K·STATE
Research and Extension

Pesticides and Bees

Nearly 75 percent of the world's food crops depend on honey bees and other pollinators. In the U.S. alone, the European honey bee, *Apis mellifera* (Figure 1) pollinates 130 different agricultural crops valued at $15 to $20 billion annually. The impact of pesticides on bees has been a concern for many years. It is an important issue for producers and others who could face economic losses as a result of declining bee populations.

Insecticides are a type of pesticide designed to kill insect pests. Although evidence suggests that inappropriate use of pesticides can harm honey bees (Figure 2) and other pollinators, studies indicate that parasites, diseases, and habitat loss and alteration may actually have a greater impact. In fact, habitat loss and alteration may be the factors most responsible for the overall decline of pollinator populations. Factors associated with declining U.S. honey bee populations are listed in Table 1. Many of these interact, causing greater harm to individual honey bees and colonies.

This publication is intended to increase awareness of the impact of pesticides on bees and offer suggestions on how to protect bees from pesticide exposure. It describes how bee behavior influences pesticide exposure and toxicity, and why laboratory studies reach different conclusions than what researchers have observed in the field. Benefits and risks associated with specific types of pesticides and application methods will be discussed, as well as complex pesticide interactions, which increase risks to bees but are not well understood.

Bee Behavior

Bees derive most of their nutrition from pollen and nectar. Bees process pollen into bee bread, a substance that serves as the main source of food for worker bees and provides larvae with protein and essential amino acids required for growth. Nectar serves as a source of energy necessary for flight, but adult bees consume more pollen than nectar.

Table 1. Factors that disrupt honey bee activity and may be responsible for declines.

- Varroa mite (*Varroa destructor*) — vector of a number of viruses including *deformed wing* and *Israeli acute paralysis virus*
- Lack of habitat that provides nutritious summer forage
- Pesticides
- Poor bee nutrition
- Habitat fragmentation (destruction)
- Diseases (*Nosema ceranae*)
- Small hive beetle (*Aethina tumida*)
- Poor beekeeping practices
- Transportation of beehives acoss the U.S.
- Genetically modified crops (GMOs)

Figure 1. Honey bee, *Apis mellifera,* feeding on a flower.

Figure 2. Honey bees foraging on a flowering plant.

Honey bees are polylectic, meaning they collect pollen and nectar from a diverse array of flowering plants. A honey bee can forage up to four miles from the hive and visit 50 to 100 flowers gathering pollen and nectar. This works to the bee's advantage by diluting exposure to insecticides from treated plants. However, there are few, if any, dilution effects in agricultural cropping systems where a single crop is grown within a large area. Foraging on only one type of flower can increase the risk of pesticide exposure.

Most pollen and nectar collected in the foraging bee's stomach is not actually ingested. In fact, bees may only ingest a small portion of the insecticide formulation. But nearly all pollen and nectar finds its way back to the hive, where non-foraging adults and larvae may be exposed through social interactions.

Any harmful effects from direct contact with a pesticide while foraging depends on the specific pesticide and the age of the bees. The death of the oldest workers, for instance, would have less impact on the hive than losing the same number of nurse bees and larvae. Body size influences a bee's sensitivity to pesticides. Large honey bees with a greater surface-to-volume ratio are more tolerant than smaller honey bees. Bumble bees are more susceptible to pesticides than honey bees because of the amount of time spent foraging. For example:

- Bumble bees remain active at lower temperatures (40˚F), whereas honey bees are active at temperatures above 60˚F.
- Bumble bees are active on cloudy and rainy days, but honey bees are less active in low light situations.
- Bumble bees are active earlier in the morning and later in the evening than honey bees.

Pesticide Exposure and Toxicity

An increase in agricultural production acreage and intensification of practices has led to greater demand for crop pollinators, thereby increasing risks of both direct and indirect pesticide exposure. Contact with wet sprays or encountering dried pesticide residues on leaves or flowers can kill adult bees. Indirect exposure involves sublethal effects on bee behavior, orientation, reproduction, and may occur as a result of social interactions such as sharing a contaminated food source.

Route of exposure. Pesticide toxicity varies depending on the type of exposure. In most cases, contact with a pesticide may be less harmful than ingestion. For instance, adult bees groom themselves constantly and can unintentionally ingest residues that accumulate on their legs and antennae. Most bee poisoning occurs when workers forage on flowering crops contaminated with residues from foliar applications, or when bees ingest pollen and nectar from flowers contaminated with systemic insecticides that have been applied to the soil. In addition, spray drift from a foliar application can kill foraging bees that visit contaminated flowers.

Product formulation. One factor affecting a pesticide's toxicity to bees and other pollinators is product formulation. An emulsifiable concentrate (EC), for example, is less harmful to bees than the same pesticide formulated as a soluble powder. Dust formulations of carbaryl (Sevin) contaminate pollen and can kill bees when residues are stored in combs or are consumed by larvae. Newer carbaryl formulations such as Sevin XLR (Figure 3) are less harmful to bees.

Microencapsulated formulations place bees at greater risk. These liquid or dry pesticide particles are covered in a plastic coating or capsule that sticks to the bee's body and can be taken back and stored in the frames of the hive. Temperature and moisture changes within the hive trigger release of the active ingredient over time, leading to decline of the colony. Inert ingredients added to a formulation to improve a pesticide's effectiveness can be more harmful to bees, especially larvae, than the active ingredient.

Flower density. The number and density of flowers (Figure 4) influences how many flowers bees visit and the number of bees exposed to pesticide residues. Pesticide-contaminated pollen and nectar brought back to the hive and consumed by workers or larvae can lead to eventual decline of the colony. But pesticide residues in pollen and nectar may not be lethal, and bee behavior can prevent contamination of honey.

Pesticides not only can kill bees directly but can negatively affect foraging behavior, reproduction, memory and learning ability, overwintering success, pollination, colony interaction and colony vigor. These indirect effects can be even more detrimental to the health of the colony. For example, when workers encounter a sublethal concentration (dose)

Figure 3. XLR formulation of Sevin (carbaryl).

Figure 4. Flowering plants that are attractive to bees.

of an insecticide and do not return to the hive with pollen and nectar, bees starve and the colony declines.

Environmental factors. Pesticide toxicity diminishes over time as residues are degraded when exposed to sunlight, rainfall, and temperature. Temperature affects bee behavior and thus, the amount of time bees are exposed to pesticides. Foraging activity increases at temperatures above 60°F. Honey bees do not forage at temperatures below 50°F or when nighttime temperatures exceed 55°F. Temperature also influences pesticide residual activity. When pesticides are applied during cool weather, residues remain on plants longer, increasing potential harm to bees. At higher temperatures, pesticides break down more rapidly, which has the opposite effect.

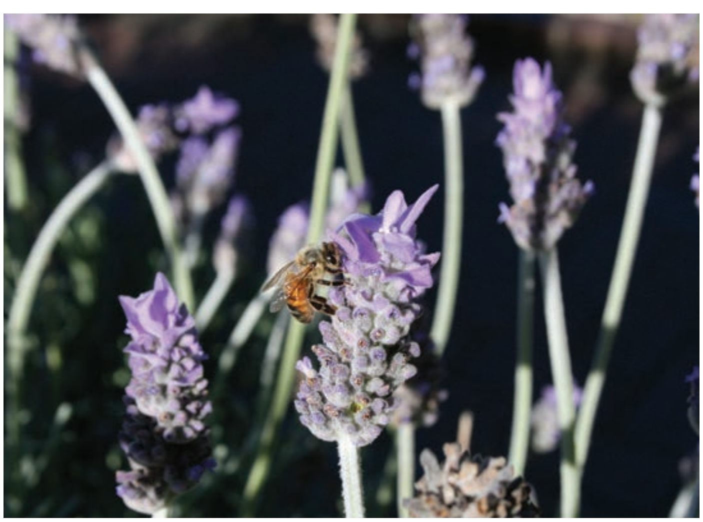

Figure 5. Honey bee (*Apis mellifera*) feeding on a lavender flower.

Application timing. The time of day of a pesticide application influences the risk of bee exposure. Apply pesticides in the early morning or late evening when bees are less active. Do not apply pesticides to flowering plants that attract bees and other pollinators. The duration of pesticide exposure varies by season, flower type, and structure. Foraging patterns are influenced by the presence of certain flowers, which can alter the cumulative, long-term effects of pesticides. For example, honey bees may spend less time foraging on the flowers of lavender, *Lavandula* spp. (Figure 5) than aster, *Aster* spp. (Figure 6). The concentration of active ingredient present in pollen and nectar varies based on the type of flower. Moreover, the concentration of pesticide bees are exposed to by way of pollen and nectar, known as the *field realistic dose,* differs depending on the type and age of the flower. Factors affecting the level of pesticide residues found in pollen and nectar are shown in Table 2.

Figure 6. Honey bee (*Apis mellifera*) feeding on an aster flower.

Table 2. Factors affecting the level of pesticide residues in pollen and nectar.

- Timing of pesticide application during the day
- Application method (foliar vs. soil)
- Application rate of pesticide
- Number of applications (carry-over) of a pesticide
- Pesticide formulation
- Water solubility of pesticide
- Plant type (species) and flower structure
- Plant age and size
- Timing of flowering
- Soil type (organic matter content)
- Environmental conditions such as temperature and light intensity
- Bee age and body size

Laboratory and Field Studies

Laboratory studies have shown that indirect exposure to pesticides can interfere with bee learning and memory, foraging behavior, and orientation or sense of direction, although they tend to overestimate these sublethal effects. For a more accurate assessment, the number of feedings in the field, the application method, and the concentration or the dose bees would typically encounter in the field should be considered.

What's the Difference?

Artificially high doses of pesticides. In some laboratory experiments, bees are fed a sugar solution or substance mixed with pollen or nectar that contains a higher concentration of a pesticide than bees would encounter while foraging. This affects bees differently than a field realistic dose of the same active ingredient.

Experimental methods and procedures. Laboratory conditions are more stressful than field conditions. Bees can sense a pesticide and change their behavior. For example, studies show that honey bees avoid sucrose solutions contaminated with pesticides, which can inhibit feeding and lead to starvation. In the field, bees alter foraging behavior to avoid flowers treated with pesticides, thereby decreasing exposure to contaminated food.

Pesticide interactions. Although direct or indirect exposure to pesticides can interfere with olfactory learning associated with the sense of smell, results from laboratory studies may not apply to real-life situations. Laboratory studies typically do not consider confounding factors and complex pesticide interactions that occur in the field.

Systemic Insecticides

Systemic insecticides are typically applied to the soil to control insects such as aphids, whiteflies, leafhoppers, and soft scales that feed on a plant's vascular system and tissues. The active ingredient is taken up by the root system and distributed throughout the plant where insects feed. There are advantages and disadvantages of using systemic insecticides.

Advantages

- Repeat applications are generally not required for protection throughout the growing season.
- Less susceptible to degradation by ultraviolet light and rainfall, or irrigation after an application.
- Few unsightly residues on leaves when applied to the soil.
- Plants are less harmful to workers and customers as compared to plants treated with spray applications.
- Negligible issues associated with drift compared to foliar sprays.
- Minimal direct effects on natural enemies and bees.

Disadvantages. Systemic insecticides accumulate in the soil. How long they persist depends on the number of applications, application rate, product persistence (residual activity), and soil type. As early as the 1960s evidence began to emerge showing that certain systemic insecticides were harmful to bees. Lord, May, and Stevenson (1968) investigated the secretion of the systemic insecticides dimethoate and phorate in nectar. Publishing their findings in the Annals of Applied Biology (61: 19-27) they indicate:

> *The death of bees following the application of insecticides may be due to direct contact with the spray and/or residues remaining on the surfaces of plants or even direct contamination of pollen. Systemic insecticides may be harmful to bees due to their translocation into pollen and nectar.*

Soil treatments. When applied to the soil, systemic insecticides can have long-term effects on individuals or entire colonies. Although studies have focused primarily on adults, the effects of larval exposure should be considered as systemic insecticides can impair or delay larval development. In general, systemic insecticides applied to the soil as liquid drenches or granules before flowering are less harmful to bees than contact insecticides applied as sprays. However, some systemic insecticides repel honey bees, which reduces bee exposure as well as crop pollination.

The concentration of active ingredient present in pollen and nectar and whether is enough to harm bees is also important due to variability by crop type and plant growth stage. An issue can arise in nursery production systems where systemic insecticides are applied and flowering weeds are visited by bees (Figure 7). In this case, the leachate or run-off that drains from the holes in the bottom of plant containers can be absorbed by the roots of nearby weeds. Therefore, systemic insecticides should be applied to plants preventively before pests begin feeding, but not when weeds are flowering.

Neonicotinoids. Neonicotinoid systemic insecticides are widely used in field crops, ornamentals, turfgrass, and vegetables and fruits. This class of systemic insecticides is under scrutiny due to supposed harm to pollinators. However, it is important to distinguish between the two groups of neonicotinoid systemic insecticides that differ in toxicity to bees due to their persistence (residual activity) in the environment: *N-nitroguanidines* (nitro-group) and *N-cyanoamidines* (cyano-group).

The time required for an insecticide to decrease by half in the soil is known as the soil half-life. The nitro-group includes imidacloprid, thiamethoxam, dinotefuran, and clothianidin. The soil half-life of neonicotinoids in the this group is between 75 and 350 days. These insecticides persist longer in the environment and are potentially more harmful to bees.

Cyano-group neonicotinoids such as acetamiprid are less harmful to bees, mainly because the active ingredient is metabolized by bees. In addition, the active ingredient targets a different site in the central nervous system. In general, acetamiprid and any metabolites produced are less harmful to bees than other neonicotinoids because the active ingredient is metabolized rapidly. Acetamiprid has

Figure 7. Example of container nursery production system.

a soil half-life of less than 25 days, which means the active ingredient is not as persistent in the environment; thus reducing the risk to bees and other pollinators. It should be noted, however, that acetamiprid can only be applied as a foliar spray. In agricultural cropping systems, seed treatments of neonicotinoid systemic insecticides are of major concern because dust emitted during planting can impact bees directly; however, in the absence of flowering plants, this may not be a factor.

Means of exposure. A bee's risk of exposure to any systemic insecticide varies depending on the body size, flower preference, social behavior, and whether bees are active when plants are flowering. Bees can also be exposed to systemic insecticides by accessing extrafloral nectaries (nectar-producing glands that are physically separated from the flower), which are available before plants flower or through exposure to plant fluids that exude from the tips or edges of leaves (guttation). The concentrations of neonicotinoid systemic insecticides present in pollen and nectar depend on the plant species, application rate, formulation, and the timing of application. Neonicotinoid systemic insecticides such as imidacloprid can repel bees, depending on the concentration of active ingredient in the plant; thus, affecting exposure and possibly pollination.

Plant distribution. In a given area, flowers change from day to day and even by time of day. Local weather and soil type can influence the number of flowering plants. The distribution of insecticide-treated flowering plants and foraging distance affect exposure to systemic insecticides. The amount of time bees spend visiting flowers, availability of suitable flowers and alternatives, and the ratio of contaminated to uncontaminated plants influence the direct or indirect effects of systemic insecticides. Distances between treated fields, nest sites, and bee hives affect exposure levels. Foraging distances are determined by the distribution of flowering plants. Therefore, systemic insecticides may not have long-term effects on bees and other pollinators if flowering plants are spread over a distance.

Pesticide Interactions

When contemplating field treatments, producers should be aware of pesticide interactions that may be harmful to bees. Synergistic effects can occur when one pesticide in a mixture enhances the toxicity of the other, thereby increasing the toxicity of the pesticide mixture to bees.

Pesticide mixtures. Mixing active ingredients can lead to synergistic effects, resulting in greater harm to bees; however, these effects are not well understood. Bees can be chronically exposed to pesticide mixtures and multiple pesticides throughout their adult lives, either simultaneously or sequentially. This increases the potential for synergistic effects and contributes to bee decline. Although not all mixtures are synergistic, pesticides can be formulated as premixtures containing multiple active ingredients in one product. For example, pyrethroid insecticides, systemic insecticides, and fungicides are available as premixtures or combination products for plant protection (Figure 8). Pesticides can also be tank-mixed. Combining two or more pesticides in a single spray solution (pesticide mixture), creates the opportunity for synergistic effects that can increase bee toxicity. Mixing insecticides with certain fungicides enhances the acute (short-term) toxicity of the insecticides to bees, especially honey bees. The activity of some pyrethroid insecticides is enhanced by certain fungicides, which increases bee toxicity. The fungicide propiconazole, for example, increases the toxicity of the pyrethroid insecticide, lambda-cyhalothrin to bees when the two are mixed together. Moreover, studies have shown that mixing some neonicotinoid systemic insecticides with certain fungicides can increase bee toxicity by as much as a thousandfold.

Pesticide byproducts. Most systemic insecticides are broken down into substances known as metabolites, which are byproducts of natural chemical reactions within plant tissues. The metabolites of systemic insecticides usually are more harmful to insect pests than the parent compound or active ingredient, and can be directly toxic to bees. Although the overall effects of metabolites on individual bees and their colonies are not well understood, a few are worth noting. Metabolites of imidacloprid, including olefin, and 4- and 5-hydroxy are toxic to bees. Thiamethoxam is converted into clothianidin, another neonicotinoid systemic insecticide, which is extremely harmful to bees.

Miticides, fungicides and herbicides. Various miticides used to manage varroa mite, *Varroa destructor,* populations in honey bee colonies can have direct or indirect effects on honey bee queen longevity and reproduction. Fungicides used to control fungal diseases of vegetable and fruit crops can harm bees directly or indirectly. A fungicide commonly detected in beehives is chlorothalonil, sold under the trade name Daconil or Bravo.

Figure 8. Pesticide premixture containing an insecticide, a miticide, and a fungicide.

Herbicides used to kill unwanted vegetation may not harm bees directly, but they can reduce or limit the number of flowering plants. Clover and dandelion flowers that provide food for pollinators are eliminated by pre- and post-emergent products used to control weeds in landscapes and turfgrass. Moreover, herbicides can repel bees or alter vegetation in an area; thus, threatening the survival of native ground-nesting bees. Components of herbicide formulations such as adjuvants and inert ingredients can harm bees even though the active ingredient may be considered safe.

To Protect Pollinators from Pesticides

- Avoid applying pesticides, such as insecticides, miticides, and fungicides, to flowering ornamental plants (Figures 9 and 10) that attract pollinators. For examples, refer to Table 3 on page 8.
- Apply pesticides before or after ornamental plants have flowered.
- Select pesticides that pose minimal risk to pollinators such as *Bacillus thuringiensis* subsp. *kurstaki* (Figure 11).
- Do not apply systemic insecticides as a soil drench or tree injection to plants with flowers that are attractive to pollinators.
- Always apply systemic insecticides long before plants are flowering.
- Avoid applying pesticides to weeds when pollinators are active.
- **Always read the pesticide label and follow specific requirements regarding pollinator protection.**

Figure 9. Do not apply pesticides to flowering plants such as sage (*Salvia* spp.) that are attractive to pollinators.

Figure 10. Do not apply pesticides to flowering trees such as linden (*Tilia* spp.) that are attractive to pollinators.

Figure 11. Insecticide products containing *Bacillus thuringiensis* subsp. *kurstaki* as the active ingredient.

Table 3. Ornamental flowering plants attractive to bees, butterflies, moths, and other pollinators.

- Bee balm (*Monarda* spp.)
- Blackeyed Susan (*Rudbeckia hirta*)
- Stonecrop (*Sedum* spp.)
- Goldenrod (*Solidago* spp.)
- Butterfly bush (*Buddleia davidii*)
- Purple conflower (*Echinacea purpurea*)
- Lavender (*Lavandula augustifolia*)
- Rosemary (*Rosmarinus officinalis*)
- Wild onion (*Allium* spp.)
- Marigold (*Tagetes patula*)
- Zinnia (*Zinnia elegans*)
- Milkweed (*Asclepias* spp.)
- Aster (*Aster* spp.)

Raymond A. Cloyd

Professor and Extension Specialist in Horticultural Entomology and Plant Protection

K·STATE
Research and Extension

Publications from Kansas State University are available at *www.bookstore.ksre.ksu.edu*

Kansas State University Agricultural Experiment Station and Cooperative Extension Service

K-State Research and Extension is an equal opportunity provider and employer. Issued in furtherance of Cooperative Extension Work, Acts of May 8 and June 30, 1914, as amended. Kansas State University, County Extension Councils, Extension Districts, and United States Department of Agriculture Cooperating, J. Ernest Minton, Interim Director.

MF3428 July 2018