Pollinator Management for Organic Seed Producers

Eric Mader and Jennifer Hopwood

The Xerces Society
for Invertebrate Conservation

Review provided by Organic Seed Alliance

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

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More than 80% of the world's flowering plants depend upon insect pollinators to produce seed; this includes more than two thirds of all agricultural species. Because of this, bees and other pollinators are of obvious importance to producers.

Organic seed producers may be particularly interested in the role of pollinators, especially when confronted by the risk of genetic contamination of their crops (such as by the accidental movement of genetically modified crop pollen). Understanding the role and diversity of seed crop pollinators, and strategies for reducing pollen movement between organic and conventional farms, can help ensure the survival of a robust organic seed industry.

Why Care About Pollinator Management?

Since the mid-1950s, the number of commercially managed honey bee hives in the United States has declined by nearly 50%. The accidental introduction of various honey bee diseases and parasites, as well as habitat loss, pesticide use, and other factors have all contributed to this trend. Despite this decline, in the same time frame, the amount of U.S. crop acreage requiring bee pollination has nearly doubled.

While the decline of honey bees has been widely reported, less attention has been paid to similar declines of our native bee species, including our bumble bees, several of which are now believed to be teetering on the brink of extinction. By incorporating pollinator conservation into an organic farm system, growers can play a meaningful role in helping to reverse these trends.

Pollinator conservation can also help farmers fulfill the biodiversity requirements for organic certification described in the National Organic Program (NOP) Rule. For example, the NOP definition of organic farming includes practices that:

> *"Foster cycling of resources, promote ecological balance, and conserve biodiversity." (§205.2)*

-and-

> *"Maintain or improve the natural resources—the physical, hydrological, and biological features, including soil, water, wetlands, woodlands, and wildlife—of the operation." (§205.200 and §205.2)*

Pollinator conservation provides a convenient framework for meeting these requirements, and can provide secondary benefits to soil and water protection. It can also enhance pest control through the protection of beneficial insects that prey upon crop pests.

How Does Pollinator Management Impact Crop Genetics?

Effective seed-crop pollination can be a delicate balancing act between limiting undesirable outcrossing of different crop varieties, while ensuring extensive pollen transfer between the desired populations of plants.

Undesirable outcrossing can occur when pollen is carried by the wind or bees into a seed crop field from an outside source. In some cases that outside source may simply be another compatible organic seed crop. For example, two different organic squash varieties growing in close proximity may cross when bees move pollen between their flowers. While the resulting seed would have two organic parents, the crossing of their genetics would produce a new squash variety that may not be desirable.

In other cases, undesirable outcrossing can occur when wind or bees move pollen between a genetically modified crop field and an organic seed crop. For example, if an herbicide-resistant alfalfa field is planted near an organic alfalfa seed field, bees may move pollen between the crops. For the organic seed producer, this could mean a seed crop that carries the genetically modified trait.

It is important to note that seed crops are often broadly categorized as either wind-pollinated or insect-pollinated. However, sometimes the lines between these two categories are blurred. For example, bees, especially honey bees, will sometimes collect pollen from plants such as corn that are considered to be wind-pollinated. This blurring of lines should be considered when factoring isolation distances (described later) between different crop varieties. Similarly, the potential for pollen contamination through the movement of beekeeping equipment is unknown, but should be considered for some crops (see the discussion of alfalfa leafcutter bees later in this publication).

While outcrossing between different seed fields can be problematic, insufficient pollen movement within a single crop variety can also create problems. For example, a few seed crops are self-incompatible, meaning they require pollen from another plant to produce seed.

Many seed crops are susceptible to inbreeding depression. Inbreeding depression can cause plants to produce less pollen, less seed, and less vigorous offspring when self-pollinated or crossed with plants that are too closely related. Plants will usually produce more vigorous offspring and more bountiful seed crops when cross-pollinated with genetically distinct individuals within the population. Onions, for example, are a crop that is commonly considered susceptible to inbreeding depression. In one study onion seed produced through cross-pollination between neighboring plants had more than 75% seedling survival when planted in the field, compared with less than 50% seedling survival when the seed was produced through self-pollination.

For insect-pollinated crops that are either self-incompatible, or are susceptible to inbreeding-depression, it is critical to ensure that large numbers of pollinators are present to move pollen between flowers.

Bee Behavior and Crop Pollination

For most vegetable and agronomic seed crops, bees are the most important pollinators. Adult bees feed on nectar. However, unlike other insects that visit flowers exclusively for nectar (such as butterflies), bees actively collect pollen as the primary food source for their larvae. In the process of visiting flowers for pollen and nectar, bees accidentally drop large quantities of pollen grains wherever they go.

Bees are also among the few groups of insects that establish nests for their larvae. In the case of honey bees, that nest is a hive filled with wax combs that contain eggs and developing brood, while bumble bees in contrast, tend to create a small cluster of wax pots to hold their eggs in an insulated cavity (such as an old rodent burrow). Solitary bees, such as sweat bees, tunnel into the ground and lay eggs in a series of dead-end chambers provisioned with pollen. Because of this nesting habit, bees tend to stay in a particular area, spending the days enlarging their nest, laying eggs, and collecting pollen to feed their offspring. Consequently bees tend to visit the same nearby plants over and over again. Seed crop producers can take advantage of this foraging range by either placing a honey bee hive in the field—ensuring adequate crop pollination in close proximity to the hive—or a producer can implement conservation practices that protect resident wild bee populations that can deliver that same (and in some cases, better) pollination service.

Finally, unlike some flower-visiting insects, bees exhibit a behavior called floral constancy, meaning they visit the same flower species in succession. This important behavior means that bees will continue to visit the same type of flower repeatedly for a given period of time, ensuring cross-pollination within the same species. For example, bees collecting squash pollen will typically continue to visit squash flowers for a number of minutes or hours, repeatedly spreading pollen between them. The presence of sunflowers or other blooming plants nearby will not entice the bees away from squash until they are ready to visit those sunflowers in repeated succession. Bees make these switches between different flower species based upon the quality and availability of pollen and nectar. Many plants will provide more nectar or pollen at particular times of day, or on a single day within their bloom period. Bees are constantly checking these resources in their environment, and selecting the most rewarding ones at a given moment to harvest.

2 Common Seed Crop Pollinators of North America

North America is home to roughly 4,000 species of bees, the vast majority of which live solitary lives, with each female constructing and provisioning a nest, laying a small number of eggs, and dying before her offspring emerge (usually the following year) as adult bees. Male solitary bees typically spend their days drinking nectar and looking for mates. They don't actively collect pollen, but may transfer it incidentally as they visit flowers to drink nectar or find female bees.

Although these solitary species make up the majority of our bee species diversity, they are often overlooked because of their typically small sizes and often drab appearances. Despite this, they are present on most farms, and contribute enormously to crop pollination—in many cases providing all of the crop pollination a farmer needs.

At the other end of the bee diversity spectrum are the larger bumble bees, which are social and form an annual colony of a single queen and dozens of her worker-daughters. A healthy organic farm will support both these large social workhorses, and myriad small solitary bees. In addition to bees, many other insect groups contribute to pollination. Of these various groups flies and wasps are sometimes of notable importance for various seed crops. These two groups can also help to control pests like aphids.

Honey Bees

Life Cycle: Honey bee (*Apis mellifera*) colonies live for multiple years and have a caste system consisting of a single egg-laying queen, non-reproductive worker-daughters, and a lesser number of male drones who exist only to mate with newly hatched virgin queens. Individual worker bees live for a few weeks; the queen may live for several years.

Nesting Behavior: Honey bees occupy relatively large cavities such as hive boxes or hollow trees, in which they make vertical combs of hexagonal cells using wax secreted from special glands. The cells are used to support developing brood and to store pollen and honey.

Distribution: Nationwide.

Appearance: Worker honey bees are 0.4 to 0.6 inches in length, moderately hairy, and vary in color from black to amber brown with stripes on their abdomens. All workers have specialized pollen baskets on their hind legs for carrying moistened pollen. Honey bees are the only bees in North America with hairs growing directly on their eyes.

Active Seasons: Honey bees are adapted to Mediterranean climates and do not tend to forage during cool and wet weather. For very early and late season blooming crops in cooler climates, this should be taken into consideration.

Commonly Visited Crops: Honey bees are very good pollinators of sunflowers, clover, vetch, cucurbits, buckwheat, and many brassicas. They tend to be less frequent visitors of umbelliferous crops like carrots and fennel, and sometimes avoid onions due to high sulfur and potassium concentrations in the flower nectar. Although honey bees will collect nectar from alfalfa blossoms, they are considered poor pollinators of the crop, preferring to avoid contact with the stamens and to rob the flowers of nectar by probing them from behind with their tongues.

(Photograph: Eric Mader/The Xerces Society.)

Notes: The honey bee was introduced to North America from Europe in the early 1600s as a source of honey and bee's wax, and became established in both managed hives and in feral colonies. In recent years beekeeping has become increasingly difficult due to disease, parasites, pesticides, and other factors. Despite this, there is a growing resurgence of backyard beekeepers making the species still common in most places.

Because of their long-distance foraging (up to 5 miles or more from the hive), honey bees may increase the risk of out-crossing between different crop varieties. This can be of particular concern when seed crops are located within a few miles of genetically modified crops of the same species. For example, despite being wind-pollinated, corn is a plant that honey bees will sometimes collect pollen from.

Bumble Bees

Life Cycle: Bumble bees live in a social unit consisting of a single egg-laying queen, her non-reproductive daughter-workers, and a lesser number of males. Bumble bee colonies only live for a single season; the old queen, workers, and drones all die at the end of the growing season. Only new queens, born late in the season, survive to the following year (by hibernating underground).

Nesting Behavior: Bumble bees usually construct nests below ground in cavities such as old rodent burrows or within the fibrous root systems of bunch grasses, as well as above ground within empty spaces in compost piles, brush piles, and hay bales.

Distribution: Bumble bees are found nationwide, although individual species have more limited, regional distributions. There are more than 45 species, in the genus *Bombus*.

Appearance: The large size (0.4 to 0.9 inches) and robust, hairy bodies of bumble bees make them easy to identify at a glance. Depending on the species they may have black, white, yellow, brown, or orange color bands, and even within a species there may be variations in individual size and color patterns. Like honey bees, female bumble bees have specialized pollen baskets on their hind legs for carrying moistened pollen.

Active Seasons: Bumble bees are active throughout the growing season, and will forage in both cooler and wetter weather than most other bee species.

Commonly Visited Crops: Bumble bees are excellent pollinators of sunflowers, alfalfa, clover (including species with deep nectaries like red clover), vetch, cucurbits, some brassicas, and solanaceous crops like tomatoes, eggplants, and peppers (likely increasing yields of even self-fertile varieties). Bumble bees will also sometimes visit self-fertile bean, okra, and cotton flowers. At least one species, the common eastern bumble bee (*Bombus impatiens*), routinely gathers corn pollen. Because the foraging range of bumble bees is believed to be a mile or less from their nest, the isolation distances required where only bumble bees are present, is likely minimal.

Notes: Bumble bees have the unique ability to "buzz pollinate" flowers by vibrating their bodies to shake pollen loose. (If you listen, the buzz is close to a middle C note on a piano.) This buzz pollination behavior is frequently observed on tomato blossoms as a means for extracting hard to release pollen (due to the poricidal anther structure of tomato flowers). While most tomato varieties are described as self-fertilizing, where bumble bees are present this buzz pollination has been demonstrated to triple yields of some varieties.

(Photograph: Mace Vaughan/The Xerces Society.)

Because of this buzz pollination behavior, several companies have domesticated bumble bees for sale to farmers. Ecologists are increasingly concerned about the role these factory-reared bumble bees play in spreading disease to wild populations. In recent years a number of species have declined, with some now teetering on the brink of extinction. Caution is urged when considering buying commercial bumble bees, especially because robust wild populations can be fostered with some simple conservation steps.

More than 45 bumble bee species are native to North America. Most are extremely gentle and unlikely to sting unless directly threatened.

Sweat Bees

Life Cycle: Depending on the species and the local conditions, sweat bees may be solitary with each female excavating her own nest independently and laying her own eggs, or gregarious with multiple females sharing a single nest tunnel and laying their own eggs in separate chambers. Some species even form temporarily social colonies with a single egg-laying queen supported by daughter-workers. Also, depending on the species and the climate, there may be multiple generations of sweat bees in a single year.

Nesting Behavior: Most sweat bees are ground-nesting species, digging tunnels directly into the soil where they excavate a series of separate dead-end chambers, each provisioned with a small clump of pollen and a single bee egg.

Distribution: Sweat bees can be found nationwide. There are more than 400 species, in several genera: *Agapostemon*, *Halictus*, *Augochlora*, *Augochlorella*, and *Lasioglossum*.

Appearance: Sweat bees range in color from black to brown to grey, as well as metallic green, and depending on the species, may be primarily solid in color or have white or yellow stripes on their abdomen. They can be between 0.2 and 0.6 inches in length. Female sweat bees carry pollen on stiff hairs located on the upper part of their hind legs.

Active Seasons: Many sweat bees begin to fly in late spring and are active through the summer and early fall.

Commonly Visited Crops: Sweat bees are active pollinators of most major vegetable seed crops, including those like onions and carrots that are relatively unattractive to honey bees or other pollinators. Sweat bees readily visit sunflowers and curcurbits, and are probably among the most important pollinators of brassicas. Common field crops pollinated by sweat bees include buckwheat, canola, and alfalfa. In one study of alfalfa pollination, wild sweat bees were documented to contact the flower stamens during more than 80% of flower visits. In comparison, honey bees contacted the stamens less than 25% of the time.

(Photograph: Eric Mader/The Xerces Society.)

Notes: Sweat bees are so named for their occasional attraction to sweat on people. Despite this occasional interaction with people, sweat bees are extremely gentle, stinging only when squeezed or trapped in clothing. Sweat bees are also often overlooked because of their small size and typically solitary life cycle. Despite this, they are the most common pollinators found on most farms.

Squash Bees

Life Cycle: Squash bees are solitary species with each female independently constructing a nest and laying eggs.

Nesting Behavior: Squash bees excavate underground nest tunnels that end in a series of dead-end chambers, each provisioned with pollen and supporting a single egg. Male squash bees in contrast are sometimes gregarious, spending evenings inside of squash blossoms drinking nectar together in a sort of "bachelor party."

Distribution: Nationwide except far northern climates and the maritime Northwest; about 20 species in two genera, *Peponapis* and *Xenoglossa*.

Appearance: Squash bees are similar in size to honey bees (0.4 to 0.6 inches), and often have a similar amber brown color. They can be readily distinguished from

(Photograph: Nancy Lee Adamson/The Xerces Society.)

honey bees however by their dark abdomen with distinct pale stripes, their slightly more round body shape, hairier appearance, and protruding lower face (which gives the impression of a having a nose).

Active Seasons: Mid to late summer.

Commonly Visited Crops: Squash bees primarily visit crops in the genus *Cucurbita* (the squash and pumpkins), and are considered to be only occasional visitors to *Citrullus* or *Cucumis* (watermelons, cucumbers, and melons). Because they are active so early in the day, many farmers don't realize that squash bees have already fully pollinated their crop before honey bees have even left the hive.

Notes: Squash bees are a small group of bees that specialize on the pollen of squash and usually nest underground at the base of squash plants, coming up to visit the flowers early in the morning, often before sunrise. It is believed that squash bees evolved with squash plants in Central America then expanded their range with human cultivation of squash farther and farther north. Today they are among the first bees to show up in farm fields when squash is planted.

Alfalfa Leafcutter Bee

Life Cycle: The alfalfa leafcutter bee (*Megachile rotundata*) is a solitary species with each female constructing and provisioning her own nest.

Nesting Behavior: Leafcutter bees use their scissor-like mandibles to snip sections—often perfectly circular—out of leaves. These are carried back to their nest and used to form cylindrical wrappers that surround their eggs. (Individual cells resemble short, stubby cigars.) These leaf wrapped egg packages are usually constructed within man-made nest blocks consisting of hollow dead-end tunnels (resembling the bee's natural nest sites of hollow plant stems or abandoned borer beetle holes in trees).

Distribution: Nationwide.

Appearance: At around 0.4 inches in length, the alfalfa leafcutter bee is a relatively small species. Distinguishing characteristics include a dark (nearly black) body with white stripes on the upper abdomen, and rows of stiff yellow hairs on the underside of the abdomen; the bees carry pollen in those abdominal hairs. Other distinguishing characteristics include a wide head and body, with a blunt, rounded abdominal tip.

Active Seasons: Summer.

Commonly Visited Crops: As the name suggests, the alfalfa leafcutter bee is principally managed (in artificial nests) for alfalfa seed production. In addition, the species is occasionally managed for the production of canola, onion, and carrot seed. The bees are also ready visitors of many other crops, like sunflower.

Notes: The alfalfa leafcutter bee is not native to North America, and likely arrived in the early twentieth century in wooden shipping containers. It rapidly spread across the continent and by the 1950s was recognized as an excellent pollinator of alfalfa. (Unlike honey bees, the alfalfa leafcutter tends to contact the flower stamens of alfalfa on every visit.) Seed producers in western states quickly realized that large populations of the alfalfa leafcutter bee could be cultivated in wooden nest blocks drilled with thousands of dead-end tunnels, and that these nest blocks could be placed in shelters surrounding an alfalfa field for pollination.

(Photograph: Eric Mader/The Xerces Society.)

Beginning in the 1980s, new diseases of alfalfa leafcutter bees began to take a serious toll on populations, and alfalfa seed producers transitioned to a system for extracting dormant leafcutter bee cocoons from polystyrene blocks. The advantage of this system was that the nests could be chemically disinfected and the cocoons could be fumigated for parasites (using insecticides at rates low enough to not kill the developing bees). Despite these measures, disease pressure has currently made alfalfa leafcutter bee management impossible in most of the United States. The species is still the primary managed pollinator of most alfalfa seed grown in the United States. However, farmers typically buy new cocoons annually from Canadian producers who can continue to raise bees in areas where disease pressure is lower.

Because of their small size and limited foraging range (usually .25 mile or less), isolation distance requirements for managed alfalfa leafcutter bees are minimal. However, there are growing questions about potential pollen contamination between organic and GMO seed crops through stored leafcutter bee cocoons and beekeeping equipment. For information about this potential risk, see "Pollination Management" in this guide.

In addition to the alfalfa leafcutter bee, hundreds of other leafcutter bees (in the genus *Megachile*) are found across North America. Most are native species, highly adapted to their local climates, and many are excellent seed crop pollinators. To sustain those native leafcutter bee populations, conserve woody debris like stumps, brush piles, and shrubs with pithy hollow stems in natural areas adjacent to the farm to provide nesting sites.

Alkali Bee

Life Cycle: The alkali bee (*Nomia melanderi*) is a solitary species; each female excavates her own nest and lays her own eggs. Despite their solitary nature, the species is considered to be highly gregarious, with females nesting immediately next to each other. Under optimal conditions a dozen or more females may excavate adjacent tunnels within just a few square feet.

Nesting Behavior: Alkali bees are a ground nesting species, digging tunnels directly into the soil where they excavate a series of separate dead-end chambers, each provisioned with a small clump of pollen and a single bee egg. Preferred nesting conditions are saline seeps, areas with high alkaline water tables, and dry lakebeds (playas) where the surface crusting of salts inhibits moisture evaporation from below the soil surfaces and maintains underground humidity.

Distribution: Western states, especially in the Great Basin and arid intermountain regions.

Appearance: Alkali bees are moderately hairy, roughly 0.5 inches in length, and have blue or opalescent stripes on their abdomens.

Active Seasons: Summer

Commonly Visited Crops: Alkali bees are considered optimal pollinators of alfalfa and have an emergence and nesting season that overlaps with the peak summer alfalfa bloom. Unlike honey bees, alkali bees readily contact the flower stamens on every visit. In a few locations, they have been noted as effective pollinators of onion seed crops, mint, and various vegetable crops. The alkali bee flies farther than many native bee species (potentially up to 5 miles from the nest in some cases) making crop isolation distances an important consideration where they are present in large numbers.

(Photograph: James L. Cane/USDA-ARS Pollinating Insects Research Unit.)

Notes: The alkali bee is managed as a commercial pollinator in parts of the Great Basin and the Inland Pacific Northwest. Alfalfa seed producers construct artificial dry lake beds through subsoil irrigation systems and amending the soil with salt. A well maintained “alkali bee bed” can support millions of bees in densities of several hundred nests per square yard.

Long-Horned Bees

Life Cycle: Long-horned bees are all solitary, with each female independently constructing a nest and laying eggs.

Nesting Behavior: Female long-horned bees dig tunnels directly into the soil where they excavate a series of separate dead-end chambers, each provisioned with a small clump of pollen and a single bee egg. In contrast to the typical solitary life of females, male long-horned bees are frequently seen clustering together in groups, sleeping on flowers such as sunflower, or while clinging to tall grasses.

Distribution: Nationwide, 300+ spp. in the genera *Melissodes*, *Eucera*, and *Svastra*.

Appearance: Their common name reflects their most obvious physical characteristic, the long antennae (especially on males) that grace their heads. Another common identifying feature is the thick tufts of pollen-collecting hairs on their hind legs that resemble chaps.

Active Seasons: Summer and fall.

Commonly Visited Crops: Many species of long-horned bees are specialists of sunflower, and can be commercially important pollinators of sunflower crops. One species, the black-and-white long-horned bee (*Melissodes bimaculata*; shown to the right), is a common pollinator of many summer blooming vegetable crops east of the Rockies, and another, *Melissodes thelypodii*, is a common visitor to cotton flowers.

Notes: The black-and-white long-horned bee deserves special mention as a conspicuous and common seed crop pollinator of the eastern United States. Nests of these bees are often found in the ground directly within farm fields, or in areas of sparse turf nearby. The species is a frequent visitor of melons (it is sometimes called the melon bee), but also of sunflowers, and surprisingly, corn. Because this bee doesn't travel far from the nest, it probably does not pose a significant risk of undesirable outcrossing to corn, even when other varieties are located nearby.

(Photograph: Nancy Lee Anderson/The Xerces Society.)

Flies

Flies are one of the most diverse orders of insects on earth, with nearly 120,000 identified species. Of these, perhaps half have been documented to visit flowers, primarily to sip nectar. While less significant pollinators than bees, flies do move some pollen between flowers, and for certain seed crops they can be important pollinators. Three of the fly families deserve special mention for farmers and gardeners: flower flies (family Syrphidae), tachinid flies (family Tachinidae), and blue bottle flies (family Calliphoridae; shown on right).

Flower flies are especially valuable to farmers since they prey upon other small insects (especially aphids) during their larval stage. As adults they sip small amounts of flower nectar for energy and spread the occasional pollen grains between flowers. The striped and sometimes hairy bodies of many flower flies can make them hard to distinguish from bees at first glance. If you look closely however, you will notice that all flies have just one pair of wings (bees have two that are hooked together in the middle). Flies also have short stubby antennae (bees have longer ones), and very large round eyes that almost press up against each other on the top of their heads (bees usually have smaller, more oval-shaped eyes).

(Photograph: Eric Mader/The Xerces Society.)

Tachinid flies also have a beneficial role in controlling many crop pests, and contributing to pollination. Tachinids usually lay their eggs on other insects (often caterpillars). When the fly larvae hatch, they burrow inside of the host insect, eating it from the inside out, and eventually killing it. They can be important for controlling tomato hornworm, cabbage loopers, and a number of other crop pests. Tachinids are variable in coloration but are usually recognized by their rounded shape and bristly hairs on their abdomens.

Blue bottle flies have an unpleasant reputation for eating carrion, detritus, and feces during their larval (maggot) stage. While this doesn't tend to endear them to many people, they play an important role in cycling nutrients and keeping the world clean. As adults they visit flowers for nectar and are easily recognized by their metallic blue abdomens and somewhat hairy bodies. Blue bottle flies are commercially available, and are often used in screened pollinator exclusion cages for the production of carrot seed.

These and other fly families tend to prefer shallow, open flowers with readily accessible nectar droplets. Common vegetable crops pollinated by flies include various brassicas and alliums. Flies are also often the primary pollinators of umbelliferous crops like carrots (shown on previous page), cilantro, and fennel.

Wasps

Wasps are the closest relatives of bees (bees are considered to be evolutionary descendants of wasps), and have life cycles that very much mirror those of bees. The biggest difference is that while bees feed on pollen during their larval stage, wasps feed on meat, usually other insects which the adults spend most of their time searching for. Because of this need to supply their nests, wasps contribute enormously to the control of farm pests like aphids, stink bugs, caterpillars, and many other types of insects.

Like bees, wasps include both solitary (ground- and wood-nesting) and social species, including several well-known exotic and often aggressive social species like the German yellowjacket (*Vespula germanica*) and the European paper wasp (*Polistes dominula*). Despite those few aggressive examples, the vast majority of North America's thousands of wasp species typically avoid people and do not sting.

Wasps come in a wider range of sizes and shapes than bees—from only a few millimeters in length to larger than a bumble bee—but most are relatively hairless. Like bees they have two pairs of wings, and sometimes have striped abdomens. A few wasp families commonly observed on crop flowers are the potter wasps, hornets, yellowjackets and paper wasps (family Vespidae; shown to the right); the digger wasps (family Sphecidae); and parasitoid wasps (families Chalcididae, Braconidae, and Ichneumonidae).

(Photograph: Whitney Cranshaw, CSU, Bugwood.org.)

Adult wasps visit flowers for nectar, and because of their short tongues they prefer shallow flowers with readily accessible nectar droplets. In the process of feeding on nectar, they help move pollen between flowers. Like flies, wasps are occasional visitors to various brassicas, and very common visitors to alliums and umbelliferous crops.

3 Pollination Management

Maintaining a minimum distance between varieties of the same species and between species that may cross is an important consideration for seed growers. Recommendations for isolation distances are based on the mating system of the target crop, which determines their dependency upon insect pollinators.

Cross-pollination is the transfer of pollen between the flowers of one plant and the flowers of another, or between flowers of differing varieties, and can be facilitated by wind or insects. Plants that are self-incompatible or self-sterile require pollen from another plant and are not receptive to their own pollen, and are entirely reliant on insects or wind for pollination. Since these plants are reliant on outcrossing, sufficient isolation distances are important.

In contrast, plants that are self-compatible (also known as self-fertile) have flowers that contain both male and female reproductive parts (known as complete or perfect flowers), are receptive to their own pollen, and are able to produce seeds and fruit from the transfer of pollen within one flower or between flowers on a single plant. Some self-compatible plants are able to self-pollinate, releasing pollen onto a receptive stigma within a closed flower. Wind or insects may still be needed by some species to transfer pollen between anther and stigma within a flower or between flowers on the same plant, and thus effect pollination. In addition, some self-pollinated crops may also outcross to a certain extent. Some self-compatible plants may produce seeds of better quality or larger quantity when cross-pollinated. Guidelines that recommend isolation distances of several feet may be misleading for these crops, especially if they attract a great deal of insect activity, which can increase out-crossing.

Managing Isolation Distances

Plant species or varieties can be isolated with time or with physical barriers. If the climate allows, one variety may be planted earlier than the other, though it must be planted enough in advance that flowering is complete before the second variety begins to bloom. Isolation of crops using physical barriers is more common. On a small scale, pollination screen cages (shown to the right) can be used to minimize potential for contamination. This approach is not always practical, because managed pollinators must be released in the cage and it can be difficult to cage a plant population of adequate size.

Plantings can be used as buffers both to decrease the flow of pollen between wind-pollinated crops and to influence the movement of insect pollinators. Windbreaks or hedgerows of trees and shrubs, as well as meadows and grassy fields, can be used to increase the distance between crops, as well as to provide habitat to support pollinators.

(Photograph: Gerald Holmes.)

Pollinator Foraging Distances

Foraging ranges of bees extend from their nesting site to patches of food. Foraging distance is correlated with bee body size, so smaller bees fly shorter distances to forage, while larger bees are able to travel farther. Many solitary bees travel an average of 0.3 to 0.7 miles to find food. Bumble bees tend to fly less than a mile, though different species may travel less or further. Worker honey bees, which forage in shifts and are guided by their sisters to particularly good places to forage, are able to travel further than most native bees. Although they prefer to forage near their hive, they can travel more than five miles if need be. This long flight distance means that bringing in honey bees to pollinate seed crops may not be ideal if a farmer is not able to separate their crops sufficiently.

Foraging ranges can be influenced by resource availability. If resources are depleted near the nest, bees are willing to expend the energy to fly farther in search of food. However, bees seem to strongly prefer to forage as close to their nest as possible, and will travel the shortest distance to find food as they can. Bees take great care when establishing their nest. They invest time and energy to seek out select sites which have the nesting conditions they need, while also having an ample food supply close at hand. Bees that have a preference for, or specialize on, a particular plant will fly great distances in search of locations with a sufficient population of their target plant. Squash bees, for example, may fly miles to find a suitable patch of squash, and once they find it, they nest near the plants so their offspring will have the best chance at being close to their food supply. Farms that have nesting opportunities for bees are more likely to have bees forage on their crops.

Tabel 1. Foraging distances of selected bees

Type of bee	Typical foraging range	Maximum known foraging range
Honey bee (*Apis mellifera*)	< 1.5 mi	Up to 6 mi
Bumble bee (*Bombus* spp.)	< 0.6 mi	Up to 1.5 mi
Solitary native bees	< 0.4 mi	1 mi

Pollen Contamination from Beekeeping Equipment

With the recent expansion of genetically modified, bee-pollinated seed crops (such as canola and alfalfa), there are new questions arising about potential for pollen contamination of organic seed crops to occur via beekeeping equipment. These questions are especially relevant where large-scale "pollination for hire" commercial beekeeping operations are present, since those operations typically transport bee hives from one location to another, pollinating multiple crops in a single season.

Currently research is still lacking on the extent to which beekeeping equipment might serve as a contamination source for off-farm pollen. However, research has demonstrated that stray pollen grains found inside honey bee hives are sometimes still viable and capable of pollinating flowers when they are inadvertently carried out of the hive by outgoing forager bees. Based upon these findings, bee hives moved from farm to farm within a short period of time to pollinate the same crop, may theoretically still contain viable pollen grains from the first farm that are capable of pollinating flowers in the second.

To assess the risk of such in-hive pollen transfer to organic seed crops, additional research is needed to assess how long the pollen of various crops remains viable. The information that does currently exist demonstrates some cause for concern. For example, guidelines for canola production published by the Australian government note that the plant's pollen may remain capable of effecting fertilization up to one week under optimal storage conditions, and up to four or five days after peak flowering under natural conditions. Since canola is capable of cross-pollinating with other brassica seed crops (see "Specific Crop Considerations" below), an organic seed producer may want to avoid introducing managed bee hives onto their farm if the bees were recently used for pollinating genetically-modified canola.

Similarly, with the development of genetically modified alfalfa varieties, there are now concerns about the potential for alfalfa leafcutter bee cocoons and beekeeping equipment to provide a pathway for genetic contamination of organic seed crops. Loose cocoons of the alfalfa leafcutter bee are typically covered with large quantities of stray pollen grains, and are stored under the refrigeration. Even older research on the viability of alfalfa pollen has demonstrated that individual grains may remain viable for several years under optimal storage conditions. Until more information is available on the potential risk of crop contamination posed by alfalfa leafcutter bee cocoons and beekeeping equipment, seed producers are advised to exercise caution, and investigate alternative pollinators, including the conservation of wild native bees already present on their farms.

Specific Crop Considerations

Below we include known information about the pollination requirements of crops, as well as relationships between specific pollinators and crop plants. For additional information on the potential for cross-pollination of recommended isolation distances, please see Table 2, starting on page 16.

Alfalfa (*Medicago sativa*)

Alfalfa flowers must be tripped and cross-pollinated in order to produce high-quality seed. Honey bees, bumble bees, and a number of solitary bees visit alfalfa and contribute to pollination to varying degrees. Honey bees are not particularly efficient at tripping alfalfa flowers—they only trip about 22% of the flowers they visit—often bypassing the keel petals (and the pistil and stamens held under tension within the keel) to tap into the flower's nectar reserves from the side. In contrast, solitary bees like alkali bees and alfalfa leafcutter bees trip around 80% of the flowers they visit. Honey bees also visit fewer flowers per minute than do native bees. When flowers are tripped, they turn brown, giving fields a brown cast. At least 5 miles should separate genetically modified (GM) and non-GM alfalfa.

Beans (*Phaseolus vulgaris*)

Beans are a self-pollinating species. However, cross-pollination can occur in some varieties to a small degree. Bumble bees, as well as some solitary bees, will visit beans, though honey bees rarely do. Cross-pollination may be more likely to occur in varieties that are more attractive to pollinators, such as pole beans, and under hot weather conditions, when the pollen of some varieties is more viable than others.

Beet, Mangel, and Chard (*Beta vulgaris*)

Although primarily wind-pollinated, sweat bees, leafcutter bees, and other insect pollinators have been documented visiting beet flowers, and may contribute to increased seed yield. Insect visitation, in addition to wind, may be worth considering when factoring isolation distances—especially in regions where GM beet crops are produced. With no barriers to obstruct pollen flow, an isolation distance of 3 miles or more is recommend for crops of different types. With barriers such as forest or hills, the isolation distance can be decreased to 1.5 miles. Isolation between GM and non-GM beet crops should be a minimum distance of 6 miles.

Buckwheat (*Fagopyrum esculentum*)

Honey bees, sweat bees, flies, and various wasps are all frequent visitors of buckwheat flowers, especially in the morning when nectar is more available. Honey beekeepers can produce large quantities of high-quality, dark, strong-flavored honey from buckwheat. Nectar secretion usually stops in the afternoon making the flowers relatively unattractive to insects.

Broccoli, Cabbage, Cauliflower, and Kale (*Brassica oleracea*)

Native sweat bees and flies are common insect pollinators of these crops. Wasps, honey bees, mining bees, leafcutter bees, and occasionally bumble bees are also regularly observed visiting the flowers. Crossing with canola can occur, though rarely. Maintain a minimum distance of 2 miles from GM canola and other *Brassica* spp.

Canola, Rapeseed, and Rutabaga (*Brassica napus*)

These crops are self-pollinated, but pollinators can in-

Sweat bee foraging on canola. (Photograph: Mace Vaughan/The Xerces Society.)

crease seed yield, though the degree to which this happens is variable. Native sweat bees, mining bees, and bumble bees are common insect pollinators. Flies, wasps, and honey bees are also regularly observed visiting the flowers. Researchers in the 1980s found that 18–65% of flower visits by nectar-collecting honey bees consisted of nectar-robbing behavior that bypassed the stigma, making other pollinators especially important for some rapeseed varieties. Isolation distances from GM canola, or crops of the same species, should be a minimum of 5 miles.

Cantaloupe (*Cucumis melo*)

Pollinators are essential to cantaloupe seed production. Bumble bees, sweat bees, small carpenter bees, and honey bees are frequent cantaloupe pollinators, although honey bees are easily attracted away from the crop to more pollen- and nectar-rich flowers.

Carrots (*Daucus carota*) **and related crops that do not cross with one another such as Parsnip** (*Pastinaca sativa*)**, Dill** (*Anethum graveolens*)**, and Fennel** *(Foeniculum vulgare)*

Insect pollinators are essential for seed production in this group of crops. The most common pollinators include flies, wasps, and small sweat bees. Long-tongued bee species such as bumble bees and honey bees usually bypass dill for species with more pollen- and nectar-rich flowers. An isolation distance of 1 mile is recommended. Cultivated carrots can cross with wild carrot/Queen Anne's lace, so be sure there is none within 1 to 2 miles or contamination may occur. If Queen Anne's Lace is growing in the vicinity, then carrot seed crop can be grown in a pollination isolation tent and blue bottle flies may be released to achieve pollination and keep seed stock uncontaminated. Similarly, use an isolation tent and flies to pollinate parsnips if populations of wild parsnip are nearby.

Clover (*Trifolum* spp.)

Pollinators are critical for seed production of clover. Red clover (*Trifolium pratense*), alsike clover (*Trifolium hybridum*), and white clover (*Trifolium repens*) are largely self-incompatible, and require pollinators to move pollen between plants in order to produce seed. Butterflies may visit red clover, but do not contribute to pollination. Mason bees, leafcutter bees, digger bees, and honey bees pollinate red clover, though bumble bees are considered the most efficient pollinators, as they are best equipped to access the deep nectar reserves of the flowers and visit more flowers per minute than other bees. Bumble bees and leafcutter bees pollinate alsike clover, as do honey bees, which can access nectar more easily than from red clover. White clovers are very attractive to honey bees, and are also pollinated by bumble bees, small sweat bees, mason bees, and leafcutter bees. Although crimson clover (*Trifolium incarnatum*) is self-compatible, the florets cannot be self-tripped and insects are needed to achieve maximum seed yields. Honey bees are the most common visitors to crimson clover. The appearance of clover can be an indication of sufficient floral visitation. When pollinator activity is good, florets will wilt and turn brown.

Coriander (*Coriandrum sativum*)

Coriander is partially self-fertile, and produces bisexual flowers. Despite this it benefits strongly from insect pollination, with research in the 1990s demonstrating an average of 76% seed-set reduction when pollinators were excluded. Fortunately, many insect pollinators are strongly attracted to coriander flowers, including honey bees, sweat bees, solitary wasps, and a large numbers of flies. In any landscape where native pollinators are present, seed-set in coriander is unlikely to be limited.

Corn (*Zea mays*)

Although corn is wind pollinated, some bees do visit corn tassels to collect pollen. Anecdotally, bee visitation to sweet corn is more common than to flint, flour, or dent varieties (although no research is available to support this claim). Bee visitation may also be more common when other pollen sources are scarce.

Primary bee visitors to corn are honey bees, a few

Honey bee collecting pollen from corn. (Photograph: Nancy Lee Adamson/The Xerces Society.)

bumble bee species (especially the common eastern bumble bee), and the black-and-white long-horned bee. Gene flow between organic and GM corn varieties is a potential risk where honey bees are present and where isolation distances are less than several miles. Bumble bees and solitary bees have shorter foraging ranges and likely pose little threat to undesirable outcrossing.

Cotton (*Gossypium* spp.)

Cotton is primarily self-pollinated, but bee pollination can increase seed production in some varieties. Cotton flowers are visited by honey bees, bumble bees, and solitary bees such as carpenter bees (in the genus *Xylocopa*), long-horned bees, and leafcutter bees.

Cowpeas (*Vigna unguiculata*)

Cowpea is a self-pollinated crop, but cowpea flowers tend to attract both honey bees and bumble bees, with bumble bees specifically reported to contribute to cross-pollination. Various bees and other insects are also attracted to the extrafloral nectaries at the base of leaf petioles.

Cucumber (*Cucumis sativus*)

Movement of pollen from separate male and female flowers by pollinators is critical for cucumber seed production. Cucumber flowers are visited by bumble bees, honey bees, numerous native sweat bees, and long-horned bees such as the black-and-white long-horned bee. Note that honey bees are easily attracted away from cucumber flowers by more pollen- and nectar-rich flowers.

Research from North Carolina demonstrated that the number of aborted cucumber fruit decreases as the number of flower visits by honey bees or bumble bees increases. The rate of fruit abortion was lowest when the flowers were pollinated by bumble bees (when compared to flower visits by other bee species).

Eggplant (*Solanum melongena*)

Eggplant is a self-pollinating crop, but insect pollination is beneficial to seed set and fruit size. Bumble bees and some solitary bees commonly "buzz-pollinate" eggplant blossoms to extract pollen.

Fava Beans (*Vicia faba*)

Varieties of fava bean rely on self-pollination to varying degrees, and consequently, benefit from insect pollinators differently. However, researchers have found that without cross-pollination, production decreases over several generations. Bumble bees, honey bees, and solitary bees such as digger bees and leafcutter bees will pollinate fava bean flowers, though not all bee visits result in pollination. Carpenter bees and bumble bees may rob nectar from flower bases, and honey bees may visit the extrafloral nectaries without contributing to pollination.

Flax (*Linum usitatissimum*)

In some varieties, flax may benefit slightly from bee pollination, but flax is predominately a self-pollinating species. Honey bees and bumble bees will visit flax.

Lentils (*Lens culinaris*)

Lentils passively self-pollinate and receive no known production increases from pollinator visits.

Lettuce (*Lactuca sativa*)

Lettuce flowers are perfect, and self-pollinating with little out-crossing occurring even among different varieties planted at relatively close distances (although occasional out-crossing with nearby wild lettuce weeds may occur). Lettuce flowers produce little accessible pollen or nectar and get few insect visitors, although small sweat bees and flies may occasionally be observed investigating the blossoms.

Onions (*Allium cepa*) **and related crops that do not cross with one another, such as Leeks** (*Allium ampeloprasum*)

Common insect pollinators such as native sweat bees, some leafcutter bees, flies, and wasps are essential for onion seed production. Honey bees often avoid onion flowers if more attractive floral resources are available. This is probably due to the presence of repellent chemical compounds in the flower nectar, and the thick viscous consistency of the nectar (especially in hot weather).

Peas (*Pisum sativum*)

Pea flowers are self-pollinating. Although they may be visited by bumble bees and some large solitary bees, there is no increase in pea seed production with animal pollination.

Peppers (*Capsicum* spp.)

Peppers are generally self-pollinated, but cross-pollination by insects can be beneficial to pepper production. The attractiveness of pepper flowers to insect pollinators varies between species, and even within varieties. Honey bees, bumble bees, various solitary bee species, and flies have all been documented as pollinators of various peppers.

Pumpkins and Squash (*Curcurbita* spp.)

Insect pollinators are essential to pumpkins and squash. Squash bees in the genera *Peponapis* and *Xenoglossa* are the considered to be among the most effective pollinators. They nest underground at the base of the plant and emerge to visit the blossoms early in the morning, often before sunrise, and before honey bees have even emerged from their hive for the day. Many commercial squash producers rent honey bees to ensure adequate pollination without even recognizing the presence of squash bees in their fields, which are already pollinating most of the crop.

Squash bees rapidly colonize new areas where squash is cultivated, and prosper in no-till, or reduced tillage cropping systems.

Bumble bees and various sweat bees are also reliable and common squash pollinators. In a study of bee visitation to squash flowers in Tennessee, researchers found that 75% of single bee visits by bumble bees resulted in whole fruit development, compared to only 31% of single bee visits by honey bees.

Radish (*Raphanus sativus*)

Radish is self-incompatible and relies on insects for cross-pollination. The blossoms of radish are highly attractive to insect pollinators including honey bees, bumble bees, various sweat bees, and nectar-seeking flies and wasps. Radish can cross with wild radish (*Raphanus raphanistrum*), an introduced weed, and to a much lesser extent, canola. Radishes should be isolated from canola, particularly GM canola, by at least 2 miles.

Runner Beans (*Phaseolus coccineus*)

Runner beans are relatively attractive to bee pollinators, and yield increases have been reported where abundant bee pollinators are present. Honey bees and bumble bees are among the most common flower visitors. Hummingbirds are also attracted to the brightly colored flowers of runner beans.

Bumble bees drinking nectar from a squash flower. (Photograph: Nancy Lee Anderson/The Xerces Society.)

Soybean (*Glycine max*)

Although self-pollinating, honey bee pollination has been demonstrated to increase yields of some soybean varieties. Attractiveness to bees is reported to vary widely among varieties. Interest in supporting pollinators of soybeans may increase greatly if breeding and seed production of hybrid varieties is developed further, because bees will be needed to provide cross-pollination.

Sunflower (*Helianthus annuus*)

Insect pollinators are critical for sunflower seed production, even in varieties of sunflowers that are self-compatible. Although self-pollination can take place in a few varieties in the absence of insect pollinators, seed set, oil content, and germination are typically reduced. Except for double-petaled varieties, sunflowers attract a huge diversity of bee species, including long-horned bees, leafcutter bees, bumble bees, many types of sweat bees, and honey bees. Flies, wasps, certain beetles, and other insects are also occasional flower visitors, but generally bees are considered the most common sunflower pollinators. Annual sunflower attracts an enormous diversity of bees. Over 280 species of bees are known to visit sunflower in North America, and of these, over 40% are pollen specialists on sunflower. Note that older, open-pollinated sunflower varieties may be highly dependent on insect pollination (producing less than 25% of potential seed set in the absence of pollinators), while some modern agronomic hybrid varieties are considered largely self-fertile.

Tomatoes (*Solanum lycopersicum*)

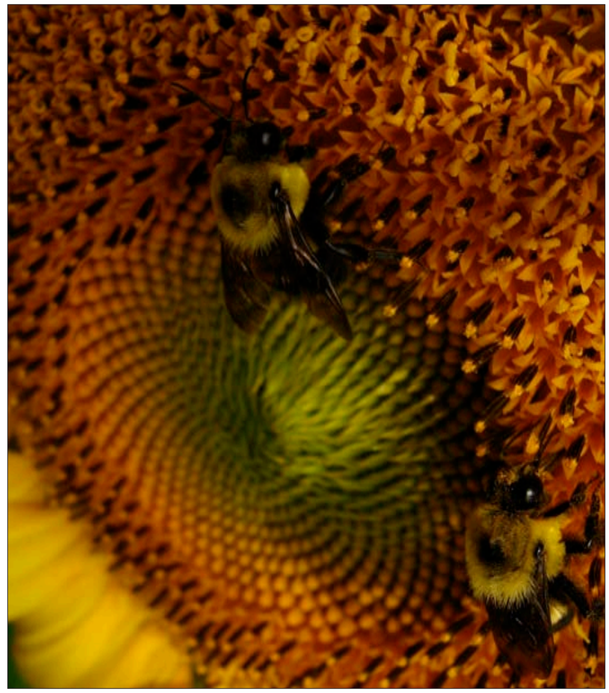
Bumble bees commonly "buzz-pollinate" tomato blossoms to remove pollen. This may increase seed set and fruit size, even among varieties considered to be self-compatible. Varieties where the stigma extends beyond the anther cone (including many potato leaf and beefsteak varieties, as well as many cherry tomatoes) probably especially benefit from bumble bee pollination. Sweat bees, long-horned bees, and digger bees (in the genus *Anthophora*) sometimes also visit tomatoes for pollen, and a few species may occasionally buzz-pollinate them in a similar manner as bumble bees.

Turnip, Field Mustard, and Napa Cabbage (*Brassica rapa***)**

Seed production of these crops benefits greatly from insect pollinators like native sweat bees. Flies, wasps, honey bees, and occasionally bumble bees are also regularly observed visiting the flowers. Because *Brassica rapa* may cross with *B. oleracea* as well as *B. napus*, a distance of at least 5 miles between *B. rapa* and GM canola is recommended to avoid contamination.

Vetch (*Vicia* spp.)

Hairy vetch (*Vicia villosa*) is entirely reliant on bees for cross-pollination, as it is self-incompatible. Bumble bees, honey bees, and carpenter bees visit the flowers. Carpenter bees are known to bypass the reproductive structures in order to rob nectar, and honey bees occasionally struggle to retrieve nectar through the mouth of the flower. Honey bees may be drawn away from hairy vetch if more attractive flowers are nearby. Pollination of common vetch (*Vicia sativa*) takes places within floral buds via self-pollination, and although bees visit open flowers they contribute little to pollination.



Common eastern bumble bees on sunflower. (Photograph: Eric Mader/The Xerces Society.)

Watermelon (*Citrullus lanatus*)

The transfer of pollen between flowers on the same plant or between flowers on different plants by bees is essential for watermelon production. Dozens of native bee species, particularly sweat bees and bumble bees, have been documented visiting watermelon flowers. Extensive research in California and the Mid-Atlantic has demonstrated that farms with sufficient adjacent natural habitat can get all of their watermelon pollination from these wild bees alone.

Research from North Carolina demonstrated that the number of aborted watermelon fruit decreases as the number of flower visits by honey bees and bumble bees increases. The rate of fruit abortion was lowest when the flowers were pollinated by bumble bees (when compared to flower visits by other bee species). Honey bees are also easily attracted away from watermelon flowers by more pollen- and nectar-rich flowers.

Table 2. Crop separation distances and pollination considerations

Crop common name	Species name	Pollination mechanism	Recommended isolation distance	Notes
Alfalfa	*Medicago sativa*	Insect pollinated	1–2 miles (1.6–3.2 km) 5 miles (8 km) where GM alfalfa is present 10 miles (16 km) where GM alfalfa and honey bees are present	
Beans	*Phaseolus vulgaris*	Self-pollinated	150 ft (46 m)for bush varieties 500 ft (152 m) for vine varieties	
Beet Chard Mangel Various others	*Beta vulgaris*	Primarily wind pollinated, though insects will also transfer pollen	3 miles (4.8 km) 6 miles (9.6 km) where GM beets are present	
Buckwheat	*Fagopyrum esculentum*	Insect pollinated	1–2 miles (1.6–3.2 km)	
Broccoli Cabbage Califlower Kale Various others	*Brassica oleracea*	Insect pollinated	1–2 miles (1.6–3.2 km) 5 miles (8 km) where GM canola is present 10 miles (16 km) where GM canola and honey bees are present	Capable of cross-pollination with *Brassica rapa*, crossing with *B. napus* is more rare
Canola Rapeseed Rutabaga Various others	*Brassica napus*	Insect pollinated	1–2 miles (1.6–3.2 km) 5 miles (8 km) where GM canola is present 10 miles (16 km) where GM canola and honey bees are present	May cross-pollinate with wild radish (*Raphanus raphanistrum*), *Brassica rapa*, and more rarely, with *B. oleracea*
Cantaloupe	*Cucumis melo*	Insect pollinated	1–2 miles (1.6–3.2 km)	
Carrots Parsnip Dill Fennel Various others	*Daucus carota* *Pastinaca sativa* *Anethem graveolens* *Foeniculum vulgare*	Insect pollinated	1–2 miles (1.6–3.2 km)	
Clover	*Trifolium pratense*, *T. incarnatum*, *T. repens*, *T. hybridum*, and others	Insect pollinated	1–2 miles (1.6–3.2 km)	
Coriander	*Coriandrum sativum*	Insect pollinated	1–2 miles (1.6–3.2 km)	
Corn	*Zea mays*	Wind pollinated Insects may also transfer small quantities of pollen	2–3 miles (3.2–4.8 km) 6 miles (9.7 km) where GM canola is present 12 miles (19.3 km) where GM canola and honey bees are present	

Crop common name	Species name	Pollination mechanism	Recommended isolation distance	Notes
Cotton	*Gossypium* spp.	Self-pollinated, but bees can increase yield in some varieties	1 mile (1.6 km)	
Cowpeas	*Vigna unguiculata*	Self-pollinated, but bees can increase yield in some varieties	0.5 mile (0.8 km)	
Cucumber	*Cucumis sativus*	Insect pollinated	1–2 miles (1.6–3.2 km)	
Eggplant	*Solanum melongena*	Self-pollinated, insect pollinated	0.5 mile (0.8 km)	
Fava beans	*Vicia faba*	Self-pollinated, but bees can increase yield in some varieties	0.5 mile (0.8 km)	
Flax	*Linum usitatissimum*	Self-pollinated, but bees can slightly increase yield in some varieties	< 0.5 mile (< 0.8 km)	
Lentils	*Lens culinaris*	Self-pollinated	20 ft (6 m)	
Lettuce	*Lactuca sativa*	Self-pollinated	20 ft (6 m)	
Onions Leeks Various others	*Allium cepa* *Allium ampeloprasum*	Insect pollinated	1–2 miles (1.6–3.2 km)	
Peas	*Pisum sativum*	Self-pollinated	20 ft (6 m)	
Peppers	*Capsicum* spp.	Self-pollinated, insect pollinated	0.5 mile (0.8 km)	
Pumpkins Squash Various others	*Cucurbita pepo*, *C. mixta*, *C. moschata*, *C. maxima*	Insect pollinated	1–2 miles (1.6–3.2 km)	Cross-pollinates with *Cucurbita pepo*, *C. moschata*, and *C. mixta*
Radish	*Raphanus sativus*	Insect pollinated	1–2 miles (1.6–3.2 km) 5 miles (8 km) where GM canola is present 10 miles (16 km) where GM canola and honey bees are present	Cross-pollinates with wild radish (*Raphanus raphanistrum*), and more rarely, may cross-pollinate with *Brassica napus*
Runner beans	*Phaseolus coccineus*	Self-pollinated, but bees can increase yield in some varieties	0.5 mile (0.8 km)	
Soybeans	*Glycine max*	Self-pollinated, but bees can slightly increase yield in some varieties	< 0.5 mile (< 0.8 km)	
Sunflowers	*Helianthus annuus*	Insect pollinated	1–2 miles (1.6–3.2 km)	
Tomatoes	*Solanum lycopersicum*	Self-pollinated, insect pollinated	0.5 mile (0.8 km)	

Crop common name	**Species name**	**Pollination mechanism**	**Recommended isolation distance**	**Notes**
Turnip Field Mustard Napa Cabage Various others	*Brassica rapa*	insect pollinated	1–2 miles (1.6–3.2 km) 5 miles (8 km) where GM canola is present 10 (16 km) miles where GM canola and honey bees are present	Cross-pollinates with *Brassica oleracea*, and *B. napus*
Vetch	*Vicia* spp.	Some varieties self-pollinate, others are insect pollinated	1–2 miles (1.6–3.2 km)	
Watermelon	*Citrullus lanatus*	Insect pollinated	1–2 miles (1.6–3.2 km)	

4 Conserving Seed Crop Pollinators

Many organic farmers already have enough wild pollinators to maximize their seed crop yields. Nonetheless, it is wise to foster those wild pollinator populations, ensuring that they are resilient and able to rebound from unexpected events like drought, climate change, or the spread of bee diseases. Pollinator conservation need not be elaborate nor expensive, and can be approached in three simple steps.

Step 1. Plant flowers, especially native wildflowers, on your farm.

It is particularly important to provide blooming plants throughout the growing season, so that bees can maximize the number of eggs they lay, and to keep them around (instead of flying away to other areas). Don't worry about the flowers competing for the bees' attention instead of your crops. They will visit both. It is especially critical that pollinators have nectar and pollen resources when the seed-crop plants are not in bloom. In the United States, financial assistance (in the form of cost-sharing grants) is available to help farmers create wildflower meadows for pollinators. These funds are offered through the USDA Natural Resources Conservation Service (NRCS). Contact your local NRCS Service Center to see if you qualify.

While native wildflowers are best, you can also support pollinators with flowering cover crops like crimson clover, vetch, buckwheat, and phacelia. In addition to supporting bees, you will also attract many other beneficial insects, including those that prey on crop pests.

Field-edge pollinator habitat. (Photograph: Jessa Guisse/The Xerces Society.)

Step 2. Minimize pesticide use, and if possible, avoid it altogether.

Even organic-approved pesticides such as spinosad, *Beauveria bassiana*, neem, and pyrethrum are deadly to pollinators and other beneficial insects.

Pest outbreaks can often be reduced by growing a diversity of crops, selecting seed from pest-resistant plants to create new varieties, by rotating crops from year-to-year, and by removing crop debris (dead crop plants, rotting vegetables, etc.). Remember that by reducing pesticide use and planting an abundance of flowers (Step 1), you will also increase populations of beneficial insects that can help suppress pest populations.

If you must use organic-approved insecticides you should try to apply them only when pollinators are not active. Many bees and other flower-visiting insects prefer warm daylight hours for active feeding, so nighttime spraying with active ingredients that have short residual toxicities is a simple strategy for reducing harm. (Note, however, that residual toxicity of many insecticides can last longer in cool temperatures, and dewy nights may cause an insecticide to remain active on the foliage the following morning. Also note that some very important nonpollinator beneficial insects, such as many predatory ground beetles, are nocturnal.)

Whenever an application is made, spray drift should be controlled to prevent poisoning of beneficial insects (and other wildlife) in noncrop areas. Spray drift occurs when spray droplets, pesticide vapors, or wind-borne contaminated soil particles are carried on air currents outside of the crop field. Weather-related pesticide drift increases with greater wind velocity, higher temperatures, and stronger convection air currents, and also during temperature inversions (that is, when air is dead calm and trapped close to the ground). The effects of wind can be minimized by spraying during early morning or in the evening when winds are calmer. Pesticide labels will occasionally provide specific guidelines on acceptable wind velocities for a particular product.

Finally, pesticide spraying on neighboring, nonorganic farms may also pose a potential risk to your resident pollinator populations. To mitigate this risk, non-flowering windbreaks and conservation buffers can be effective barriers to reduce pesticide drift from neighboring fields. For example, windbreaks of dense evergreen trees, which typically attract relatively few beneficial insect species, can be a relatively simple barrier for reducing pesticide drift from neighboring farms. The USDA Natural Resources Conservation Service can provide guidance and financial support for the construction of pesticide buffers. Contact your local NRCS office for more information.

Step 3. Protect nesting and overwintering habitat.

Most native bees are ground nesting, preferring patchy, but usually noncultivated soil. Reducing tillage has been demonstrated to increase squash bee populations for example. Sandy loam soils are especially favored by many ground-nesting bees, but are not absolutely required by many species. If you have sandy soils however, consider exercising special caution. Steps to mitigate the potential harm to pollinators from tillage include using the shallowest cultivation tools available for the job, and using alternatives like flame weeding and smother crops.

Bumble bees tend to prefer overgrown areas for nesting, such as brush piles, and unmowed areas with tall, patchy native bunch grasses. Such undisturbed natural habitat also supports spiders, songbirds, and other wildlife that can provide natural pest control. It is possible to construct artificial nest boxes for bumble bees and wooden nest blocks for wood-nesting pollinators (like leafcutter bees), however sanitation can be a concern as those structures can become contaminated with disease spores. A simpler, and more ecologically sound approach, is simply to conserve undisturbed natural habitat on the farm.

Entrance tunnels of ground-nesting bees, surrounded by excavated dirt. (Photograph: Eric Mader/The Xerces Society.)

Appendix A. Additional Resources

Xerces Pollinator Conservation Resource Center

The Pollinator Conservation Resource Center is a comprehensive source of regional information about habitat restoration plant lists, native bee conservation guides, pesticide reduction information, and other aspects of pollinator conservation. Site visitors choose their location on a map of the U.S. and Canada to find a library of locally relevant, free publications.

http://www.xerces.org/pollinator-resource-center

Organic Seed Alliance

Organic Seed Alliance advances ethical development and stewardship of the genetic resources of agricultural seed. We accomplish our goals through collaborative education, advisory services, and research programs with organic farmers and other seed professionals. Additional publications and other resources on seed production are available online.

http://www.seedalliance.org

eXtension

Several resources on organic seed production are available on eXtension including the organic seed resource guide http://www.extension.org/pages/18434/pollination-and-fertilization-in-organic-seed-production. This eXtension article on Pollination and Fertilization provides a comprehensive overview of seed crop reproductive cycles, seed formation, and pollination in seed production.

Saving Our Seeds

Our mission is to promote sustainable, ecological, organic vegetable seed production in the Mid-Atlantic and South. Saving Our Seeds provides information, resources, and publications for gardeners, farmers, seed savers, and seed growers. Saving Our Seeds offers several publications on seed production and managing isolation distances.

http://www.savingourseeds.org/

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