaporative cooling at temperatures 90°F (30°C) and higher to protect pollen from heat damage (Milkovich, 2024). Cool temperatures can likewise reduce pollen performance by slowing down metabolic processes that could in turn reduce fertilization and subsequent berry development. One study found pollen germination was below 50% at 41°F (5°C) and lower with pollen tube growth similarly suppressed (Gan et al., 2020). Below freezing temperatures [i.e., <28°F (<-2.2° C)], on the other hand, can kill developing flowers unless freeze mitigation measures are in place.

Below 41° F (5° C)
Reduced pollen germination and slower pollen tube growth.

68-85° F (20-29° C)
Optimal!

Above 86° F (35° C)
Compromised with potential for no recovery.

Shape and structure influence on flower visitation

Blueberry flower shape and structure may influence how easily a bee may access nectar and pollen (Figures 4-7). It has been observed that honey bees may prefer some cultivars over others when foraging on blueberries (Marucci, 1966) and they mostly forage for blueberry nectar rather than pollen (Graham et al., 2023). However, honey bees foraging for nectar can still effectively pollinate blueberries (Hoffman et al., 2018) because they inadvertently transfer pollen from their bodies to the stigmas (as shown in Figure 4). Measurements of nectar secretion, corolla length, stigma protrusion, and corolla opening (i.e. "aperture diameter") help researchers unpack the reasons why certain bees seem to prefer a specific blueberry cultivar over another (Figure 6) (Courcelles et al., 2013). Sections of this guide will further address the ways that different kinds of bees may interact with blueberry flowers and their subsequent implications for pollination. A cultivar with difficult to access nectar may cause a primary nectar robber such as carpenter bees (*Xylocopa* spp.) to chew a hole through the side of the flower to reach the nectar more easily. This problem with carpenter bees is primarily restricted to the eastern United States. Honey bees and other species can then secondarily rob nectar by collecting it through the holes that are made by primary robbers (i.e., "nectar thieves"). When bees rob nectar from the flower, pollination is limited as contact with the plant's reproductive parts (anthers and stigmas) is limited. Additionally, bee tongue lengths vary, and some short-tongued bees may have difficulty reaching the nectar if their bodies are too big to get into the flower (Figure 5). Generally, if the bee head is wider than the corolla opening (Figure 6 and Figure 7) it will not visit the flower, unless either the tongue is long enough to reach the nectaries at the base of the flower, or it is able to sonicate pollen from the outside of the flower.

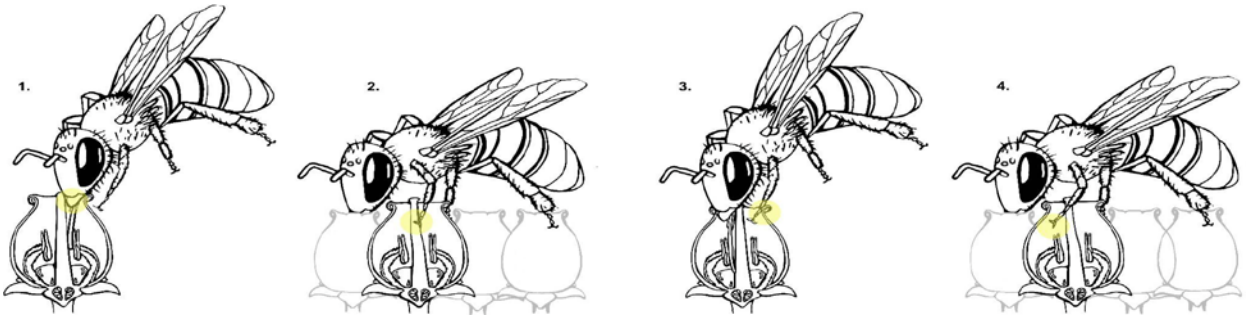


Figure 4. Honey bees can effectively pollinate blueberry flowers without collecting blueberry pollen (as described in Hoffman et al., 2018). There are four distinct ways that honey bees make contact with the stigma while foraging for nectar: (1) head probing a corolla opening while foraging for nectar, (2) claw grab onto a stigma, (3) leg across corolla opening, and (4) leg entered corolla. Yellow highlights depict where pollen transfer can occur. Image by Zoe Little.

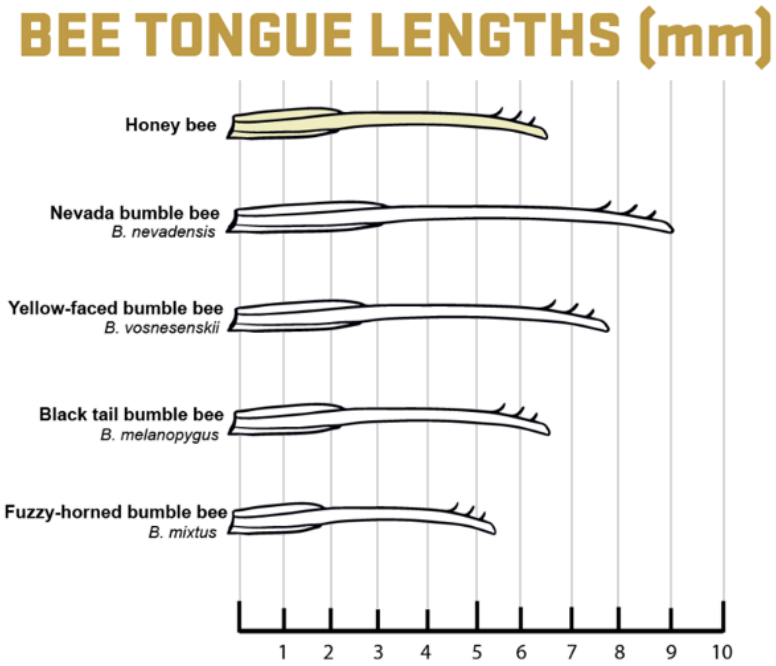
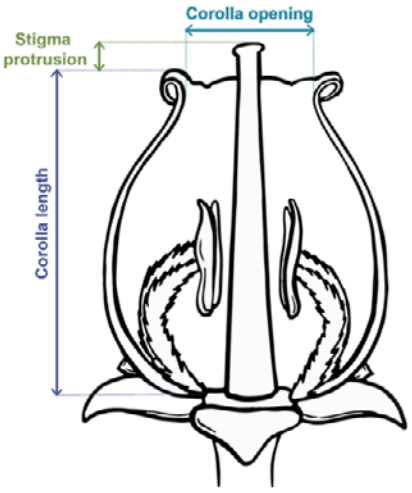


Figure 5. The length of a bee tongue can affect whether or not it can reach the nectary within a blueberry flower. Image by Zoe Little.

FLOWER MEASUREMENTS (mm)



Cultivar	Corolla opening	Corolla length	Stigma protrusion
Aurora	3.0	7.3	0.5
Bluecrop	2.9	8.8	-0.4
Draper	3.2	8.4	-0.2
Duke	3.4	9.2	0.2
Elliot	2.8	7.3	0.1
Jersey	3.0	7.9	1.0
Legacy	2.7	9.1	-0.3
Liberty	2.3	7.7	0.3
Nelson	3.0	7.7	0.5

Measurements are from greenhouse studies by research teams at the University of Florida and Michigan State University.

Figure 6. The shape of blueberry flowers varies by cultivar and can influence how easily a bee may access nectar and pollen. Some important features of the flower shape, such as the diameter of the flower opening (corolla opening) depth of the flower (corolla length), and the extent that the stigma protrudes beyond the flower opening can either make the flower easier or more difficult for bees to access.

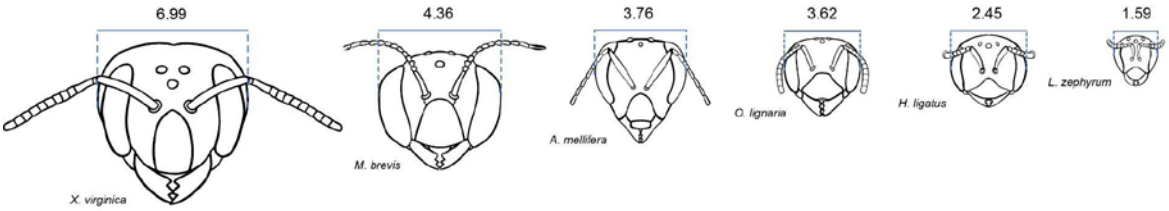


Figure 7. Head width (mm) of representative groups of bees – *Xylocopa virginica* (Eastern carpenter bee), *Megachile brevis* (common leafcutter bee), *Apis mellifera* (Western honey bee), *Osmia lignaria* (blue orchard mason bee), *Halictus ligatus* (ligated furrow bee), and *Lasioglossum zephyrum* (zephyr sweat bee). Some types of bees, such as *X. virginica*, may have heads that are too wide to enter the corolla opening. Small bees can fit their whole body inside a blueberry flower, whereas larger bees will use their long tongues and vibrate their bodies (i.e. "buzz pollinate") to release pollen.

Pollinators of Blueberry

Managed Bees

Honey bees

Honey bees form large colonies consisting of 10,000-60,000 individuals that remain active through an entire year. This is different than most other bee species, but it allows for beekeepers to provide pollination services. Honey bee colonies consist of a single queen who is the mother of all the individuals in the colony. The queen is surrounded by thousands of reproductively sterile worker bees. These worker bees conduct tasks associated with the growth of the colony, including foraging for nectar and pollen, feeding these provisions to developing larvae, producing wax to build combs, tending the queen, and defending the colony. Seasonally, the colony will produce male drones to mate with queens. The large colonies formed by honey bees, coupled with the fact that honey bees come out of the winter with a workforce, allow beekeepers to deliver populous colonies to early season crops like blueberries.

Honey bee colonies remain alive, yet inactive through the winter months, living off stored dehydrated nectar in the form of honey inside the hive. The colony population shrinks when pollen availability becomes sparse in the transition from fall to winter. Colony pollen intake is directly linked to colony population, as pollen is the protein source for creating new workers. Beekeepers will often stimulate colonies in late winter to accelerate the rearing of new workers either by moving them to southern states, where winter pollen supply is more abundant, or by feeding syrup and protein substitute directly to colonies. As bee colonies grow in the spring, beekeepers can replace any lost colonies by obtaining newly mated queens from producers in California and other states, dividing the viable colony workforce, and placing a new queen in

each division. Not only does dividing help beekeepers maintain their colony numbers, but it can also prevent the colony from dividing naturally through a process known as swarming. Frequently, peak swarming season occurs during blueberry pollination (Figure 8). A swarmed colony consists of the old queen and half the workforce, which weakens the colony. Since swarms are frequently not recovered, it represents a loss to the beekeeper.

A honey bee colony used for blueberry pollination will typically be housed in three or four boxes, with the bottom two boxes being where the queen lays eggs (brood nest) and additional boxes being where honey is stored (super). These boxes will usually be placed on an integrated pallet that can house 4-6 colonies (Figure 9) and facilitates transportation.

Figure 8. Swarmed honey bees on trellis posts in a blueberry field. These swarms typically will remain in place for a few hours before moving away. Image by Dani Gray.

Figure 9. Integrated pallet with four colonies (two in front and two in back). Images by Salena Helmreich and Andony Melathopoulos, respectively.

Problems faced by honey bee colonies during blueberry pollination

The primary source of revenue for most commercial beekeepers are rental fees from pollination, but beekeepers can face many challenges in maintaining healthy bee colonies in these settings. Beekeepers frequently contract their colonies to multiple crops. Sufficient time between contracts is necessary to allow the beekeeper to perform essential maintenance tasks, such as colony inspection, feeding, swarm management, requeening, and any other tasks crucial to ensure that a

colony remains strong across a pollination contract. But in some circumstances, weather or logistics may delay departure of colonies from one crop, shortening the interval a beekeeper has to manage colonies before the next contract begins. In the case of blueberries, a rainy period before pollination may constrict the time a beekeeper has to tend to their colonies before they need to be delivered for pollination.

Honey bee colonies may also face a range of diseases and parasites that can weaken or kill the colony if left untreated. There are two issues which are of particular importance for blueberry pollination. The first is the Varroa mite (*Varroa destructor*), which is an external parasite of honey bees that feeds on workers and also transmits viruses. Varroa mite populations build up in late summer, sometimes resulting in heavy losses that beekeepers cannot replace in time for crops like blueberry. It is recommended that growers contact their beekeepers in late February to check on colony supply for the coming season. Another disease of major importance in blueberries is European foulbrood (*Melissococcus plutonius*), referred to as "EFB". EFB is a bacterial disease of honey bee larvae which has been associated with blueberry pollination since the 1980s (Grant and Melathopoulos 2021). Although the connection between EFB and blueberry remains poorly resolved, beekeepers have experienced high levels of EFB in colonies leaving blueberry pollination contracts across North America. This results in thousands of dead larvae, reducing the number of colonies available for pollination later in the year. Moreover, the disease frequently reappears in the colony in future years, resulting in a perennial chronic loss of revenue to beekeepers.

As honey bee colonies are often placed adjacent to the crop, they can also be damaged by farm equipment or by excessive irrigation. It is important for growers and beekeepers to discuss placement location and ways to reduce risk to colonies to ensure their health and foraging activities. Honey bees can also be exposed to pesticides given they are frequently located in and around agricultural fields that may be treated with pesticides. We address reducing exposure, risks to bees, and pesticide best practices for pollinators in greater detail in the "Pesticide Stewardship" section of this guide.

Hive placement

Placement of honey bee hives in blueberry farms should be done in consultation with beekeepers and should factor in space requirements for hives, maximize beekeeper efficiency, and prioritize locations that minimize potential exposure to pesticides (Figure 10). Many growers request that beekeepers strategically place hives immediately adjacent or along the edge of their fields due to the idea that this may increase pollination (Figure 11). However, research has shown that this strategy does not actually increase honey bee visitation to blueberry flowers. Instead, higher visitation rates can be achieved by clustering hives away from the field edge (Figure 12; Brouwer et al., 2024). Placing hives away from field edges also can reduce pesticide exposure and maximizes beekeeper efficiencies during hive delivery, removal, and for any in-field maintenance that may be required.

Figure 10. Comparison of clumped. vs. dispersed arrangements of honey bee hive pallets in a blueberry field. Image by Kayla Brouwer.

Figure 11. Pallets of honey bee hives in a dispersed arrangement. In this arrangement, pallets are placed adjacent to the blueberry field edge. Image by Salena Helmreich.

Figure 12. Pallets of honey bee hives placed in a clustered arrangement. In this arrangement, pallets of hives are aggregated together and placed away from the blueberry field edge. Image by Lisa DeVetter.

Stocking densities

Guidelines to improve pollination from honey bees often focus on ensuring stocking densities (i.e., hives per acre) are adequate, where stocking density is linked to the number of foragers able to pollinate flowers in a field. The number of flowers in a field is impacted by several factors, including cultivar, planting age, and planting density. The number of open flowers also varies temporally through the season as bloom progresses. Therefore, growers depending on honey bees for pollination will want to ensure there is a sufficient number of foraging honey bees for their unique field conditions, specifically bloom density in the field. Furthermore, while the primary way they manipulate bee density is through stocking density, hives can also vary widely in the numbers of bees per hive and in bee health.

Stocking density guidelines typically range from 0.5 to 10 honey bee hives per acre in blueberry, and these densities have increased over time as the industry transitions to higher planting densities and new cultivars with greater bloom densities. However, research linking hive density to honey bee visitation and pollination outcomes shows inconsistent relationships. The lack of consistent results may be due to factors such as landscape and colony strength, which influence the number of honey bees available to pollinate and where they choose to forage.

Larger pollen loads deposited on blueberry stigmas significantly enhance fruit set and seed production, but there is a threshold beyond which further pollination does not result in increased fruit size (Dogterom et al., 2000). One study found that increased honey bee stocking and even increased honey bee visitation did not result in greater pollen deposition, and farms with fewer bees had closer to optimal pollen transfer and larger berries (Mallinger et al., 2021; Ramírez-Mejía et al., 2024). From an economic standpoint, slightly reducing the number of hives in a field can reduce costs while providing a similar level of pollination.

The stocking density of hives across the surrounding landscape can affect the number of honey bees visiting the crop, with research showing that the presence of other hives within a 0.6-mile (1km) radius influences honey bee visitation more than a field's specific stocking density (Figure 13; Eeraerts et al., 2023). Indeed, field-level hive recommendations miss the contributions of other hives in the landscape. This signifies that growers in regions with other blueberry fields or blooming crops that overlap with blueberry should consider potential pollination contributions from neighboring fields or apiaries. Landscapes also have other plants that may be attractive to honey bees, such as maple and wild cherry trees, that can draw bees away from pollinating blueberries. However, non-agricultural habitat types in landscapes around fields may also contribute wild bees and other insect pollinators that improve pollination independent of honey bees. These non-agricultural habitat types also improve the health of honey bees as they provide pesticide free-forage, as well as flowers for bees to visit before and after the blueberry bloom period. As a result, non-agricultural habitat within a few miles of a farm is typically considered beneficial for pollination.

Colony size, also referred to as "strength", is related to the number of foragers available to pollinate the crop. The size of the brood nest impacts colony strength and only a colony with a healthy and growing brood nest will provide a large pollinating workforce. This is why most pollination contracts state a minimum number of frames that should be covered with worker honey bees when the colonies are delivered. Many beekeepers understand these relationships and increase stocking densities if hives are of low strength. However, measuring colony strength is challenging, with some methods requiring opening up and disturbing hives. Growers should never open hives without beekeeper permission but should discuss colony strength expectations with their beekeeper during the winter when setting up the contract.

One non-invasive way growers can assess the strength of their hives is through returning forager counts (Figure 14). This approach entails visually assessing the rate at which foraging bees return to the hive during good foraging conditions [>65°F(>18°C) and wind speeds less than 10 miles per hour]. A strong colony will have > 90 bees per minute returning to the hive, medium or average between 40-90, and weak <40 bees per minute returning to the hive. Growers are advised to contact their beekeeper if colonies are weak or dead so they can be replaced as soon as possible. A training video "Grading colonies using hive entrance counts for blueberry pollination,"[1] has been developed for those interested in learning how to conduct return forager assessments.An emerging approach that encompasses stocking density and colony strength is known as stocking strength, which can be estimated by multiplying stocking density by the average returning forager count in a given amount of time (Equation 1):

Stocking strength = Hive density × Returning Forager Count (averaged from 10 colonies)

Stocking strength was found to be strongly linked to honey bee visitation in blueberry pollination studies in Michigan, indicating its potential as a measure that determines whether fields are stocked with an appropriate number of strong hives to optimize pollination outcomes. Furthermore, stocking strength was found to be more correlated with honey bee visitation to blueberry flowers than stocking density or estimates of colony strength alone.

Research on how to apply and interpret this method for commercial blueberry farms is ongoing, but this measurement highlights the importance of providing a sufficient number of strong hives to optimize pollination outcomes. When stocking fields, it's important to be mindful of the potential consequences of overstocking fields. While renting more hives than necessary for pollination services is costly to growers, it may also have ecological ramifications in terms of reducing other pollen and nectar sources in the landscape for wild pollinators and possibly impacting honey bee colony health as well. Excessively high stocking densities may also stress honey bees by increasing the risk of disease and pest transmission between hives and likewise diminish food resources in the landscape if there are more foraging bees than what the landscape can support. If it is determined that more honey bees are needed to achieve higher levels of pollination, growers should consider renting fewer, larger colonies as opposed to many smaller colonies.

1 Training video: https://www.youtube.com/watch?v=3Jq6HMjzBlE

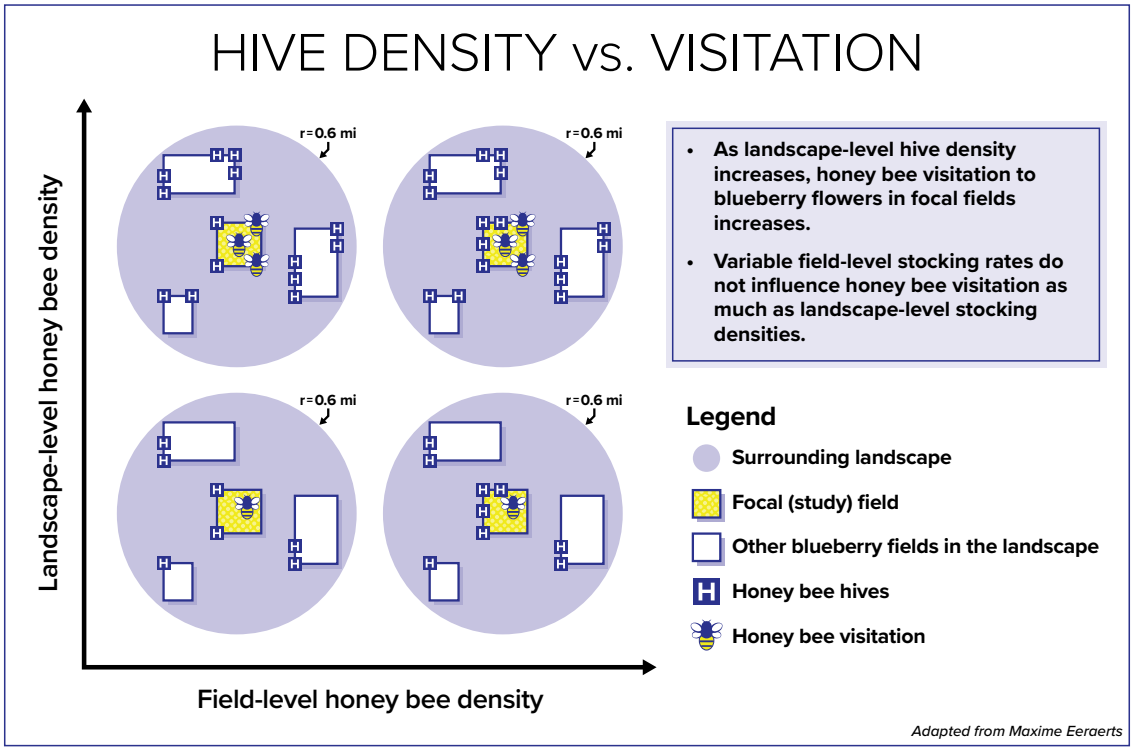


Figure 13. A field study in northwestern Washington across 16 blueberry fields showed that landscape-level hive density is a better predictor of honey bee visitation to blueberry flowers than field-level hive density. Image by Andrew Mack (adapted from Rogers et al., 2023).

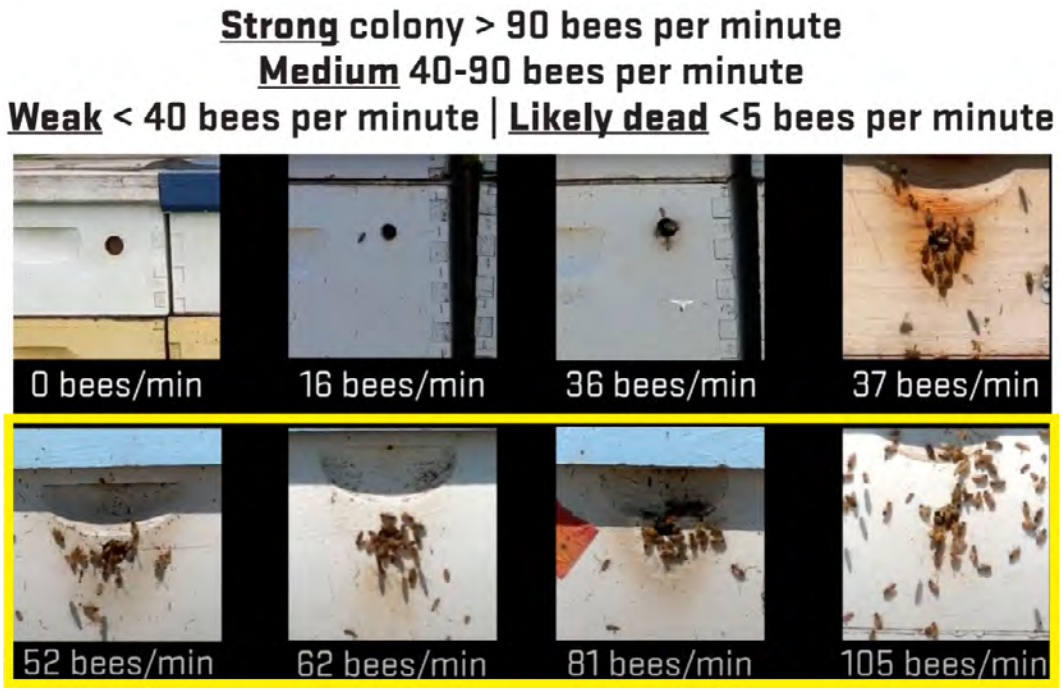


Figure 14. Rough grading of colonies using returning forager counts. Average rate of foragers to colonies you have rented is a rough predictor of the bees pollinating blueberry flowers. Watch our training video to learn how to grade your colonies. Image by Andony Melathopoulos.

Alternatives to Honey Bees

Many insects are capable of pollinating blueberry, but bees are likely to do most of the pollen transfer (Figure 15). Furthermore, different species of bees are active at different temperatures and times of day. This section will review alternative insect pollinators that may be available as managed or wild species. If you are interested in experimenting with the addition of alternatively managed bees in your pollination plan, reach out to your local extension agent or connect to the resources listed in this document for more information about what is available and appropriate in your area. Also, be aware of any state restrictions on the use of non-native bees in your area.

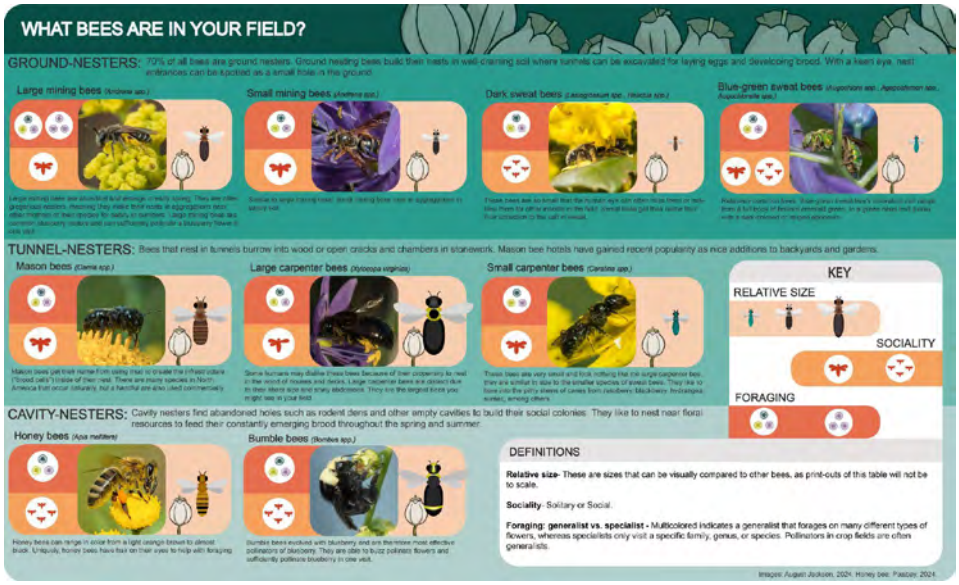


Figure 15. Common bees observed in blueberry fields in North America. Image by Zoe Little and Salena Helmreich.

Bumble bees (*Bombus* spp.)

Bumble bees are highly effective at pollinating blueberry and can successfully pollinate a blueberry flower in one visit. Bumble bees use a unique and effective strategy of vibrating their wing muscles, called buzz pollination or sonication, which shakes and releases pollen from the anthers inside the flower. Some sweat bees, miner bees, and carpenter bees are also capable of buzz pollination. Bumble bee colonies are much smaller than honey bee colonies, usually with 25 to 400 individual bees that nest underground. At the time of blueberry bloom, depending on geographic region, bumble bees might only have a small colony or could be just getting started at building their nests (Figure 16). Bumble bees collect pollen for their young and carry it back to the nest using pollen baskets on their rear legs similar to honey bees. Their large body size and ability to generate heat to warm their bodies allows bumble bees to be active at lower temperatures than honey bees, which is especially relevant for early spring blooming crops like blueberry.

Commercial bumble bee colonies reared to full size 200-400 workers, and these can be advantageous over wild colonies that are often just getting started at the time of blueberry pollination (Figure 17). Depending on species and region, there are mixed results for improving blueberry yield using commercially managed bumble bees. Commercial bumble bee colonies are also costly, so it is important to consider the benefits of adding this pollinator. With this in mind, it is suggested to estimate the wild bee abundance surrounding a field before making stocking rate decisions. Fields with noticeably few bumble bees may benefit from a higher stocking rate of commercial bumble bees, whereas a lower stocking rate or zero colonies is preferred in areas with a large wild bee presence. It is important to use only species that are native to the region, such as *B. vosnesenskii* and *B. huntii* in California and the Pacific Northwest (including British Columbia), and *B. impatiens* in the eastern USA. The body of research on the use of commercial bumble bees to supplement blueberry pollination is growing. If you would like more information about supplementing your pollination plan with commercial bumble bee colonies, reach out to your local extension agent for recommendations and information relevant to your area.

There are a variety of ecological concerns and considerations about the use of managed bumble bees for crop pollination, such as use of queen excluders, how to protect colony health during pollination, and colony disposal after pollination. The guide "Commercial Bumble Bee Best Management Practices (pdf)[2]" is a useful reference for additional information.

2 Protecting Wild Bee Crop Pollination Services: Commercial Bumble Bee Best Management Practices: https://smallfruits.wsu.edu/documents/2024/02/protecting-wild-bee-crop-pollination-services-commercial-bumble-bee-best-management-practices.pdf/

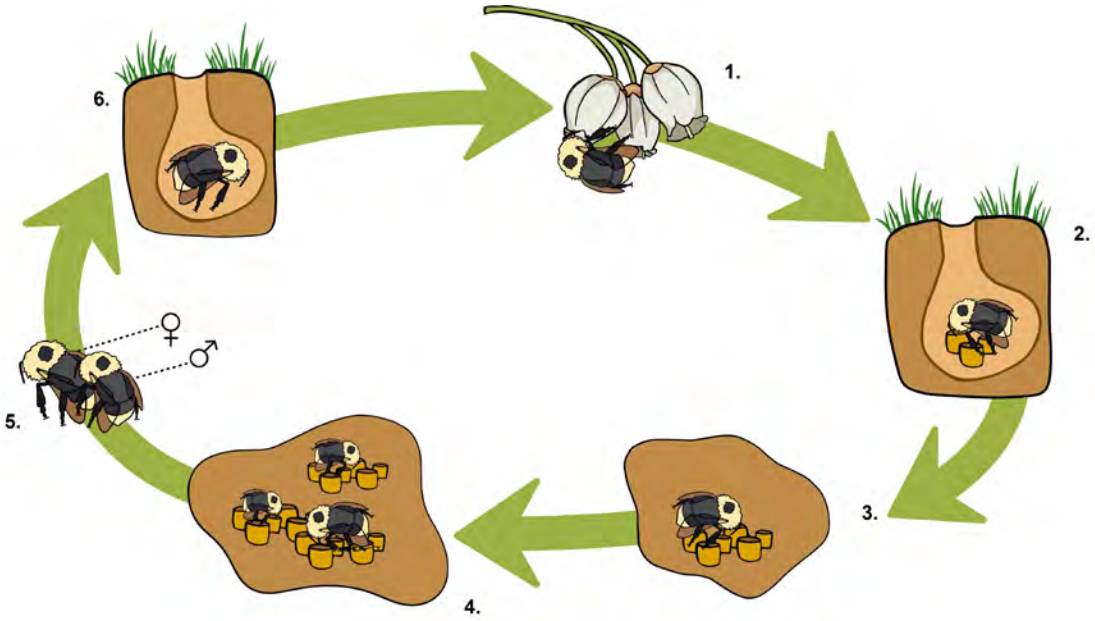


Figure 16. (1) Bumble bee queens become active in early spring and will forage on early blooming flowers such as blueberry. (2) When she is ready, the bumble bee queen will search for a pre-existing cavity to create a nest. A common choice of nesting habitat for bumble bees are abandoned rodent burrows and brush piles. (3) When she finds the right spot for a nest, she will build wax pots to lay her eggs and store pollen and nectar for her brood. Although bumble bees produce wax for their nests, they do not produce honey. (4) As bloom progresses, the first of the queen's offspring, which are female workers, will emerge from development and take on other tasks in the nest. These first workers will be much smaller in size from the founding queen. (5) In late summer, new queens and males will hatch and leave the nest to go find mates. (6) Newly mated queens will then disperse in the landscape, looking for loose dry material such as forest duff to spend the winter. They enter a state of diapause, similar to hibernation. The parental nest dies out in the fall. After several months of diapause, the cycle begins again in the spring. Image by Zoe Little.

Figure 17. (1) Commercial bumble bee colony placed in a greenhouse. (2) Bumble bee exiting from her nest box. The blue queen excluder, pictured here, is an important part of managing bumble bees. Without a queen excluder, wild queens may enter the colony and be killed. (3) Commercial bumble bee colonies placed in a field. Boxes containing colonies are provided with shade to prevent colonies from overheating. Images by Lisa DeVetter.

Solitary cavity-nesting bees: Mason bees (*Osmia* spp.) and Leafcutter bees (*Megachile rotundata*)
There are a few solitary cavity-nesting bee species that can be managed to increase their abundance during bloom, such as mason bees and leafcutter bees. While there are hundreds of species of these bees, a few species are commercially available, most prominently the blue orchard bee (*Osmia lignaria*) and the introduced Japanese horned-face bee (*Osmia cornifrons*), as well as the native blueberry bee (*Osmia ribifloris*). The alfalfa leafcutter bee (*Megachile rotundata*) has been used broadly to supplement pollination in lowbush blueberry production, however usage in northern highbush blueberry is still experimental.

All species of mason bees are smaller than bumble bees and tend to be smaller than honey bees. They are largely metallic in appearance, ranging from green (e.g., *Osmia ribifloris*), blue (e.g., *Osmia lignaria*), black (e.g., *Osmia montana*), to rust-red (e.g., *Osmia cornifrons*). They get their name from the mud they use to separate their brood cells, which are individual compartments that larvae grow in while feeding on a ball of pollen mixed with nectar that is provided by their mother. Some mason bee species do not use mud for these partitions. For example, the blueberry bee (*O. ribifloris*) builds its partitions from pulped leaf material. All commercial species make their nests in cavities of wood and hollow sticks, which enables them to be managed in nest boxes stocked with natural or artificial nesting materials (Figure 18). The Orchard Bee Association[3] is an excellent resource to learn more about mason bees. Interested growers can also purchase, develop, overwinter, and deploy their own mason bees every year if desired. The guide "Building and Managing Bee Hotels for Wild Bees (pdf)[4]," by Michigan State University Extension is a useful resource and available for free online.

Of the mason bees available for pollination, *Osmia lignaria* is native to much of the United States and got its name as the blue orchard bee due to its use in tree fruits. *O. lignaria* is the most researched species of mason bee for crop pollination and can be available for commercial use in large numbers. In some parts of the United States, Vaccinium specialist mason bees (*O. ribifloris*), native to Oregon and California, ranging to eastern Texas, are gaining popularity. *O. ribifloris* has also been introduced for crop pollination in the eastern and south-central USA. *O. bruneri* is another emerging mason bee native to the Intermountain West and Rocky Mountains. Emergence timing is something to be conscious of, as *O. bruneri* emerges in late spring and might be more appropriate for late-blooming blueberry cultivars (Andrikopoulos and Cane, 2018). One advantage of mason bees is that the timing of their emergence can be manipulated with refrigeration during the winter. With experience, their emergence can be timed for bloom in specific cultivars.

Less information is available about using leafcutter bees for blueberry pollination. Leafcutter bee nests look similar to the mason bees (Figure 19), however instead of mud they line their nests with cuttings from leaves. Consult with your local extension agent for recommendations and information relevant to your area.

Figure 18. Commercial *O. ribifloris* nest in a blueberry field. Image by Andony Melathopoulos.

3 Orchard Bee Association: https://www.orchardbee.org/
4 Building and Managing Bee Hotels for Wild Bees: https://www.canr.msu.edu/uploads/resources/pdfs/bee_hotels-e-3337_wcag_2.1.pdf

Figure 19. Leafcutter bees (*Megachile rotundata*) tunnel-nesting in a manmade wood block. Closed holes conceal developing bee brood. Image by Salena Helmreich.

State restrictions on non-native bees

Many states have restrictions or bans on the use of non-native bumble bee species for open-field pollination. These restrictions aim to address concerns about potential competition with or displacement of native bee species and transmission of viral, fungal, or bacterial pathogens between introduced and native bees. For example, Washington and Oregon have bans on the use of the common eastern bumble bee, *B. impatiens*. Be sure to check whether there are any legal restrictions before using a managed pollinator. It is also best to use alternative managed bees that are collected or reared locally if possible.

Wild bees

Although commercial honey and bumble bees are social and the most easily recognized by humans, there are over 4,000 other species of wild bees in North America, and some surveys of blueberry fields have recorded over 100 bee species visiting this habitat. Most bees are solitary, meaning that they build their own nests and do not form large colonies. Seventy percent of wild bees nest in the ground (Figure 20). The rest are cavity nesters that build their homes in wood, brush piles, crop stubble (e.g., raspberry and blackberry stubble left after pruning), and other vegetation (Figure 21). Bees can range from 2-25mm (about 1-inch) in length. A range of 12-82% of all bees that visit blueberry flowers are wild and the proportion of bees that are wild visiting blueberry flowers can vary based on field size and landscape (Isaacs and Kirk, 2010; Benjamin and Winfree, 2014). Habitat where there is season-long blooming of flowering plants in and around the crop will promote a healthy and diverse local bee community.

If adding floral resources to support wild bees, select flowering plants with bloom times that have minimal to no overlap with blueberry (blooms before and after the crop) and are not a known host to spotted wing drosophila (*Drosophila suzukii*, hereafter referred to as "SWD"). SWD is a major pest of soft fruit, including blueberry. In general, important plant groups to consider that do not host SWD include shrubs that bloom before blueberry, notably willows (*Salix* spp.), heathers (*Calluna* spp.) and heaths (*Erica* spp.). These shrubs may help attract and establish bumble bee nests prior to the onset of blueberry bloom. After blueberry bloom relatively inexpensive and attractive plants will include species from the legume family (e.g., clovers (*Trifolium* spp.), vetches (*Vicia* spp.) and lupines (*Lupinus* spp.), the mint family (e.g., hyssops (*Agastache* spp.), lavenders, beebalm (*Monarda* spp.), catmints (*Nepeta* spp.), marjorams (*Origanum* spp.) and selfheals (*Prunella* spp.) and the sunflower family (e.g., yarrow (*Achillea millefolium*), blanketflower (*Gaillardia* spp.), coneflowers (*Rubeckia* spp.), goldenrod (*Solidago* spp.) and American asters (*Symphyotrichum* spp.). Summer blooming trees can also provide sustained nectar and pollen for bees and may include redbuds (*Cercis* spp.), catalpas (*Catalpa* spp.) and linden trees (*Tilia* spp.). Check with local extension specialists or conservation district professionals regarding species selection for your location that are not hosts to SWD or other important pests and have blooming periods with minimal-to-no overlap with blueberry.

Figure 20. A cellophane bee, *Colletes inaequalis*, guarding her ground nest. Image by Salena Helmreich.

Figure 21. Tunnel nesters like the small carpenter bee (*Ceratina calcarata*) build their homes in wood, brush piles, crop stubble (e.g., pruned raspberry or blackberry canes), and other vegetation. Image by Salena Helmreich.

Best Practices for Pollination

Effective pollination is crucial for achieving high yields and quality fruit in blueberry cultivation. Implementing best practices for pollination involves a multifaceted approach that includes responsible pesticide use, employing pollination aids and tools, and understanding the factors that affect open-field and polytunnel pollination. These practices have the potential to boost crop productivity and ensure the wellbeing and sustainability of pollinator populations. This section will explore these best practices, highlighting the significance of pesticide stewardship and promoting pollinator habitat around blueberry fields.

Semi-natural habitat

Proximity to semi-natural habitat can increase pollination rates by wild bees with a minimum of 15-20% of semi-natural habitat providing these benefits to pollinator-dependent crops (Garibaldi et al., 2021; Eeraerts, 2023). Semi-natural habitats are habitats that have been altered by human activity but still maintain some biodiversity and natural ecological processes.

Examples of semi-natural habitats include but are not limited to insectary or wildflower strips, hedgerows, forest edges, shrubland, wooded land, ditch banks, grasslands, and wetlands. These habitats play a crucial role in promoting wild pollinator populations in agricultural landscapes. Both natural and semi-natural habitats act as refuges and corridors for wild pollinators, providing essential food and nesting resources that promote biodiversity.

The floral diversity provided by semi-natural habitats can ensure a continuous and varied supply of nectar and pollen is available throughout the season, which is vital for the survival and health of wild bee populations. Commercial blueberry production is traditionally done in a monoculture, which offers limited floral resources to nourish wild bees during the rest of the season. Neighboring semi-natural habitats can thus provide a buffet of options for wild pollinators, helping them meet the full spectrum of their nutritional needs. Semi-natural habitats also reduce or prevent food shortages for honey bees, which can otherwise happen in simple landscapes and compromise honey bee health (Verrier et al., 2024).

Many wild bee species also require specific nesting conditions that may not be available in intensively managed agricultural areas like commercial blueberry fields. Nesting is a requirement to ensure species reproduce and are present over time. Semi-natural habitats often provide suitable nesting sites such as bare ground, dead wood, and plant stems. These habitats offer a variety of nesting opportunities, from underground burrows to hollow plant stems, supporting diverse insect species with different nesting preferences.

Semi-natural habitats can also serve as refuges, shielding bee populations from the direct impacts of pesticide use in agricultural fields. Additionally, semi-natural habitats often harbor other beneficial insects that prey or parasitize pest species, helping to maintain a natural balance in the agroecosystem and reducing the need for pesticide applications.

Finally, if there are interconnected patches of habitat across the landscape, semi-natural habitats can promote gene flow and genetic diversity within wild bee populations. This genetic diversity enhances the resilience of populations in the face of environmental stressors such as disease outbreaks, extreme weather, and habitat loss. Healthy, genetically diverse populations are better equipped to adapt to changing conditions and maintain stable agroecosystems.

Habitat enhancement

There are generally three areas to enhance habitat for blueberry pollinating bees. These are: 1) the turf dominated headlands that surround blocks cultivated to blueberries, 2) field edges that are dominated by trees and shrubs and 3) the strips of turf between rows of blueberry plants. We recommend that habitat enhancements be focused on the first two areas (headlands) and not between rows of blueberries, as the latter is at highest risk of being contaminated with pesticides. There remains a risk of pesticide contamination of enhanced habitat in field headlands through spray drift (Graham et al., 2024) so enhancements should either placed outside the zone where drift is heaviest (300 feet for most toxic insecticides, but estimates can be calculated using **"Models for Pesticide Risk Assessment"**[5]) or protected with a drift buffer consisting evergreen trees planted perpendicular to the wind direction that is most common when insecticides and fungicides are applied.

Prior to conducting enhancements take stock of existing habitat around your fields. Riparian areas around the property, for example, may already have several flowering shrubs and trees that managed and wild bees use. Similarly, there may be flowering plants such as clovers (*Trifolium* spp.) and dandelion (*Taraxacum* spp.) as well as many other species that readily establish in headland turf that can be allowed to fully bloom before mowing.

Enhancements should build on existing habitat around the field headlands. Enhancements generally require establishment and maintenance costs. Cover crops, for example, will require annual seeding and site preparation. Flowering strips consisting of annual and perennial plants may require up to two years of chemical or mechanical fallow to reduce grass and invasive weed competition, in addition to patterns of mowing that are less frequent and of different timing than headland turf. Flowering trees and shrubs tend to have higher initial cost, but may have less ongoing maintenance costs, although considerations need to be given towards routine weed management as hedgerows tend to accumulate undesirable species such as invasive blackberry species.

In the United States, there are **Natural Resource Conservation Service (NRCS) cost-sharing programs**[6] supported by the Farm Bill that can assist with implementing habitat restoration and enhancement, as well as evergreen pesticide drift buffers. The key programs are as follows:

5 Models for Pesticide Risk Assessment: https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/models-pesticide-risk-assessment
6 Natural Resource Conservation Service (NRCS) cost-sharing programs: https://www.nrcs.usda.gov/programs-initiatives

1. Environmental Quality Incentives Program (EQIP)[7]:
   - Producers with a natural resource concern (e.g., erosion, wildlife, pollinators, etc.) can contact their local NRCS office to assess resources on their land. Together, the NRCS representative and producer can determine 1-3 specific practices that can be contracted and implemented to address the natural resource concern(s) on working lands.
   - Producers can receive approximately 50% cost sharing with the federal government. Historically underserved demographics may receive up to 75% cost-sharing.
2. Conservation Stewardship Program (CSP)[8]:
   - This is a contract that rewards producers for already maintaining natural resource conservation practices on their land. Producers are paid per acre and are expected to take on additional enhancements such as creating pollinator habitat, hedgerows, pastures designed to lead to more bloom, etc.
3. Agricultural Conservation Easement Program (ACEP)[9]:
   - Land is permanently retired from production, restored, and managed for its natural resources. These are permanent easements. If the land is of high restoration value (e.g., high biodiversity, high value to the ecosystem), 100% of the cost of restoration will be covered by the NRCS.
4. Conservation Reserve Program (CRP)[10]:
   - Land is retired for 10–15-year contracts to achieve large-scale environmental benefits. Producers receive rental payments and cost-share assistance from the NRCS for removing environmentally sensitive land from production with the goal of improving soil health, water quality, and wildlife habitat.

Pesticide Stewardship

Honey bees can be exposed to insecticides, fungicides, and herbicides when placed in blueberry fields for pollination. While exposure to acutely toxic insecticides can result in thousands of foraging bees killed, pesticides may also have sublethal or possibly lethal effects depending on factors such as formulation, rate, and exposure levels. The Environmental Protection Agency (EPA) evaluates all new pesticides for lethal and sublethal effects, and applicators will find information on restrictions to protect bees under the Environmental Hazards and Specific Use Directions of the label (Figure 22). In general, fungicide labels may not contain any warning or restrictions, although chronic effects of excessive fungicide exposure have been connected to declining honey bee colony health. Likewise, herbicides may not contain any warning or restriction, but there is some concern about the synergistic effects of herbicides and other pesticides when applied in combination. It is therefore important to adopt management practices to minimize any pesticide applications during bloom.

Pesticide labels, however, do not account for increased toxicity associated with tank mixing different pesticide products or the addition of adjuvants. There is increasing evidence that the combination of insecticides of relatively low risk to bees can become highly toxic when combined with a fungicide (e.g., the insecticide chlorantraniliprole combined with the fungicide propiconazole is highly toxic to honey bee larva, even though neither is toxic on its own) (Wade et al., 2019). Moreover, while adjuvants are considered by EPA as inert ingredients and information on their risk to bees is not required prior to their registration, there is some evidence that adjuvants may be toxic to bees under laboratory and field conditions, even though their labels may not specify any risk to bees (Shannon et al., 2023).

The risk of a pesticide application to managed and wild bees is significantly reduced by applying treatments before bloom (before bees visit the field) or immediately after bloom when honey bee colonies are removed from fields and wild bees are likely foraging elsewhere (Figure 23). During bloom, no products labeled as toxic to bees should be applied, unless label mitigations are followed. Mitigations will be indicated in the Environmental Hazards or General/Specific Use Directions on the label (Figure 22) and may include applying the pesticide when bees are not actively foraging, either in the evening or during the daytime when temperatures are below 50°F (10°C).

7 Environmental Quality Incentives Program (EQIP): https://www.nrcs.usda.gov/programs-initiatives/eqip-environmental-quality-incentives
8 Conservation Stewardship Program (CSP): https://www.nrcs.usda.gov/programs-initiatives/csp-conservation-stewardship-program
9 Agricultural Conservation Easement Program (ACEP): https://www.nrcs.usda.gov/programs-initiatives/acep-agricultural-conservation-easement-program
10 Conservation Reserve Program (CRP): https://www.fsa.usda.gov/resources/programs/conservation-reserve-program

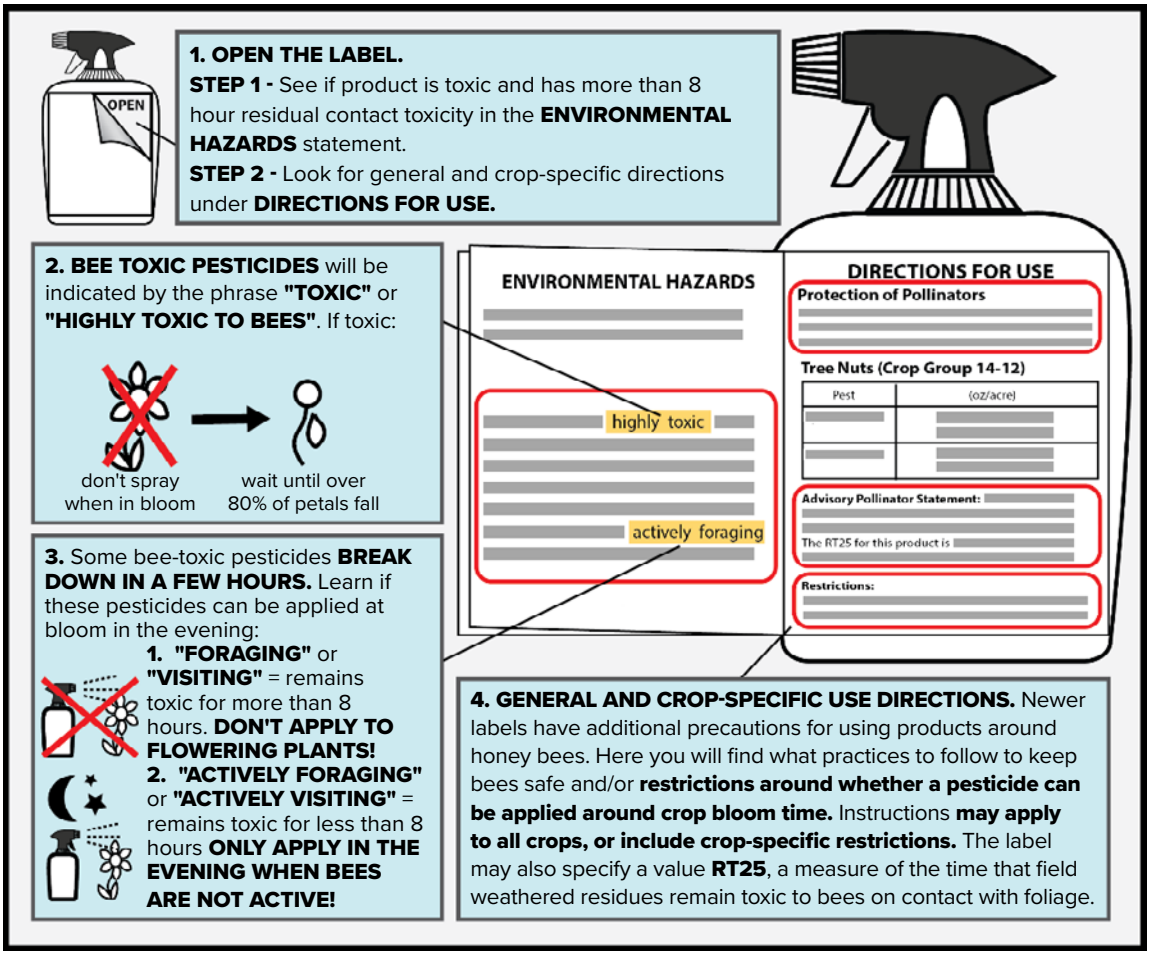


Figure 22. Information on the toxicity of pesticides will be located on the label (1). First, look through the Environmental Hazards section of the label (2-3) which highlight products that are toxic to bees (2) and which may leave persistent residues (3). Labels for products registered or reviewed after 2017 will typically have more detailed crop-specific restrictions outlined under General or Specific Use Directions (4). Image adapted from Oregon State University Extension.

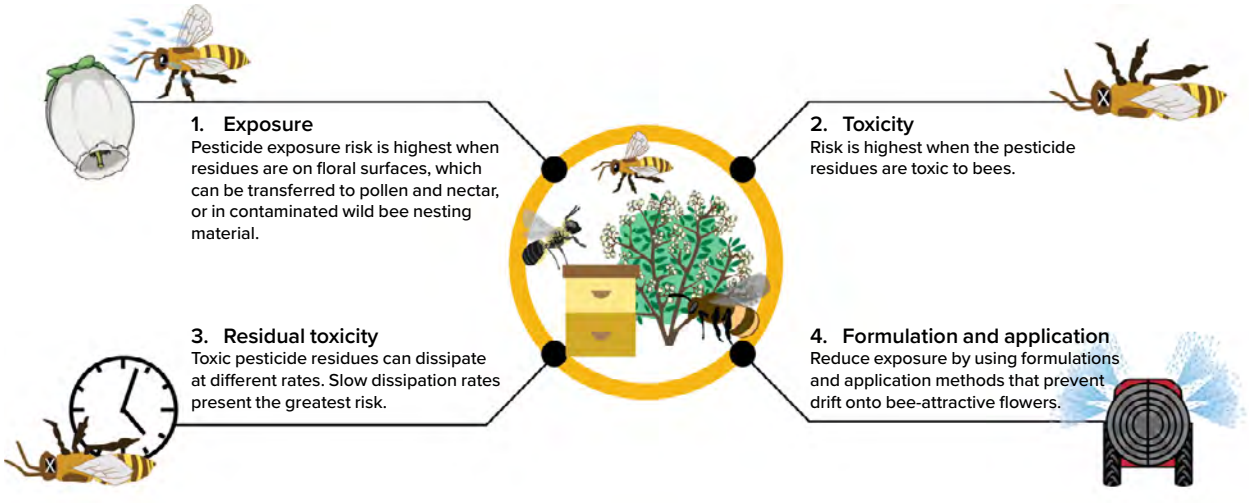


Figure 23. Four factors determine the risk of a pesticide application to bees: (1) whether bees are likely to be exposed to the pesticide on flowers depending on their foraging behaviors, (2) the toxicity of the product, (3) residual time a pesticide remains active after application, also affecting exposure, and (4) the formulation or application used, affecting drift and exposure. Image by Andony Melathopoulos.

Best practices

Beyond restrictions on pesticide labels, growers can employ the following strategies to reduce pesticide exposure during the bloom. First and foremost, maintain proactive communication with your beekeeper, letting them know if pest or disease pressure is mounting and the options you have available to manage these problems. In most cases, beekeepers will be unaware of the pest management constraints growers face. Take time before the field season to talk with the beekeeper to explain the key diseases and pests of blueberry around bloom and general tactics for managing these.

Insecticide and miticide treatments should be avoided during the bloom time unless pest pressure warrants treatment. This can be achieved, for instance, by using a broad-spectrum insecticide or miticide as a clean-up spray prior to bees arriving. If sprays are made around bloom, growers should consult with their beekeeper if they need to apply a pesticide treatment during the pollination period to arrive at a mutually agreeable plan of action.

Fungicide treatments should be restricted to evening applications. If disease monitoring indicates disease spread, then growers should try to restrict treatments when bee activity is reduced (after 8 p.m. until 30 minutes before sunrise). Treatments can be applied during the day if temperatures are not expected to rise above 50°F (10°C) for 2-3 hours after treatments are completed (as honey bees would not be foraging in these cool temperatures). Adjuvant products should be used in tank mixes only when recommended on the fungicide label. An even better option is to select fungicides that are effective without the addition of additional adjuvants. Moreover, fungicides should not be mixed with insecticides during bloom, even if the insecticide labels do not specify restrictions for use around bloom. Using an IPM framework that includes protection of pollinators too, fungicides should only be used when pest risk models indicate an infection period for disease and insecticides should be applied only when traps and degree day models or crop scouting indicate a need to protect the crop .

Insecticide programs after bloom are dominated with sprays for SWD. Most insecticides used for SWD will be toxic to bees. SWD populations should be monitored to better target sprays in order to limit unnecessary insecticide applications. Moreover, measures should be taken to reduce insecticide drift onto bee-attractive blooming plants, including mowing out blooming headland plants within 300 ft (92m) of the field edge and turning off outward facing spray nozzles when spraying the outer row of blueberry plants. Finally, spray technology that reduces drift, such as electrostatic sprayers or smart sprayers, can help prevent the contamination of flowering plants in headlands.

Pollinating in tunnels

Blueberries are sometimes grown under polytunnels to achieve a high berry quality and high yields (Figure 24). Polytunnels modify air temperature, humidity, airflow, light intensity, and light wavelength, which can affect bee foraging behavior. However, honey bees rely heavily on polarized light for navigation and this process is disrupted in polytunnels. Other kinds of bees may also struggle with the modifications to light that polytunnels provide. This combined with possibly suboptimal environmental conditions (increased heat and altered humidity) inside polytunnels can lead to poor pollination and reduced yields.

A combination of alternative pollination strategies must often be deployed to ensure effective pollination when using polytunnels (Goodwin, 2012). One option is to avoid using UV-absorbing plastics, when possible, to lessen the effects polytunnels have on bee navigation. If environmental conditions are too hot and/or humid for pollinator activity and pollen release, ventilation should be increased by lifting the tunnel edges and leaving the ends open during bloom to promote airflow. If possible, tunnels should be less than 330 feet (100 m) long as conditions can be suboptimal near the middle of long tunnels and lower pollination success (Hall et al., 2020).

Different species of pollinating insects may also be considered. For example, bumble bees are less sensitive to polarized light and can be used in greenhouses and in polytunnels. Environmental conditions should still be considered, however, as temperatures may still be too high for bumble bees. Hoverflies and other stingless bees may also be considered but their overall efficiency is still being characterized through research.

Some success using honey bees as the primary pollinating insect in polytunnels has been achieved. Like open-field pollination, hives should be healthy with frames full of brood in all stages. Colonies can be placed near the end of tunnels so they can fly in and out of the polytunnel, but some mortality should be expected due to diminished navigation and foragers being unable to return to their colonies. If long tunnels are used, consider placing hives inside the tunnels and

rotating every 2 weeks with new colonies to maintain strong foraging populations. High-contrast landmark signals (e.g., yellow and purple) placed at tunnel edges and interiors may also be used to help honey bees navigate in the absence of solar information (Horridge, 2009; Kheradmand and Nieh, 2019). These landmark signals should be large, boldly colored circles centrally placed with distinctive images consisting of symmetric patterns of bars (Figure 25).

Figure 24. Outside and inside view of polytunnels. Images by Salena Helmreich.

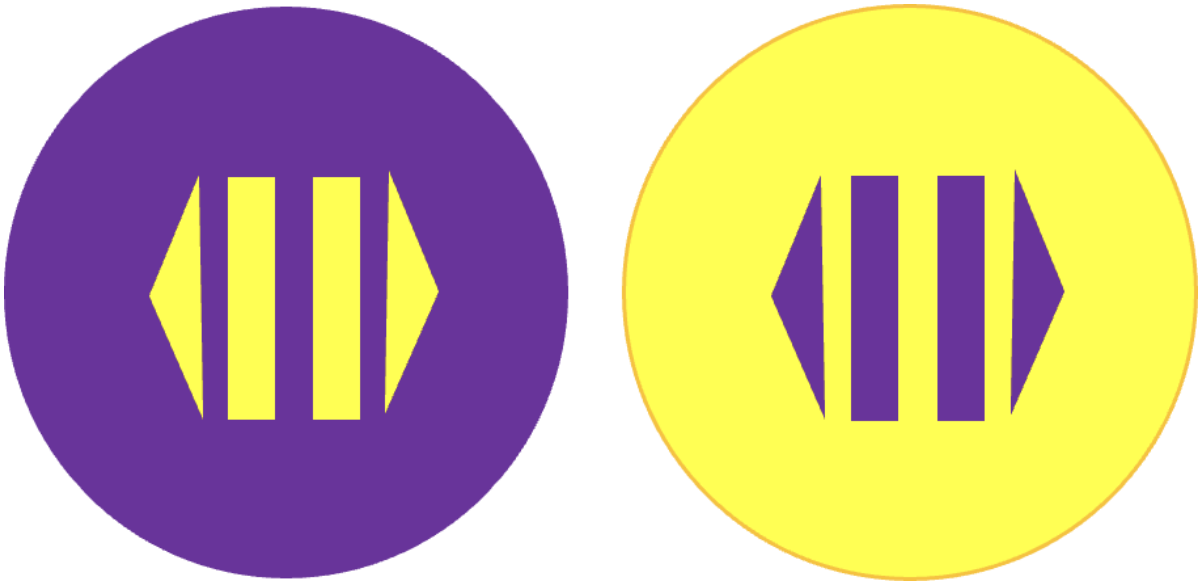


Figure 25. High-contrast landmark signals can be placed inside and at tunnel edges to help honey bees navigate in polytunnels. Image by Salena Helmreich.

Tools available for growers

Growers are frequently enticed to use commercially-available pheromones or attractants designed to stimulate honey bee recruitment and pollination of blueberry flowers. Many of these commercially manufactured pheromones and attractants are applied in the crop field and are designed to mimic brood, queen mandibular, and Nasonov pheromones that are used by honey bees for in-hive communication but not necessarily flower recruitment and foraging. Indeed, research shows many of these products are not reliable at increasing pollination and yield outcomes (Schultheis et al., 1994; Connell, 2000; Ellis and Delaplane, 2009; Williamson et al., 2018). As a result, commercially available pheromones and attractants applied in the crop field are not considered good pollination investments based on the current literature. Some research does however indicate feeds given to honey bee colonies containing crop flower scents laced with caffeine or arginine and delivered pre-bloom can aid pollination (Farina et al., 2020; Arnold et al., 2021; Estravis-Barcala et al., 2021). These "training" feeders hold promise for promoting targeted pollination of blueberry as well as pollination of cultivars that are less attractive to honey bees.

New technologies

Other new technologies and services are emerging that claim to improve pollination services and bee health. Examples of some of these technologies include new pheromones and attractants, honey bee dietary feeds and/or supplements that claim to increase colony health, mechanical pollination, and decision support tools (Figure 26). It will be critical to evaluate the efficacy of these new technologies and if they are cost effective for both blueberry growers and beekeepers. Universities and organizations financially independent of pollination technology companies are best suited to objectively evaluate these technologies. In addition, some universities are at the precipice of offering decision-support tools free-of-charge that provide predictions of crop phenology and comparisons of the cost-benefits of variable honey bee stocking densities. These tools and others are available as guides to enable more evidence-based management decisions for both growers and beekeepers. Contact your local extension agent or crop specialist to learn more about what is available in your region. In addition, new information and tools can also be found on the university-sponsored Blueberry Pollination Project website[11].

Figure 26. Sensor placed on honey bee colonies that enable growers to track pollination through real-time reports. Image by Andony Melathopoulos.

Conclusion

Pollination is a critical factor in the successful cultivation of blueberries, directly impacting fruit set, berry size, quality, and overall yield. By understanding the complex interplay between different pollinators, environmental conditions, and agricultural practices, growers can develop and implement a comprehensive pollination strategy that maximizes productivity. This guide has provided a roadmap for utilizing both managed and wild pollinators, optimizing habitat conditions, minimizing pesticide exposure risks, and incorporating innovative technologies to support long-term sustainable and efficient blueberry production. By implementing some of these best practices, growers can ensure the health of their blueberry crop while also contributing to the broader ecological health of their farms.

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11 Blueberry Pollination Project: https://blueberrypollination.org/.

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WHAT BEES ARE IN YOUR FIELD?

GROUND-NESTERS:

70% of all bees are ground nesters. Ground nesting bees build their nests in well-draining soil where tunnels can be excavated for laying eggs and developing brood. With a keen eye, nest entrances can be spotted as a small hole in the ground.

Large mining bees *(Andrena spp.)*

Large mining bees are abundant and emerge in early spring. They are often gregarious nesters, meaning they make their nests in aggregations near other mothers of their species for safety in numbers. Large mining bees are common blueberry visitors and can sufficiently pollinate a blueberry flower in one visit.

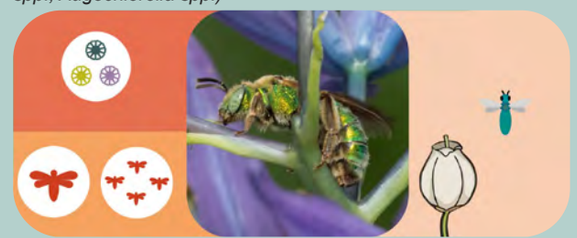
Small mining bees *(Andrena spp.)*

Similar to large mining bees, small mining bees next in aggregations in sandy soil.

Dark sweat bees *(Lasiolossum spp., Halictus spp.)*

These bees are so small that the human eye can often miss them or mistake them for other insects in the field. Sweat bees get their name from their attraction to the salt in sweat.

Blue-green sweat bees *(Augochiora spp., Agapostemon spp., Augochlorella spp.)*

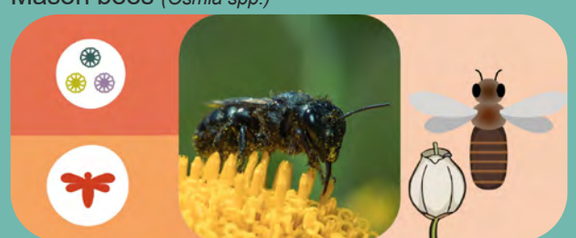


Relatively common bees. Blue-green sweat bees coloration can range from a full body of brilliant emerald gree, to a green head and thorax with dark-colored or striped abdomen.

TUNNEL-NESTERS:

Bees that nest in tunnels burrow into wood or open cracks and chambers in stonework. Mason bee hotels have gained recent popularity as nice additions to backyards and gardens.

Mason bees *(Osmia spp.)*



Mason bees get their name from using mud to create the infrastructure ("brood cells") inside of their nest. There are many species in North America that occur naturally, but a handful are also used commercially.

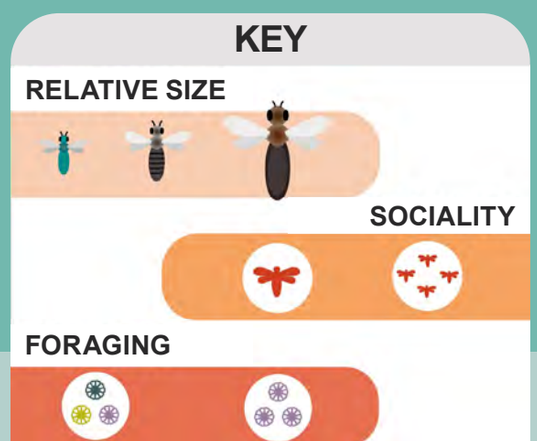
Large carpenter bees *(Xylocopa virginica)*

Some humans may dislike these bees because of their propensity to nest in the wood of houses and decks. Large carpenter bees are distinct due to their sheer size and shiny abdomens. They are the largest bees you might see in your field.

Small carpenter bees *(Ceratina spp.)*

These bees are very small and look nothing like the large carpenter bee; they are similar in size to the smaller species of sweat bees. They like to bore into the pithy stems of canes from raspberry, blackberry, hydrangea, sumac, among others.

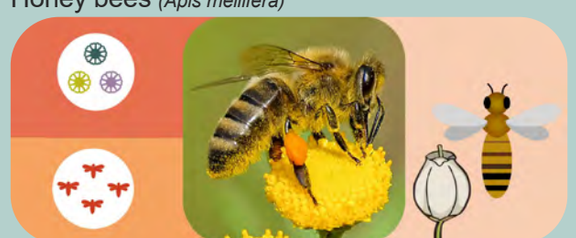
KEY



CAVITY-NESTERS:

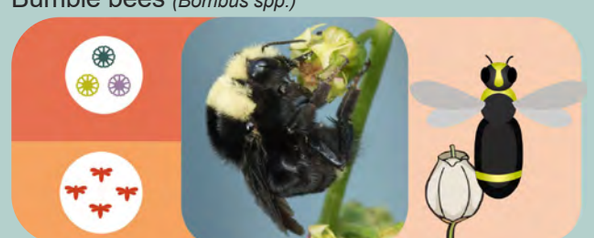
Cavity nesters find abandoned holes such as rodent dens and other empty cavities to build their social colonies. They like to nest near floral resources to feed their constantly emerging brood throughout the spring and summer.

Honey bees *(Apis mellifera)*



Honey bees can range in color from a light orange-brown to almost black. Uniquely, honey bees have hair on their eyes to help with foraging.

Bumble bees *(Bombus spp.)*



Bumble bees evolved with blueberry and are therefore most effective pollinators of blueberry. They are able to buzz pollinate flowers and sufficiently pollinate blueberry in one visit.

DEFINITIONS

Relative size- These are sizes that can be visually compared to other bees, as print-outs of this table will not be to scale.

Sociality- Solitary or Social.

Foraging- generalist vs. specialist - Multicolored indicates a generalist that forages on many different types of flowers, whereas specialists only visit a specific family, genus, or species. Pollinators in crop fields are often generalists.

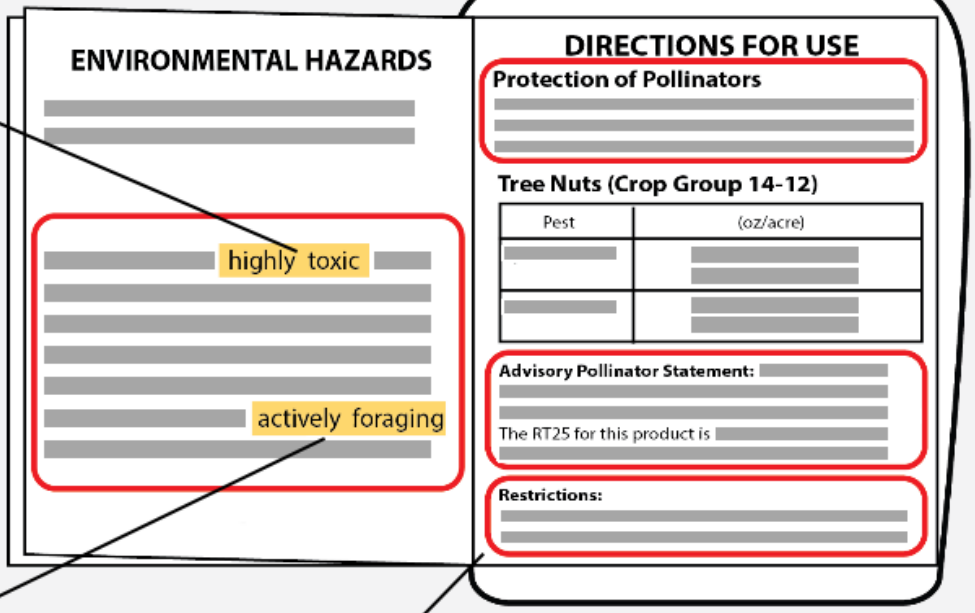
Images: August Jackson, 2024. Honey bee: Pixabay, 2024.

1. OPEN THE LABEL.
STEP 1 - See if product is toxic and has more than 8 hour residual contact toxicity in the **ENVIRONMENTAL HAZARDS** statement.
STEP 2 - Look for general and crop-specific directions under **DIRECTIONS FOR USE.**

2. BEE TOXIC PESTICIDES will be indicated by the phrase **"TOXIC"** or **"HIGHLY TOXIC TO BEES"**. If toxic:

don't spray when in bloom

wait until over 80% of petals fall



3. Some bee-toxic pesticides **BREAK DOWN IN A FEW HOURS.** Learn if these pesticides can be applied at bloom in the evening:

1. **"FORAGING"** or **"VISITING"** = remains toxic for more than 8 hours. **DON'T APPLY TO FLOWERING PLANTS!**

2. **"ACTIVELY FORAGING"** or **"ACTIVELY VISITING"** = remains toxic for less than 8 hours **ONLY APPLY IN THE EVENING WHEN BEES ARE NOT ACTIVE!**

4. GENERAL AND CROP-SPECIFIC USE DIRECTIONS. Newer labels have additional precautions for using products around honey bees. Here you will find what practices to follow to keep bees safe and/or **restrictions around whether a pesticide can be applied around crop bloom time.** Instructions **may apply to all crops, or include crop-specific restrictions.** The label may also specify a value **RT25**, a measure of the time that field weathered residues remain toxic to bees on contact with foliage.