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Neonicotinoid insecticides and pollinators: What's all the buzz about?

Pesticide applicators should take precautions to protect pollinators from potential danger.

Recent events and mounting scientific evidence have increased concerns that the widespread use of neonicotinoid insecticides may be at least partially responsible for the declining health of honey bees (*Apis mellifera*), wild pollinators and other wildlife across North America. Similar concerns across the Atlantic have prompted the European Commission to implement a two-year moratorium on the use of neonicotinoid insecticides, but the U.S. Environmental Protection Agency (EPA) (12) has taken a more measured approach toward the issue. Although the EPA is not currently banning or restricting the use of neonicotinoid insecticides, these products are being subjected to registration review to ensure they meet current health and safety standards. The EPA has also mandated that labels for many, but not all, insecticide products containing neonicotinoids incorporate a new "bee advisory icon" drawing attention to the specific hazards associated with their use (Figure 1). To ensure that these products remain available for its use, the green industry must demonstrate that its members are using these products responsibly. We need to be proactive in addressing the concerns of regulators and take concrete steps to minimize the potential for negative environmental side effects associated with insecticides used to manage insect pests of turfgrass and ornamental plants.

Figure 1. The U.S. EPA requires this bee advisory icon to be placed on the label of most insecticide products containing a neonicotinoid as one of the active ingredients. **Illustration courtesy of U.S. EPA**

The danger to honey bees

A look at the broader picture will show what is at stake. About one-third of our food supply depends on the services of pollinators. Without these services, our food supply would be at risk. Bees are important, and the declining health of bees across North America has made a lot of people very nervous. At present, it cannot be said with confidence that neonicotinoids are the sole — or even the main — force driving honey bee declines; there are simply too many other factors at play. What is known is that neonicotinoids are extremely toxic to bees (Table 1) and, given current usage patterns, there is almost no place in time or space where they can avoid exposure to these compounds. This is especially the case in agriculturally productive areas of the U.S. where the total amount of neonicotinoid insecticide applied per square mile can approach 2 pounds (0.91 kilogram) of active ingredient (Figure 2). One would be hard pressed to name a single crop where neonicotinoids are not routinely used.

Media attention began to focus on the potential link between neonicotinoids and the decline of honey bees after a study by some of our Purdue colleagues working in field crops was published in 2012 (6). Almost every single kernel of seed corn planted in the Midwest is coated with enough of the neonicotinoid insecticide clothianidin (Poncho, Bayer; others) to kill approximately 80,000 honey bees. Most annual crop seeds are planted using pneumatic ("air") planters that use vacuum to place individual seeds onto planting discs for precise placement. The dust (planter exhaust) generated during the planting process liberates a surprising amount of the insecticide, which then settles out in adjacent fence rows, old fields, prairies, forests and water sources where honey bees and other pollinators are likely to forage. The authors also reported that honey bees readily foraged on contaminated corn pollen, taking it back to the hive for storage. Similar troubling situations can be observed with canola production in the northern U.S. and Canada, and an increasing majority of soybean seeds are now coated with a mixture of neonicotinoids and fungicides. The rationale for these seed treatments is that they "protect against a suite of yield-limiting pests," but little evidence supports this assertion, and many of the key annual crop pests across the Corn Belt are relatively unaffected by these treatments.

Green industry use

Based on these findings, it would be easy to place the blame for increased public scrutiny of neonicotinoid use squarely on the shoulders of large-scale production agriculture, but this would be a mistake. Neonicotinoids are by far the most widely used insecticides in the green industry, and the usage data presented in Figure 2 do *not* include neonicotinoids used on turf and ornamental crops. For our purposes, this group includes several excellent white grub insecticides, which, depending on the particular active ingredient, can provide very effective control of many surface-feeding turfgrass insects. They are also commonly used to protect perennials, woody plants and landscape trees against a variety of sucking and wood-boring insects, including the emerald ash borer (*Agrilus planipennis*). To say the least, neonicotinoids represent a valuable set of insect management tools that are much safer (for people and other mammals) than the older generation of insecticides they replaced. However, their breadth of use in the green industry does carry with it the risk of pollinator exposure.

Honey bees are complex social animals, and it is important to remember that acute poisoning is only the tip of the iceberg when it comes to understanding how neonicotinoids could impact their well-being. We should be wary of studies that make conclusions about the hazard of neonicotinoid exposure based on acute toxicity (that is, brief exposures followed by death in short order). Such studies only lend insight into the amount of material required to kill honey bees over an exposure period that is relatively brief. These studies provide an important starting point, but they do not come close to capturing the complexities of exposure in nature, where bees may be exposed to low, but variable levels of these ner-

Ecotoxicology of several neonicotinoid insecticides

Insecticide (trade name/ company)	Toxicity†			
	Mammal LD_{50} (mg/kg)‡	Bird LD_{50} (mg/kg)‡	Fish LC_{50} (mg/liter)§	Honey bee LD_{50} (μg/bee)‖
Clothianidin (Aloft/ArystaLifeScience; Arena/Nufarm)	>500	430	104	0.004
Dinotefuran (Zylam/PBI-Gordon)	>2,000	>2,000	>100	>0.023
Imidacloprid (Merit/Bayer; others)	424	152	211	0.0037
Thiamethoxam (Meridian/Syngenta)	>1,563	576	>125	0.005

†Toxicity only refers to active ingredient and does not take into account formulation. Data from IUPAC (5).
‡LD_{50} for mammals and birds represents acute oral toxicity.
§LC_{50} for fish represents acute 96-hour toxicity.
‖LD_{50} for honey bees may represent either acute contact or oral toxicity.

Table 1. Ecotoxicology of several neonicotinoid insecticides in several different animal species. LD_{50} represents the amount of material (per unit body mass or individual) required to kill 50% of a test population. LC_{50} represents the concentration of material in water required to kill 50% of the test population.

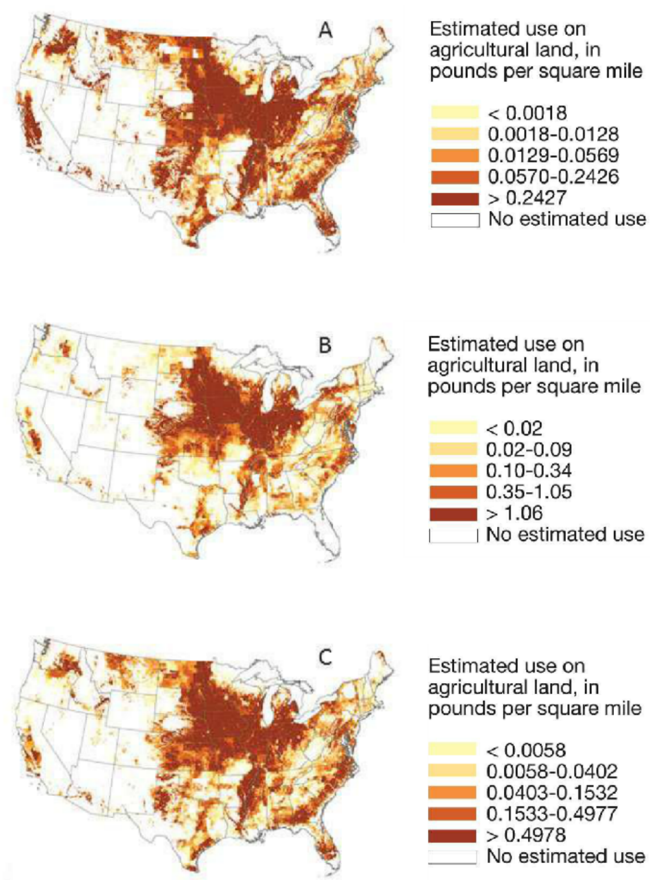


Figure 2. Usage of three common neonicotinoid insecticides on agricultural crops in 2011 (most recent data available) expressed in pounds of active ingredient per square mile. **A,** imidacloprid (http://water.usgs.gov/nawqa/pnsp/usage/maps/graphics/H_IMIDACLOPRID_2011.png); **B,** clothianidin (http://water.usgs.gov/nawqa/pnsp/usage/maps/graphics/H_CLOTHIANIDIN_2011.png); **C,** thiamethoxam (http://water.usgs.gov/nawqa/pnsp/usage/maps/graphics/H_THIAMETHOXAM_2011.png). Usage data for nonagricultural crops (turf and ornamentals) not included. Source: United States Geological Survey, Water Quality Assessment Program

Ecotoxicology of several common insecticides

Insecticide (trade name/company)	Insecticide class	Toxicity†			
		Mammal LD_{50} (mg/kg)‡	Bird LD_{50} (mg/kg)‡	Fish LC_{50} (mg/liter)§	Honey bee LD_{50} (µg/bee)//
Azadirachtin (Azatrol/PBI-Gordon; others)	biorational	>5,000	>225	440	>5.9
Beta-cyfluthrin (Tempo/Bayer)	pyrethroid	>77	>2,000	0.000068	0.001
Bifenthrin (Talstar/FMC)	pyrethroid	54.5	1,800	0.00026	0.1
Carbaryl (Sevin/Bayer)	carbamate	614	>2,000	2.6	0.14
Chlopyrifos (Dursban/Dow AgroSciences)	organophos-phate	64	13.3	0.0013	0.059
Chlorantraniliprole (Acelepryn/Syngenta)	anthranilic diamide	>5,000	>2,250	>12	>4
Emamectin benzoate (TREE-äge/Arborjet)#	avermectin	24	23	0.174	0.0035
Lambda-cyhalothrin (Scimitar/Syngenta)	pyrethroid	56	>3,950	0.00021	0.038
Spinosad (Conserve/Dow AgroSciences)	biorational	>5,000	>2,250	2.69	0.024
Trichlorfon (Dylox/Bayer)	organophosphate	212	>36.8	0.7	>0.4

†Toxicity only refers to active ingredient and does not take into account formulation. Data from IUPAC, material safety data sheets (MSDS), or U.S. EPA.
‡LD_{50} for mammals and birds represents acute oral toxicity.
§LC_{50} For fish represents acute 96-hour toxicity.
//LD_{50} for honey bees may represent either acute contact or oral toxicity.
#Ornamental insecticide not labeled for use in turf at the time of this writing.

Table 2. Ecotoxicology of several common insecticides in several different animal species. LD_{50} represents the amount of material (per unit body mass or individual) required to kill 50% of a test population. LC_{50} represents the concentration of material in water required to kill 50% of the test population.

vous system toxins over an extended period of time. Environmental monitoring data suggest that these compounds are present in soil, water and pollen and nectar of various plants throughout the season and across many environments. There are relatively few "neonicotinoid-free" areas for pollinators to forage in human-dominated environments.

The intricate communication system on which a bee hive relies for optimizing its collective foraging efforts involves subtle physical and chemical cues. Bees returning from a successful foraging journey can communicate very precise navigational information to their hive mates, allowing them to fly to the exact location of a newly discovered source of nectar. Research conducted in France has demonstrated that sublethal exposure to neonicotinoids interferes with this crucial information network, putting the entire hive at risk because foragers given low doses of neonicotinoid cannot find their way back to the hive (1). Imagine stopping at a gas station for directions only to find the attendant stone drunk behind the counter. How reliable would his directions be? Understanding acute toxicity is important, but the hazard of chronic exposure could be equally devastating. Unfortunately, we know very little about this aspect of the neonicotinoid story.

Products in the green industry

Use of neonicotinoids in the green industry is mainly represented by four active ingredients: imidaclorpid (Merit, Bayer; others), clothianidin (Aloft, Arysta LifeScience; Arena, Nufarm), thiamethoxam (Meridian, Syngenta) and dinotefuran (Zylam, PBI-Gordon) (Table 1). Because these four compounds belong to the same class of insecticides, they have many shared properties. Aside from their direct mode of action as synaptic poisons at the molecular level, they are highly water-soluble, they are systemic via the xylem of plants, and they have exceptional residual activity.

These shared properties are part and parcel of what makes them excellent insecticides, but these properties also contribute substantially to their potential as environmental contaminants. The high water solubility of neonicotinoids means they are easy to mix and apply as liquids and this undoubtedly lends to their systemicity, or their ability to be taken up by and moved throughout the plant via vascular tissue. High water solubility also means that irrigation or rainfall will allow the compounds to move with relative ease into the soil profile, where they can protect against damage from soil-inhabiting insects such as white grubs. Because most of the compounds in this class have a relatively long residual half-life, the application window tends to be much larger, allowing turfgrass managers, in particular, the opportunity to take advantage of a more flexible application-timing window and the ability to target multiple pests with a single applica-

(**Top**) Bees will forage on bird's-foot trefoil, which is considered both an invasive weed and an excellent forage plant for livestock. **Photos by A. Patton**

(**Right**) Dandelion flowering in closely mowed turf. Dandelions are a popular forage species for bees in early spring.

tion. These useful qualities can provide tangible logistical and monetary benefits to pest managers and are a big reason why these compounds have become the dominant class of insecticides worldwide in a relatively short time.

On the downside, however, high water solubility also means these compounds are likely to be very mobile. Although the mobility of neonicotinoids in turf and ornamental situations is complex and not well studied, their presence in surface waters (3,13) and ground water (4) has been documented in the relatively few systems examined. Their mobility in turf situations needs to be investigated.

Bees like to forage on white clover in turf as it is usually abundant, it is a good source of nectar and it flowers for a long period in summer.

Nonetheless, the extended residual activity of most neonicotinoids means they have the potential to act as persistent environmental contaminants, sometimes taking years to completely degrade in the soil.

Adding systemic activity to this short list of chemical properties means that neonicotinoids can and will end up in places other than where they were applied. Soil applications will inevitably end up in both the vegetative and reproductive structures of any plants rooted in treated soil. This includes the blooms (including pollen/nectar) of flowering plants that are particularly attractive to honey bees and other pollinators.

Off-target exposure

With any insecticide, the risk of off-target exposure is always a concern, and neonicotinoids are no exception in this regard. Although these insecticides are generally less toxic to mammals and fish (Tables 1, 2), their record against beneficial insects is somewhat of a mixed bag (10), and they are generally very toxic to bees. Aside from the previously mentioned risks, direct contact with and ingestion of treated or downwind material (that is, drift) represents another potential source of environmental contamination that may be problematic for pollinators. Current labels for most neonicotinoid products clearly warn against treating areas where bees are present or likely to be foraging.

In a widely publicized episode last year, a commercial landscape company in Oregon made an off-label application of dinotefuran to flowering linden trees, resulting in the death of more than 25,000 bumblebees (*Bombus* species) and a temporary statewide moratorium on the use of dinotefuran. This serves as a stark reminder of the hazards associated with the careless use of these products and the likely response of state and local authorities under pressure from enraged constituents. It is hoped that the new bee advisory icon strategically located on many neonicotinoid insecticide labels will eliminate these kinds of events, but this assumes that applicators actually read the label.

We know from personal experience and from their own testimony that not all licensed pesticide applicators take the time to read the entire product label before applying an insecticide. For many reasons, such as the incident described above, reading the entire label is a necessity. An industry that is anxious to preserve its ability to use its most valuable chemical tools should do everything it can to encourage safe practices among its members. Pesticide labels do include useful information, and they reflect a significant investment in time, effort and expense by registrants and regulators.

Granted, more science is necessary before we have a clear picture of the relationship between neonicotinoids and pollinator decline, but the industry might consider a few commonsense steps in order to minimize the potential hazard to bees associated with our use of these insecticides. We are admittedly working ahead of the science here, and some of the following suggestions may seem overly cau-

Mowing white clover and other weeds before applying insecticide will remove 90% of the flowers, which reduces bee foraging in these areas and thus reduces the impact of an insecticide application on bees. Before mowing (**left**); after mowing (**right**).

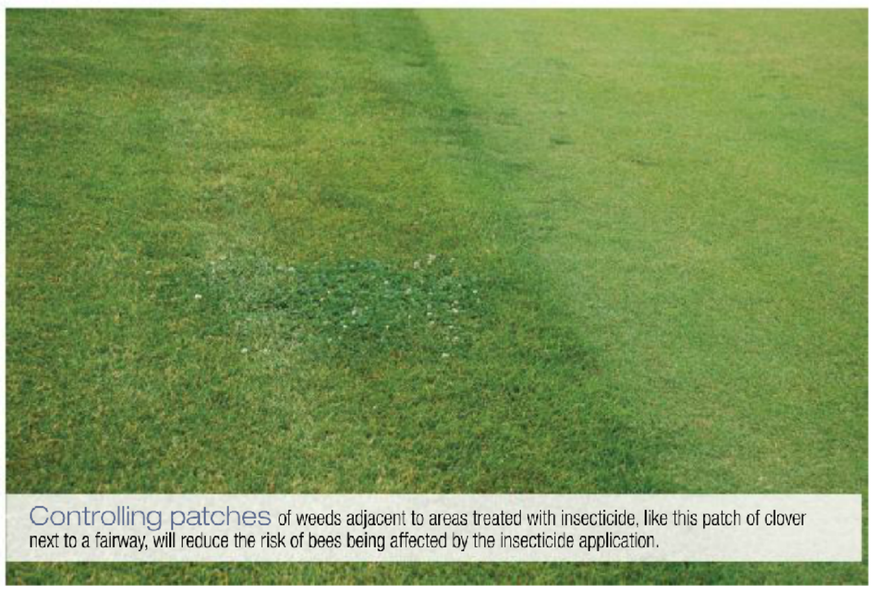
tious. In this instance, it seems prudent to be proactive and implement simple practices that may serve us — and the bees — well in the long term since how and where we are able to use these products is sure to change.

Minimizing the potential hazard to bees from neonicotinoids

Weed control. Pollinators in general and honey bees in particular forage for nectar and pollen on a wide range of flowering plants, including some of the most common weeds. Bird's-foot trefoil (*Lotus corniculatus*), dandelion (*Taraxacum officinale*), ground ivy (*Glechoma hederacea*), heal-all (*Prunella vulgaris*), speedwells (*Veronica* species), white clover (*Trifolium repens*) and other weeds provide forage for a variety of pollinators in mowed turf. In unmowed native areas of the golf course, an even wider variety of flowering weeds provide such forage.

If any of these weeds are present and flowering at noticeable levels, it may be wise to do one of the following:

- Avoid treating weedy areas (flowering weeds) with neonicotinoids. This is consistent with many insecticide labels that advise not to treat blooming nectar-producing plants with neonicotinoid insecticides if bees may visit the treatment area.
- Mow the turf immediately before spraying an insecticide. Mowing should remove 90% or more of the flowers and reduce bee foraging. Research at the University of Kentucky has shown this strategy to be effective in protecting bees (7).
- Remove weeds with an herbicide in areas you plan on treating with an insecticide. Turf that is relatively weed free should not pose a substantial risk to pollinators should a neonicotinoid be applied. Effective weed control should be a prerequisite for using neonicotinoid insecticides. Treat areas where you plan on using a neonicotinoid insecticide as well as areas adjacent to these sites. It is not known how much of the neonicotinoid insecticide ends up in the pollen and nectar of our most common weeds, but if no weeds are available to take up the insecticide, the risk to pollinators can be significantly reduced.



Controlling patches of weeds adjacent to areas treated with insecticide, like this patch of clover next to a fairway, will reduce the risk of bees being affected by the insecticide application.

Although there are some reports of the herbicide 2,4-D causing injury to bees (8), these reports are specific to formulations of 2,4-D no longer used in the U.S., such as isopropyl ester (11). The dimethylamine salt formulation and the isocytyl ester formulation of 2,4-D are currently the most commonly used 2,4-D formulations in turf. Their safety has not been tested on all bee species, but both are nontoxic to honey bees at labeled rates (9). Other commonly used broadleaf herbicides are also relatively safe on honey bees as the LD_{50} for these products is as follows: 94 µg/bee for 2,4-D and >100 µg/bee for dicamba, mecoprop (MCPP), fluroxypyr and triclopyr (5).

Time of day. Bees are most actively foraging during the middle of the day, so making liquid applications during early morning or late evening can help minimize the risk of hitting bees directly as they move about in the field. That precaution will also minimize the chances that drift will directly contact foraging bees. This approach should not be used in place of, but rather in conjunction with, the other recommendations listed.

Buffer strips. Most managed landscapes, including lawns, golf courses, parks and gardens are composed of large areas of turfgrass with landscape beds placed in various arrangements throughout. These landscape beds usually contain flowering plants that are attractive to a variety of pollinators. Furthermore, many golf courses contain native areas with various forbs (flowering broadleaves) where bees forage. Although the boundaries between landscape beds, native areas and turf are often well-defined above ground, these boundaries are not so clear below ground. The intermingling of plant roots creates a much softer boundary in the soil with the roots of ornamental plants creeping unseen beneath the cover of turf and vice versa. As a result, applications of neonicotinoid insecticides aimed at protecting the turf could potentially be taken up by flowering plants within adjacent landscape beds that otherwise appear to be spatially discrete from the application area. In these circumstances, it may be advantageous to leave a buffer strip of 2-3 feet (0.6-0.9 meter) between the treated turf and the margin of the landscape bed to minimize the potential for flowering plants to take up the insecticide through their roots.

We admit that there is no scientific evidence supporting the idea that making treatments right up to the margin of a landscape bed provides a serious threat to pollinators through systemic uptake by untargeted plant material. Nonetheless, common sense indicates it is a possibility, and we can think of no serious downside to leaving a buffer strip until we learn otherwise through research. The farther nontarget plants are from neonicotinoid application sites, the less likely it is they will take up the pesticide.

Petal fall. Sometimes neonicotinoids may be required to address an insect problem associated with landscape trees. When no good alternatives are available, we suggest waiting until flower petals fall before applying these insecticides. After petal fall, honey bees and other pollinators will not be attracted to these trees and the risk of the bees' acquiring the insecticide from the nectar or pollen of such plants is minimized.

It is worth mentioning that neonicotinoids are often used to protect high-value ash trees from the emerald ash borer, which is devastating ash trees throughout the Midwest. These products perform admirably in this capacity and are simpler to use than products requiring direct injection into the trunk. Although ash trees are wind-pollinated and do not require the services of pollinating insects, honey bees and other opportunistic pollinators may occasionally visit their flowers. This likely occurs at a very low rate, and there is probably little risk of pollinators being exposed to significant levels of neonicotinoids in the flowers of ash trees. Still, in keeping with our cautious approach, the relatively minor pollinator hazard associated with neonicotinoid-treated ash trees can be further reduced by waiting until the trees have fully bloomed before making an application. This should allow time for the flowers to senesce before the neonicotinoid can be taken up and translocated throughout the tree, a process that typically takes two or more weeks. Adopting this strategy will *not* reduce the effectiveness of these products against emerald ash borer.

Alternatives. No matter what the green industry does, the EPA review of registration of all neonicotinoid insecticides indicates an outside possibility that these products may be restricted or even lost in the relatively near future. We are not trying to start a panic because an extreme regulatory response seems unlikely, especially if we can prove we are good stewards of the technology. But there are likely to be changes, given the pace of the science on this issue and public awareness about pollinator declines.

Our responsibilities as university Extension specialists require us to look ahead at the possibilities, hope for the best, but prepare for the worst. In other words, we need to be thinking about what our industry would look like without these tools. What alternatives are available and what would we do without neonicotinoids?

Even though the neonicotinoids represent some of the best tools available for a number of applications, many time-tested alternatives are available for use against turf and ornamental insects (Table 2). The anthranilic diamide chlorantraniliprole (Acelepryn, Syngenta) is a very effective white grub chemistry, especially when used in a preventive or early curative program. This same chemistry also performs well against many surface insects. We also still have trichlorfon (Dylox, Bayer) for use as a late curative white grub control. Trichlorfon and carbaryl (Sevin, Bayer) also can be used to treat white grubs in an early curative program, before damage occurs. The pyrethroids (Talstar, FMC; Tempo, Bayer; Scimitar, Syngenta; and others) and chlorpyrifos (Dursban) have good activity against surface feeding insects, and spinosad (Conserve, Dow AgroSciences) is a solid caterpillar insecticide and miticide. For protecting landscape trees against wood-boring insects such as the emerald ash borer, azadirachtin (Azatrol, PBI-Gordon; Aza-Direct, Gowan; and others) should provide excellent control when trunk-injected. In laboratory studies, the other alternative for controlling emerald ash borer, emamectin benzoate (TREE-äge, Arborjet), is just as toxic or more toxic to bees when compared to the neonicotinoids, and its residual activity is much longer (up to two years) (2). However, the capacity of this material to get into the nectar and pollen of trees is not known.

Many more products could be mentioned, and the above list is just a starting point. We encourage turf professionals to work with their local Extension specialists to determine the best chemistry and application timing for the problematic pests in their region. The bottom line is that we could, if pressed, find a way to manage our key insect pests without the neonicotinoids, but we hope will not be forced to do so in the near future.

Conclusion

Neonicotinoids are powerful and versatile pest management tools and they have changed the way we manage insect pests. These compounds are definitely safer to handle and use than most of the insecticides they replaced, and they have made our lives easier by taking a lot of the guesswork out of application timing. We are sure that, as an industry, we recognize the benefits of having these tools at our disposal, and we have never shirked our responsibilities for using such tools responsibly. It is important that we in the industry step up to do the simple things within our power to continue to maintain the smallest environmental impact possible. Concern about the use of neonicotinoids and the health of bees represents just such an opportunity.

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The RESEARCH SAYS

- Recent declines in populations of honey bees and other pollinators have been tentatively linked to neonicotinoid insecticides, which are used widely in agriculture and turf and ornamentals.
- Honey bees may be exposed to these chemicals over long periods of time and in many situations.
- The four most common neonicotinoids in the turf industry are: imidacloprid, clothianidin, thiamethoxam and dinotefuran.
- Because these products remain in the soil for a long period and they are easily taken up and moved throughout a plant's vascular system, they have the potential to harm non-target beneficial insects.
- The potential hazard to bees can be reduced by avoiding treatment of flowering weeds with neonicotinoids; mowing turf before an insecticide application; removing weeds with a herbicide before applying an insecticide; applying insecticides when bees are not active; creating buffer strips between treated turf and landscape beds; delaying treatment of flowering trees until after petal fall; and considering alternative chemistries.