BEYOND THE BIRDS AND THE BEES

Effects of Neonicotinoid Insecticides on Agriculturally Important Beneficial Invertebrates

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FOR INVERTEBRATE CONSERVATION

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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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Front Cover Photograph

Natural predators and parasites of crop pests are an important and economically valuable part of any farming system. Assassin bug consuming a harlequin bug, by Nancy Lee Adamson, The Xerces Society.

CONTENTS

EXECUTIVE SUMMARY

Neonicotinoids are now the most widely used group of insecticides in the world, and their use has been steadily increasing in the United States (see Fig. 1, page 5). Neonicotinoids have been replacing organophosphate and carbamate compounds, uses of which are increasingly being restricted due to concerns about pest resistance and effects on human and environmental health. Since initial registration in the mid-1990s, neonicotinoids have been promoted as low-risk chemicals, chemicals that have low impact on human health, low toxicity to nontarget organisms, lower application rates, and compatibility with Integrated Pest Management (e.g., Jeschke and Nauen 2008).

Unfortunately, the many studies completed since uses of these compounds were approved have not born out the validity of these assumptions. Although neonicotinoids are less acutely toxic than older insecticides to mammals and some other vertebrates, they may be more toxic and targeted to nonpest invertebrates than older chemistries. Numerous studies demonstrate the negative impact of these insecticides on honey bees and native bees such as bumble bees (for reviews see Hopwood et al. 2012, Blacquière et al. 2012, Goulson 2013). Studies also show that neonicotinoids are detrimental to aquatic organisms (for a review see Mineau and Palmer 2013), and they have now been found in surface waters as well as groundwater in several states (Starner and Goh 2012; Bacey 2003; Huseth and Groves 2013). Lower use rates do not always correspond to reduced risk to nontarget organisms.

The majority of attention on neonicotinoid pesticides in recent years has focused on the known and potential risks to bees. Terrestrial invertebrates such as earthworms or predatory ground beetles, although less charismatic than bees, play critical roles in healthy, functioning ecosystems. Beneficial predatory and parasitic insects and other arthropods provide natural pest suppression to farms—an ecosystem service conservatively valued at more than $4.5 billion annually (Losey and Vaughan 2006)—as well as to natural areas and developed landscapes. Soil invertebrates influence a number of biological and chemical processes in the soil, and contribute significantly to soil and ultimately to plant productivity (Anderson 1988; Setala et al. 1988; Stork and Eggleston 1992).

Findings of this Report

This paper provides a review of research on the effects of neonicotinoids on nontarget terrestrial invertebrates. The following are the findings from this review.

- Although neonicotinoids have been promoted as safer for beneficial insects than older insecticides, the balance of evidence suggests that neonicotinoids are generally harmful to a variety of beneficial insects. Neonicotinoids are environmentally persistent and beneficial insects can be exposed through multiple routes. Although some applications (e.g. a seed dressing) might reduce the risk of direct contact exposure to some beneficial insects, beneficial insects are still exposed to residues in the soil, vegetation, or floral resources. Studies have shown that the loss of predator and parasitoid insects due to neonicotinoids can disrupt the process of biological control and foster secondary pest outbreaks. While neonicotinoids may be a preferred alternative to older groups of insecticides in some circumstances, they are not a universally safer option for beneficial insects.
- Widespread preemptive application of neonicotinoids (or any pesticide) represents a fundamental shift away from Integrated Pest Management, since chemicals are applied before pest damage has occurred, and often in the absence of any current pest abundance data. Economic thresholds, a cornerstone of IPM, are not employed when seed treatments are applied to annual crops.

- Use of neonicotinoid seed treatments on annual field crops has increased dramatically in the last decade (Jeschke et al. 2011). However, preventative treatments like neonicotinoid seed coatings on soybeans may not consistently result in yield benefits and can be less cost effective than other control measures (e.g., Johnson et al. 2009). Recent field trials in field corn, conducted at several sites in Indiana, have not documented any pest management or yield benefit from low or high rates of neonicotinoid-treated seed compared with untreated seed of the same hybrid. This suggests that the current approach of treating all corn seed with insecticides is unwarranted and unsupported by pest pressures or yield increases (C. Krupke, pers. comm.).
- Though neonicotinoid seed treatments may be unnecessary or more expensive than other treatments in some circumstances, it is very challenging for farmers to obtain non-organic field crop seed that is not treated with neonicotinoids; neonicotinoid seed coatings are sold as the default option (C. Krupke, pers. comm.).
- Neonicotinoid resistance has been documented in a number of pests, including green peach aphid (*Myzus persicae*) (Jeschke and Nauen 2008), whitefly (*Bemisia tabaci*) (Horowitz et al. 2004), and Colorado potato beetle (*Leptinotarsa decemlineata*) (Olson et al. 2000). The environmental persistence of neonicotinoids such as imidacloprid and clothianidin, coupled with their widespread use, can facilitate pest resistance.
- Although there has been less research on the impact of neonicotinoids to soil organisms, most studies to date have found that neonicotinoids may have negative effects on earthworms and other soil invertebrates, which can be exposed to neonicotinoids when they are applied to the soil as drenches or granules, or through seed coating residues. Given the diversity of plants treated with neonicotinoids in this way, soil invertebrates face exposure in agricultural settings as well as in suburban and urban areas. The widespread use of neonicotinoids across landscapes raises concerns about the broad impact of these chemicals on soil health.

Neonicotinoids, intended to kill plant-damaging pests, have indirect impacts on beneficial predatory insects. Spotted lady beetle (*Coleomegilla maculata*) eating eggs of Colorado potato beetle. (Photograph: Whitney Cranshaw, Colorado State University, Bugwood.org.)

Recommendations

A growing body of research demonstrates risks from neonicotinoids to beneficial insects. These risks occur particularly in agricultural systems but are also found in urban and suburban ornamental landscapes. Based on available research, the Xerces Society makes the following recommendations.

1 The U.S. Environmental Protection Agency should re-assess the ecological safety of currently approved neonicotinoids and immediately suspend registration of imidacloprid, clothianidin, thiamethoxam and dinotefuran for all applications where there is a risk to nontarget organisms. These bans should remain in force until we understand how to manage the risk to nontarget species.

2 The U.S. Environmental Protection Agency should significantly speed up the registration review process for neonicotinoids. The risk from exposure to neonicotinoid insecticides needs to be scientifically evaluated against the risk posed to beneficial species by alternative control measures.

3 The U.S. Environmental Protection Agency should expand the number of nontarget terrestrial insect species used in the risk assessment process, such as by including a lady beetle and a parasitoid wasp. The suite of nontarget organisms used for risk assessment in Europe should be adopted here in the U.S.

4 The U.S. Environmental Protection Agency should adopt risk assessment protocols for exposure to nontarget insects that account for cumulative and synergistic effects, effects of long-term exposure to low concentrations, and exposure to pesticides through pollen and nectar. The European Food Safety Authority recently developed guidelines for assessing risks of systemic plant protection products to pollinators that might be adapted for Environmental Protection Agency risk assessments.

5 The USDA Risk Management Agency's Federal Crop Insurance Corporation should approve reductions in crop insurance premiums for producers who avoid prophylactic use of neonicotinoids where the pest pressure does not warrant use. This would provide an incentive to encourage farmers to use Integrated Pest Management.

6 The prophylactic use of neonicotinoids on crops should be halted until we understand if neonicotinoids can be used without causing undue harm to beneficial insects. Neonicotinoids should only be used as part of an Integrated Pest Management plan with pest scouting or forecasts of pest pressure, and after considering alternative pest management strategies.

7 The use of neonicotinoids for cosmetic reasons (such as against aphids in parks and gardens) rather than economic reasons on city- and county-owned lands should be banned because of the risks to nontarget invertebrates.

8 Neonicotinoid use may be merited for applications such as the control of invasive species that pose risk of plant-species extirpation or control of termites in house foundations. However, neonicotinoids should only be used after all other options are exhausted.

1 Introduction

Neonicotinoids are currently the most widely used group of insecticides in the world. With annual sales worth $1.9 billion, they comprise roughly 25% of the global agrochemical market (Jeschke et al. 2011). Some uses of neonicotinoids have been granted conventional Reduced Risk Pesticide status by the U.S. Environmental Protection Agency, and are considered to be preferable alternatives to organophosphate insecticides, a group of compounds that affect the nervous system of insects, humans, and other animals.

Less toxic to mammals and many vertebrates than the organophosphates that they replaced, neonicotinoids are nonetheless highly toxic in small quantities to most insects and other invertebrates. Neonicotinoids are systemic insecticides; the compounds are absorbed by a plant and are transported throughout its tissues by means of the vascular system. This systemic action allows protection of treated plants from boring, sucking, chewing, and root-feeding pests (Jeschke et al. 2011). Neonicotinoids can be applied to plants in a number of ways. The compounds might be applied to blueberry as a foliar spray, to corn seeds as a seed coating, around a rhododendron shrub as a soil drench, to turf as a granule, or injected directly into the trunk of a maple tree.

Six neonicotinoids—imidacloprid, thiamethoxam, clothianidin, dinotefuran, thiacloprid, and acetamiprid—are approved for use on numerous crops. Agricultural use of neonicotinoids has increased substantially in the last ten years (Fig. 1). The EPA estimates that from 2009 to 2011 over 3.5 million pounds of neonicotinoids were applied to nearly 127 million acres of agricultural crops each year (EPA 2012). Given that field crop seed treatments alone account for nearly 200 million acres, this is likely an underestimate (C. Krupke, pers. comm.). In addition to uses in agriculture, imidacloprid, thiamethoxam, clothianidin, dinotefuran, and acetamiprid are approved for various uses on ornamental plants like turfgrass and garden shrubs. Consequently, neonicotinoids can be applied in diverse settings beyond farms, including gardens, schools, parks, and city streets.

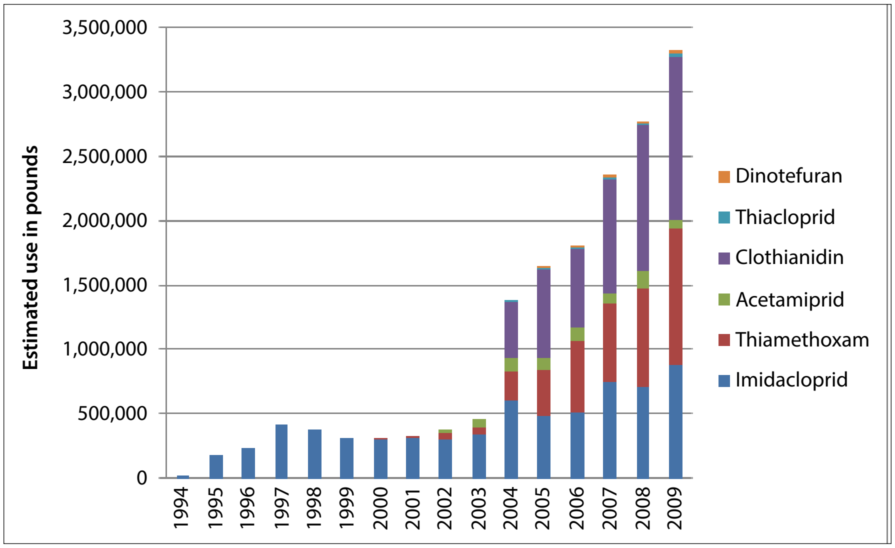
Compared with organophosphates, neonicotinoids have reduced impacts on human health and are used at lower rates (Harper et al. 2009; Gervais et al. 2010). However, concerns about the environmental persistence of neonicotinoids, exposure to nontarget wildlife, resistance of pests, and equivocal compatibility with Integrated Pest Management are growing.

Notable differences between neonicotinoids and previous compounds include the persistence of neonicotinoids in soil and within plants. Neonicotinoids can have residual activity within plant tissues for surprising lengths of time. Imidacloprid residues could be found in needles, twigs, and sap of hemlock trees up to three years after application (Cowles et al. 2006), and in rhododendron flowers up to six years after treatment (Doering et al. 2004). Residue levels within plants following an application will decrease over time but may remain at high enough levels to be toxic to pests for months or even years. For example, a single chemigation application of thiamethoxam to citrus was enough to suppress pests for five months (Castle et al. 2005). Similarly, one soil application of imidacloprid suppressed wooly adelgids on hemlocks for more than two years (Cowles et al. 2006) and a single soil application of imidacloprid controlled a wood-boring pest of maple trees for up to four years (Oliver et al. 2010). During the extended periods in which treated plants remain toxic to pests, they are also toxic to nontarget insects.

Persistence of neonicotinoids in soil varies between compounds and across soil types. Acetamiprid and thiacloprid degrade quickly in soil, with half-lives estimated at 8 and 27 days respectively (EPA 2002; EPA 2003a). In contrast, imidacloprid, clothianidin, thiamethoxam, and dinotefuran have significantly longer half-lives. Clothianidin may remain in the soil for a year to over three years (EPA 2003b). With such persistence in soil, it would be expected that residues would accumulate in the soil from repeated applications over time, but no data is available to confirm this. However, it has been demonstrated that plants can pick up residues in soil from applications in previous years (Bonmatin et al. 2005).

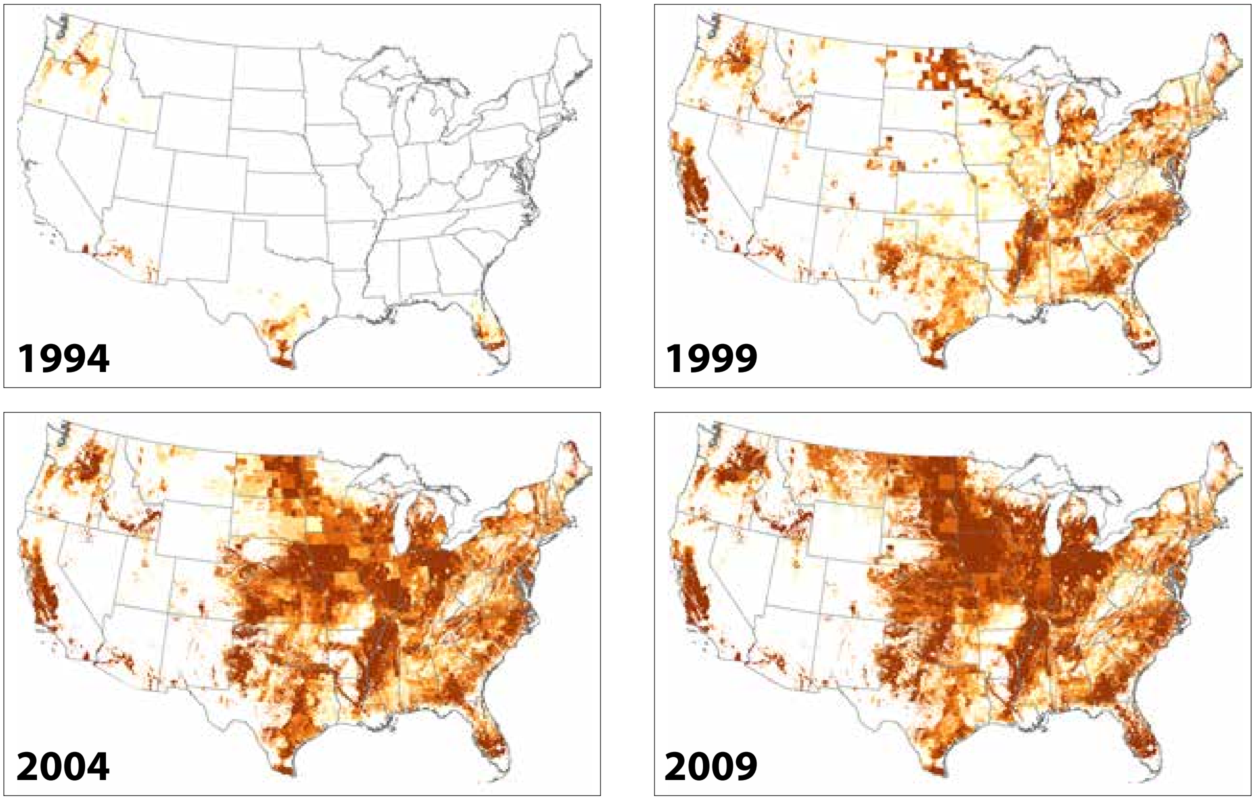
Fig. 1 Neonicotinoid Use in the United States, 1994–2009

Total pounds of neonicotinoid insecticides used in agriculture, 1994–2009



Data from: Stone, W.W. 2013. "Estimated annual agricultural pesticide use for counties of the conterminous United States, 1992–2009." U.S. Geological Survey Data Series 752, 1p. pamphlet, 14 tables.

Imidacloprid use on farms. Darker color indicates greater quantity used per square mile.



Source: USGS National Water-Quality Assessment Program Pesticide National Synthesis Project, http://water.usgs.gov/nawqa/pnsp/usage/maps/compound_listing.php (accessed 9/16/13).

The threat from neonicotinoid residues to bumble bees and other flower-visiting insects is well known. The risk to beneficial predators and parasitoids of plant pests has generally been overlooked. (Photograph: Matthew Shepherd, The Xerces Society.)

Neonicotinoids are water soluble (e.g., Gervais et al. 2010), and accordingly, have the potential to move into surface water or leach into ground water under some uses. Some, such as imidacloprid, may be persistent in water (Tisler et al. 2009). In California, 89% of samples from rivers, creeks, and agricultural drains contained imidacloprid (Starner and Goh 2012). Imidacloprid, clothianidin, and thiamethoxam are highly toxic to freshwater invertebrates, and while acutely toxic levels in surface waters may be unusual, concentrations that cause chronic toxicity or sublethal effects may not be uncommon. In the California study, 19% of samples exceeded the EPA's chronic invertebrate Aquatic Life Benchmark (Starner and Goh 2012).

As use of neonicotinoids becomes increasingly widespread, it becomes more and more vital to understand their impacts on nontarget wildlife and consequently, ecosystem health. Much concern has been focused on the effects of neonicotinoids on bees. Bees and other pollinators are exposed to neonicotinoids in several ways, including insecticide-contaminated dust and residues in pollen and nectar. Although the balance of evidence from published research suggests that exposure through pollen and nectar rarely causes direct mortality, there is an ever-growing body of anecdotal evidence as more bee kills are reported and investigated (Health Canada 2013). What there is no doubt about is that such exposure causes sublethal effects that reduce bumble bee reproduction and honey bee foraging. The Xerces Society's report *Are Neonicotinoids Killing Bees?* (Hopwood et al 2012) summarized all available peer-reviewed research on the impact of these pesticides on bees. Subsequent published studies continue to provide evidence that these insecticides are having a negative impact on both honey bees and native pollinators. Concerns have also been raised about effects on birds. Birds that consume treated seeds can be poisoned outright or may have reduced reproduction. A recent report from the American Bird Conservancy (Mineau and Palmer 2013) details impacts to birds as well as to aquatic macroinvertebrates, a portion of the food supply for many birds.

Although less charismatic than bees and birds, terrestrial invertebrates such as earthworms or predatory ground beetles play critical roles in ecosystem functioning. This report reviews the published science on three ways in which neonicotinoids affect nontarget invertebrates:

- How neonicotinoids impact beneficial predator and parasitoid insects;
- The compatibility of neonicotinoids with biological control and Integrated Pest Management; and
- How neonicotinoids impact beneficial soil fauna, and the possible long-term effects of their use on soil health.

2 Effects of Neonicotinoids on Nontarget Beneficial Insects

Billions of dollars are spent every year in the United States on measures to control agricultural pests, but these expenses would be exponentially larger without the free, and typically overlooked, pest control provided by beneficial predatory and parasitoid arthropods (a phenomenon known as "biological pest control"). The economic value of biological pest control in the United States provided by wild beneficial insects is conservatively estimated to be at least $4.5 billion annually (Losey and Vaughan 2006). This is likely an underestimate; for example, in soybean in just four states (Iowa, Michigan, Minnesota, and Wisconsin), natural suppression of soybean aphid is worth $239 million a year (Landis et al. 2008). Losses of beneficial insects can lead to increased pest outbreaks (especially secondary pest outbreaks by species that were previously suppressed by beneficial insects), a greater need for pesticide use, and loss of crop yields.

Although beneficial insects prey upon other insects during part of their life cycle, many are omnivorous and feed on pollen, nectar, or plant tissues when prey is scarce or during certain life stages. For example, adult parasitoid wasps frequently feed exclusively on nectar, and have a reduced ability to control pests without it (Lundgren 2009). Beneficial insects can obtain nonprey foods from some crops, as well as from noncrop ornamental plants found in urban and suburban areas. When pollen, nectar, or plant tissues are contaminated with neonicotinoid pesticides, the health of these beneficial insects may be compromised. Beneficial insects also need habitat that provides shelter and alternative food sources (Landis et al. 2000). Nontreated vegetation growing near treated plants has the potential to be contaminated via deposition of abraded seed coating dust or contaminated talc (Krupke et al. 2012) or potentially through uptake of neonicotinoids from the soil, though contamination of adjacent plants has not been well studied.

There is a growing body of evidence that beneficial insects are exposed to neonicotinoids through a number of pathways and that neonicotinoid exposure can cause harmful effects. In addition to direct contact with neonicotinoid spray, invertebrates that chew plant tissues, sip plant fluid, or chew into wood will consume some amount of the active ingredient (Jeschke et al. 2011). Residues are also present in pollen (e.g., Bonmatin et al. 2005), nectar (e.g., Krischik et al. 2007), and plant exudates (e.g., Girolami et al. 2009). Contaminated talc or dust released into the air from seed planters can contact flying insects (e.g., Krupke et al. 2012). Residues can also contact invertebrates in the soil (Kreutzweiser et al. 2008) or in water (Van Dijk et al. 2013). Effects of exposure may include death; sublethal effects that reduce reproduction, foraging, and longevity; or indirect effects such as a loss of prey or hosts.

Below we provide a brief summary of studies related to neonicotinoids and beneficial insects that are known to provide biological control.

Currently the recognized impacts of neonicotinoids on insects that provide biological control include death, sublethal effects (on reproduction, foraging, and longevity), and a loss of alternative prey/hosts.

Syrphid flies have very different food needs as adults and larvae, and are beneficial during both stages. The larvae are excellent predators of aphids and other soft-bodied plant pests, and the adults are pollinators. (Photograph: Mace Vaughan, The Xerces Society.)

Neonicotinoid Impacts on Predator and Parasitoid Insects

Insects can be exposed to neonicotinoids in various direct and indirect ways. Direct contact occurs when foliar sprays are applied to plants and spray contacts the insect, or when the insect comes in contact with spray residues on the surface of vegetation or residues in the soil. Beneficial insects may also be indirectly exposed when they consume prey or plant materials that are contaminated with an insecticide.

A number of studies have looked into the impacts of direct contact due to spray applications or residues on vegetation.

- Dinotefuran sprays at label rates were highly toxic to a parasitoid wasp (*Leptomastix dactylopii*) and spray applications of acetamiprid, clothianidin, and dinotefuran were toxic to mealybug destroyer beetles (*Cryptolaemus montrouzieri*) (Cloyd and Dickenson 2006).
- Acetamiprid spray at the field rate was toxic to the predatory plant bug *Deraeocoris brevis* (Kim et al. 2006).
- Acetamiprid is toxic to a predatory thrip (*Scolothrips takahashi*) and a lady beetle (*Stethorus japonicus*) (Mori and Gotoh 2001, as cited in Naranjo and Akey 2005).
- Imidacloprid spray applied at field rates caused significant mortality to nymphs and adults of the predatory stink bug *Podisus maculiventris* (De Cock et al. 1996).
- Imidacloprid spray treatment to pest eggs only slightly reduced emergence of *Trichogramma cacoeciae*, a parasitoid wasp, but direct exposure to spray caused high mortality of the adult parasitoid wasps (Saber 2011).
- Under lab conditions, acute contact applications of imidacloprid caused increased mortality in predaceous true bugs and lady beetles, although not to two species of predatory mites (Mizell and Sconyers 1992).
- Parasitoid wasps confined with citrus leaves that were treated with either imidacloprid or thiamethoxam had significantly higher mortality (Prabhaker et al. 2011).
- All life stages of the multicolored Asian lady beetle (*Harmonia axyridis*) used in biological control were susceptible to topical treatment of a dose at label rates of acetamiprid, thiamethoxam, and imidacloprid (Youn et al. 2003).
- Contact with imidacloprid significantly reduced fecundity of *Neoseiulus californicus*, a predatory mite found in annual crops in Italy. In contrast, fecundity of the two-spotted spider mite (*Tetranychus urticae*), a pest in annual crops in Italy (and in other crops around the world), was significantly increased by exposure to imidacloprid (Castagnoli et al. 2005).

Ground-dwelling beneficial insects such as predatory ground beetles (Carabidae) and rove beetles (Staphylinidae) contact neonicotinoid residues present in soil. Ground and rove beetles are both major predators of turfgrass pests and are present in crop fields. Studies indicate that the effects of neonicotinoids are not consistent between different invertebrate groups. An application of imidacloprid, for example, may kill ground beetles but not ants.

- Applied to a growing medium at labeled rates, clothianidin, dinotefuran, and thiamethoxam were highly toxic to adults of a rove beetle (*Atheta coriaria*) and imidacloprid was harmful to all life stages (Cloyd et al. 2009).
- Imidacloprid, via applications to turf at label rates, reduced the abundance of Hister beetles and the

Ground beetles such as this blue-margined ground beetle (*Pasimachus elongatus*) are predators as both adults (shown) and larvae. They may be exposed to neonicotinoids directly when applied as a soil drench and indirectly via contaminated food items. (Photograph: Whitney Cranshaw, Colorado State University, Bugwood.org.)

larvae of predatory ground beetles and rove beetles (Kunkel et al. 1999).

- Ground beetle and rove beetle abundance was significantly reduced by applications of imidacloprid granules to turf at label rates (Peck 2009b). Ground beetle populations were reduced by up to 84% initially, and did not recover within a year (Peck 2009b).
- Neonicotinoid exposure does not always kill beneficial insects directly, but may make them more vulnerable to other threats. For example, ground beetles (*Harpalus pennsylvanicus*) exposed to imidacloprid through direct spray or fed food contaminated by turf treatments exhibited sublethal effects like temporary paralysis and impaired walking that made them significantly more susceptible to ant predation (Kunkel et al. 2001).
- While some groups of beneficial insects such as ground beetles and rove beetles are susceptible to neonicotinoid applications, other groups may not be affected to the same degree. For example, ant populations were not affected by granular applications of imidacloprid to turf (Zenger and Gibbs 2001).

Many beneficial insects are omnivorous to some degree and require nonprey foods such as pollen, nectar, or plant foliage during at least one life stage. For example, adult ground beetles may consume pollen or occasionally seeds, the multicolored Asian lady beetle will feed directly on corn seedlings to obtain plant-specific nutrients, and pirate bugs are known to feed on plant tissues when prey is scarce. When they feed on treated plants, beneficial insects can ingest neonicotinoid residues present in nectar, pollen, or plant tissues.

- The minute pirate bug (*Orius insidiosus*)—a major predator of soybean aphids—feeds on plant tissues when prey is scarce and died as a result of exposure to soybeans grown from thiamethoxam-treated seeds (Seagraves and Lundgren 2012).
- In the absence of prey, minute pirate bugs (*Orius insidiosus*) had significantly higher mortality when confined with corn seedlings treated with imidacloprid seed treatments than with nontreated corn seedlings (Al-Deeb et al. 2001). Pirate bugs are known to feed on plant tissues when prey is scarce.

Aptly named, the minute pirate bug (*Orius insidiosus*) is a tiny but voracious predator. Pirate bugs can consume around 30 small insects or eggs per day, and excel at seeking out prey at low densities (Photograph: John Ruberson, University of Georgia, Bugwood.org.)

- Parasitoid wasps (*Microplitis croceipes*) experienced reduced foraging ability and shortened longevity after feeding on the extra-floral nectar of imidacloprid-treated cotton plants treated at manufacturer-recommended rates in a lab experiment (Stapel et al. 2000).
- Pink lady beetles (*Coleomegilla maculata*) had reduced mobility and lower survivorship when chronically exposed to imidacloprid residues in soil-treated sunflowers (Smith and Krischik 1999).
- Encyrtid parasitoid wasps (*Anagyrus pseudococci*) showed reduced mobility and lower survivorship after chronic exposure to flowers from plants treated with label rates of soil-applied imidacloprid (Krischik et al. 2007).
- Green lacewings (*Chrysoperla carnea*) exhibited significantly reduced survival after feeding on flowers treated with soil applications of imidacloprid (Rogers et al. 2007).
- Parasitoid wasps (*Avetianella longoi*) of pests of eucalyptus in California had reduced survival and reproduction after feeding on nectar from trees treated with imidacloprid at label rates five months before bloom (Paine et al. 2011).
- In addition to consuming pests like corn rootworms, adult ground beetles may also eat foods such as pollen or occasionally, seeds. In lab tests, ground beetle consumption of corn seeds treated with label rates of thiamethoxam, imidacloprid, or clothianidin caused nearly 100% mortality in the 18 species tested, though consumption of contaminated corn pollen caused no ill effects (Mullin et al. 2005).
- Lady beetles are common in agricultural crops, where they feed on aphids and other crop pests. The multicolored Asian lady beetle (*Harmonia axyridis*), an introduced species, will also feed directly on corn seedlings to obtain plant-specific nutrients. Larvae that fed briefly on seedlings grown from seeds treated with clothianidin or thiamethoxam experienced significantly higher mortality, but also sublethal effects like trembling, paralysis, or loss of coordination (Moser and Obrycki 2009).
- Predaceous stink bug nymphs (*Podisus nigrispinus*) that consumed plant sap from thiamethoxam-treated cotton plants had reduced survival. Their survival rates decreased with increasing amounts of thiamethoxam (Torres et al. 2003).

Beneficial insects may also be exposed to neonicotinoids through consumption of prey that has survived exposure to neonicotinoids.

- The lady beetle *Hippodamia undecimnotata* experienced reduced survival, longevity, and egg production following predation on aphids reared on bean plants treated with imidacloprid, applied to soil at a fraction of the label rate (Papachristos and Milonas 2008).
- The vedalia beetle (*Rodolia cardinalis*), a natural enemy introduced to North America to control cottony cushion scale (*Icerya purchasi*), currently provides the most effective control of the scale pest

in citrus groves. After feeding on cottony cushion scales that had been raised on neonicotinoid-treated plants, adult vedalia beetles had lower survival and reduced fecundity, and larvae had high mortality rates (Grafton-Cardwell and Gu 2003).

- Ground beetles confined in a microcosm jar with soil, clothianidin treated corn seedlings, and corn rootworm prey had significantly higher rates of mortality than did beetles confined in seedling microcosms of fungicide-only treated seed, at least in part due to the ingestion of contaminated prey (Mullin et al. 2005).
- Minute pirate bugs (*Orius insidiosus*) experienced significantly increased rates of mortality after consumption of corn rootworm eggs sprayed with imidacloprid (Elzen 2001). In contrast, big-eyed bugs (*Geocoris punctipes*) suffered less mortality, but imidacloprid exposure did reduce big-eyed bug consumption of pest eggs (Elzen 2001).

Two unexplored routes of exposure to neonicotinoids for beneficial insects include the drinking or collecting of surface water contaminated with neonicotinoid residues, and the drinking of guttation fluids (xylem sap exuded by plants in the morning, appearing as droplets on leaf edges or at the tip of the plant).

- Imidacloprid was found in 89% of surface waters sampled in agricultural regions in California, demonstrating that imidacloprid can move offsite from where it is applied and can contaminate water (Starner and Goh 2012). To our knowledge, no research has investigated the effects of neonicotinoids on beneficial insects that have been exposed to contaminated surface water. However, given that nearly 20% of the water samples exceeded the EPA benchmark for toxicity to aquatic invertebrates (Starner and Goh 2012), exposure of beneficial insects to neonicotinoids through surface water seems worthy of examination. Levels harmful to aquatic invertebrates are likely to be similarly harmful to terrestrial invertebrates as well.
- Guttation fluid of seed-treated corn can contain concentrations of imidacloprid, clothianidin, and thiamethoxam at levels that are toxic to beneficial insects (Girolami et al. 2009). Toxic levels of imidacloprid have also been reported in guttation of melons grown in imidacloprid-treated soil (Hoffman and Castle 2012). Guttation drops can serve as a water source for beneficial and pest insects, though the extent to which guttation fluid is consumed by beneficial insects in a field setting is unknown.

Not all groups of beneficial insects, even those that are closely related, respond similarly to exposure to neonicotinoids in similar uses.

- Field rates of imidacloprid applied to control aphids in stone fruits are toxic to some species of predatory mites, ground beetles, rove beetles, spiders, and predatory true bugs, but other species in these groups tolerated exposure (James and Vogele 2001, as cited by James and Price 2002).
- Imidacloprid spray at field rates for hops was highly toxic to the predatory mites *Galendromus occidentalis* and *Neoseiulus fallacis*, but had lower toxicity to *Amblyseius andersoni* (James 2003). Bostanian et al. (2010) also found imidacloprid to be highly toxic to *Neoseiulus fallacis*.
- In a lab experiment, acetamiprid, thiamethoxam, and imidacloprid were not toxic on contact to *Anystis baccarum*, a predatory mite that is commonly found in Quebec, Canada, apple orchards (Laurin and Bostanian 2007).
- Tested in a lab, acetamiprid and imidacloprid were moderately toxic to a predatory mite (*Neoseiulus fallacis*) found in North Carolina apple orchards, while thiacloprid and thiamethoxam were not toxic (Villanueva and Walgenbach 2005). However, thiacloprid, imidacloprid, and thiamethoxam did significantly reduce reproduction (Villanueva and Walgenbach 2005).

- Comparisons were made between predator species richness and abundance in fields planted with and without imidacloprid-treated corn seed. Populations of spiders, lady beetles, and ground beetles in treated fields were not significantly different from untreated fields, whereas populations of rove beetles and some predatory true bugs were significantly smaller in treated fields (Albajes et al. 2003).

The different types of neonicotinoids vary in their toxicity to beneficial insects, with some appearing to be more toxic to beneficial insects than others.

- Imidacloprid and thiamethoxam are considered to be highly toxic to a predatory mite (*Neoseiulus fallacis*), while acetamiprid and thiacloprid are considered only mildly toxic (Bostanian et al. 2010).
- In cotton fields treated with either acetamiprid or imidacloprid foliar sprays, numbers of predatory big-eyed bugs (*Geocoris punctipes*) were similar to control fields. However, big-eyed bug populations were significantly lower in fields treated with foliar applications of thiamethoxam (Kilpatrick et al. 2005).
- Spray of dinotefuran at a label-recommended rate was 120 times more toxic to the parasitoid wasp *Leptomastix dactylopii*, a natural enemy of citrus mealybug, than acetamiprid or clothianidin (Cloyd and Dickenson 2006).

Much of the research investigating the effects of neonicotinoids on beneficial insects has involved imidacloprid; the effects of other neonicotinoids are less known. In particular, dinotefuran, which is currently allowed for use in vegetables, leafy greens, some tree fruits, and some ornamental plants, is particularly understudied with regards to effects on nontarget insects.

3 Neonicotinoids and Integrated Pest Management

The natural pest suppression that beneficial insects provide is an integral component of Integrated Pest Management (IPM), a framework for managing pests that combines biological, cultural, physical, and chemical tools in a way that minimizes economic, health, and environmental risks.

In the United States, it is the policy of federal agencies, including the U.S. Department of Agriculture, to use IPM in management activities or promote IPM through regulatory action (Food Quality Protection Act of 1996). Following the basic tenets of IPM, control measures are instituted only after a regular surveillance program and/or a field history of pest damage determines that pest impacts have risen to an economically damaging level. When action is taken, the ideal approaches focus on the pests while doing minimal harm to nonpest organisms. There are many successful examples of this approach in agriculture, including in apple, citrus, and greenhouse crops.

Neonicotinoids have been promoted as low risk for nontarget organisms and the environment, for example, because applications via seed coatings can be made with minimal exposure to nontarget organisms or can be made when beneficial insects are not present (Elbert et al. 2008). However, this does not account for the full extent of exposure that beneficial insects may receive over the growing season. Because neonicotinoids are persistent in plants and soil well beyond the time of application, beneficial insects can be harmed when they contact or ingest residues days, weeks, or months after application.

Neonicotinoids can disrupt biological control in some cropping systems and urban and suburban ornamental landscapes by causing harm to beneficial insects.

Integrated Pest Management

Integrated Pest Management (IPM) is a decision-making framework that utilizes least hazardous pest management options only when there is a demonstrated need, and takes special precautions to reduce the hazards of pest management activities to living organisms and the environment.

IPM employs a four-phase strategy:

(1) Reduce conditions that favor pest populations;

(2) Establish an economic threshold of how much damage can be tolerated before pest control must occur;

(3) Monitor pest populations; and

(4) Control pests when the pre-established damage threshold is reached.

- Researchers found that foliar application of imidacloprid did not control citrus pest species in California citrus orchards and it disrupted biological control. The suppression of parasitoid wasps and vedalia beetles by imidacloprid allowed pest populations to increase beyond those of untreated orchards (Grafton-Cardwell et al. 2008).
- In an experiment in Indiana, imidacloprid and thiamethoxam did not control euonymus scale (*Unaspis euonymi*), a pest common in ornamental plantings in yards and cities. To compound this lack of effectiveness, the neonicotinoids decreased parasitism of the scale by its natural enemy, a parasitoid wasp (*Encarsia citrina*), which led to increases in the scale pest (Rebek and Sadof 2003).
- Acetamiprid can contribute to control of a whitefly in cotton but is not a suitable substitute for insect growth regulators in an IPM program, because it reduces predators more than do the more targeted insect growth regulators (Naranjo and Akey 2005).
- Soybean fields can host a diverse community of beneficial insects, but imidacloprid or thiamethoxam seed treatment reduced predatory insects, including pirate bugs and lacewings, while pests such as

soybean aphids, grasshoppers, and thrips were unaffected by neonicotinoid seed treatment (Seagraves and Lundgren 2012).

- The parasitoid wasp *Tiphia vernalis* was introduced to North America to control the Japanese beetle. Exposure to imidacloprid applied to the soil for Japanese beetle control did not increase adult wasp mortality or reduce longevity but it did reduce their ability to parasitize beetle grubs, compromising biological control of the beetle (Rogers and Potter 2003).
- In a lab experiment, predatory mites (*Neoseiulus californicus* and *Phytoseiulus macropilis*) were exposed to two-spotted spider mite eggs sprayed with acetamiprid, thiamethoxam, or imidacloprid. Poletti et al. (2007) found that imidacloprid significantly increased the time it took for the predatory mites to find, identify, and attack their spider mite prey. Consequently, the predatory mites consumed significantly fewer pest mites.

Pesticides are typically used to improve harvest quality or crop yield. In some cropping systems, however, neonicotinoids have demonstrated little control of major pests or little or no improvement of yield.

- Imidacloprid and thiamethoxam seed treatments on soybean had less impact on natural enemies than foliar insecticide applications made after aphid populations developed, but seed treatments provided limited and inconsistent yield protection compared with foliar treatments (Ohnesorg et al. 2009).
- Preventative application of thiamethoxam as a seed treatment to soybean did not significantly reduce soybean aphids or prevent yield loss compared with a well-timed insecticide application as part of an IPM program (Johnson et al. 2009).
- No statistical differences in yields were found between soybean crops in which pests were managed through prophylactic use of insecticides (including imidacloprid) or IPM, though costs were lower with the IPM approach (Bueno et al. 2011).
- Neither imidacloprid nor thiamethoxam treatments to soybean seeds resulted in yield benefits (Cox et al. 2008; Magalhaes et al. 2009; Schultz et al. 2011; Bueno et al. 2011; Seagraves and Lundgren 2012).
- Compared with imidacloprid seed-treated corn, untreated corn suffered more insect damage but yields between treated and untreated corn plots did not differ significantly (Pons and Albajes 2002).
- In a comparison among a thiamethoxam seed treatment, an IPM treatment, and a preventative application of foliar insecticide treatment to soybeans to control soybean aphid, IPM had the highest probability of recouping treatment cost and seed treatment had the lowest (Johnson et al. 2009).
- Predicting economic returns from prophylactic seed treatments can be difficult. When pest activity is high, neonicotinoid seed treatment

Applications of neonicotinoids to control pests are not always effective, and often will decrease parasitism of pest species by their natural enemies. (Photograph: USDA-ARS/Scott Bauer.)

The economic benefits from neonicotinoid treatment of crops are mixed. Studies of soybean and corn crops demonstrate limited or inconsistent yield protection, and the cost of treatment wasn't always covered by the increased yield. (Photograph: Dwight Burdette, Wikimedia Commons.)

of corn can increase yields but when pest pressure is reduced, there are no consistent effects of seed treatment on yield (Wilde et al. 2007). Similarly, in winter wheat, economic returns from imidacloprid seed treatments were consistent with high aphid and virus pressure, but in crops with reduced virus and aphid pressures, the cost of the insecticide exceeded the yield benefits in crops (Royer et al. 2005).

Clearly, there is a need for additional studies of other crops detailing circumstances under which neonicotinoid use (particularly prophylactic use) may or may not provide a cost-effective alternative.

Neonicotinoids were registered with the expectation that their impact on nontarget wildlife would be less than that of organophosphates. Although many comparisons between toxicity of neonicotinoids and older insecticides to pests exist, few direct comparisons of toxicity to beneficial insects have been made.

With their environmental persistence and multiple pathways of exposure, the balance of evidence suggests that neonicotinoids are generally harmful to beneficial insects. However, in some situations, neonicotinoids may still be a preferable alternative to the use of organophosphate or carbamate broad-spectrum insecticides. One example is for management of the potato psyllid (*Bactericera cockerelli*), a major pest in potato, tomato, and other solanaceous crops in North America, Central America, and New Zealand. In addition to damage caused by feeding, the potato psyllid can transmit the bacterium that causes zebra chip disease, a condition which significantly lowers potato yields and the quality of tubers. The threshold for damage is very low; very little damage can be tolerated before treatment becomes necessary (Munyaneza et al. 2007). Current IPM plans for control of the psyllid (and indirectly, zebra chip disease) rely on insecticide treatments, in particular the use of imidacloprid (Goolsby et al. 2007), which has been found to lower transmission rates by deterring feeding of the psyllid on potato (Butler et al. 2011).

In the case of eastern hemlock trees (*Tsuga canadensis* and *Tsuga caroliniana*), trees that are valuable to Eastern U.S. ecosystems, neonicotinoids have been used as a stopgap while more sustainable long-term measures are developed to curb damage from the hemlock wooly adelgid (Cowles et al. 2006). The adelgid is an invasive species that is rapidly killing hemlock trees, with negative consequences for hemlock-associated ecosystems (Nuckolls et al. 2009).

Neonicotinoids should be applied only when their need is identified within an IPM program, and in uses that minimize impact on nontarget organisms. They should not be used prophylactically, i.e., applied routinely irrespective of whether or not they are needed.

Pest Resistance to Neonicotinoids

The environmental persistence of neonicotinoids such as imidacloprid and clothianidin, coupled with widespread prophylactic use, has led to resistance of some pests to neonicotinoids. To date, field resistance to neonicotinoids has been seen in a number of pests, including tobacco whitefly (*Bemisia tabaci*) (Horowitz et al. 2004), green peach aphid (*Myzus persicae*) (Jeschke and Nauen 2008), brown planthopper (*Nilaparvata lugens*) (Wen et al. 2009), Colorado potato beetle (*Leptinotarsa decemlineata*) (Olson et al. 2000), greenhouse whitefly (*Trialeurodes vaporariorum*) (Gorman et al. 2007), and cotton aphid (*Aphis gossypii*) (Wang et al. 2002).

Resistance to neonicotinoids can occur in pest species that have some existing degree of tolerance for nicotine (e.g., green peach aphid), in pest species that have built resistance after extensive exposure to many other classes of insecticides (e.g., Colorado potato beetle), and in pest species that have developed resistance through long-term selection after exposure to neonicotinoids (e.g., tobacco whitefly) (Tomizawa and Casida 2003).

Six neonicotinoid compounds are currently allowed for use on crops in the United States. The broad-scale use of these neonicotinoids can facilitate the development of pest resistance by enhancing conditions that favor resistant pests (Jeschke and Nauen 2008). Once resistance develops to one neonicotinoid compound, some pests may show some degree of resistance to the whole neonicotinoid class (Elbert et al. 2008). For example, in lab tests of all available neonicotinoids, researchers found that Colorado potato beetle had cross-resistance to all neonicotinoids tested, including some that had never been used in the field before (Mota-Sanchez et al. 2006).

A key strategy to reduce selection pressure upon pests is to use a product only when the need is demonstrated, such as when pest density exceeds an economic threshold. Extensive use of preemptive treatments like seed coatings contributes to increased likelihood of pest resistance, as all pests (and non-pests) in a treated area are exposed each year—regardless of whether they are at damaging levels. Recommendations for managing resistance to neonicotinoids developed by industry scientists state that neonicotinoids should be rotated with other insecticides with different modes of action, and that neonicotinoids be used to complement biological control practices (Jeschke et al. 2011). Without crop-specific guidelines for use of neonicotinoids to minimize impact on beneficial insects, and without availability of field crop seeds that are not pretreated with neonicotinoids, following these recommendations to manage resistance can be challenging for growers. Given the persistence of neonicotinoids and their increasing ubiquity, increasing pest resistance is likely in the future.

Secondary Pest Outbreaks

One unintended effect of insecticide use occurs when beneficial insects are killed, causing a sudden increase in pests that had previously been suppressed. Often those pests had not been recognized as a significant threat, and had not required pesticide-based control measures.

- Imidacloprid seed-treatment on corn controlled some pests, but increased others such as European corn borer (Pons and Albajes 2002).
- Hemlock trees treated with imidacloprid to control the hemlock woolly adelgid suffered greater injury from spruce spider mite and hemlock rust mites than untreated trees (Raupp et al. 2004).
- Spider mite populations were higher, with consequently greater plant damage, on imidacloprid-treated marigolds, because the insecticide reduced populations of a spider mite predator (Sclar et al. 1998).
- Neonicotinoid treatments of citrus orchards to prevent glassy-winged sharpshooters, which oviposit on the trees, may contribute to outbreaks of cottony cushion scale because the treatment reduces survival of the predatory vedalia beetle (Grafton-Cardwell et al. 2008).

- After imidacloprid treatment to elm trees, insect predators decreased, and spider mite populations increased (Szczepaniec et al. 2011).
- High predator mortality due to applications of thiamethoxam in cotton resulted in a resurgence of bollworm larvae (Kilpatrick et al. 2005).
- In a California vineyard, imidacloprid applications decreased populations of western predatory mite (*Galendromus occidentalis*), but did not decrease populations of the Pacific spider mite (*Tetranychus pacificus*), a damaging spider mite pest in California vineyards (Stavrinides and Mills 2009).
- Imidacloprid decreased plant defense capabilities in cotton, corn, and tomato against herbivores not susceptible to the treatment. The disruption of plant defense contributed to spider mite outbreaks in both greenhouse and field settings (Szczepaniec et al. 2013).

Due to their toxicity profiles, systemic nature, and persistence, neonicotinoids have shown negative effects in a variety of beneficial insect populations. This can lead to a disruption in biological control, which may make it more challenging to integrate neonicotinoids (especially when used systemically as seed treatments or root drenches) into existing or novel IPM programs.

4 Effects on Nontarget Invertebrates Living in Leaf Litter or Below Ground

Invertebrates such as earthworms, ants, and mound-building termites are considered to be "ecosystem engineers" for their ability to influence natural functions on a landscape level (Jones et al. 1994). Soil invertebrates enhance microbial activity, speed up decomposition, and influence movement of water, nutrients, oxygen, carbon dioxide, salt, and pollutants within the soil (Anderson 1988; Setala et al. 1988; Stork and Eggleston 1992). Earthworms, for example, influence important biological and chemical processes in the soil by moving organic matter while burrowing, and can ultimately increase plant productivity.

Earthworms and other invertebrates that dwell in soil or leaf litter can be exposed to neonicotinoids applied as soil drenches, granules, or seed coatings. Given the range of plants treated with neonicotinoids in this way, soil invertebrates face exposure in agricultural settings as well as in suburban and urban settings. Such extensive use of neonicotinoids across landscapes raises concerns about the broad impact of these chemicals on soil health, soil food webs, and soil invertebrate communities.

Earthworms, which are often used as a model test organism for ecotoxicology studies, are among the better studied soil invertebrates for nontarget effects of neonicotinoids.

- Imidacloprid, clothianidin, thiacloprid, and acetamiprid are more toxic to earthworms than other modern synthetic insecticides, including carbamates, organophosphates, and pyrethroids (Wang et al. 2012). Of the four neonicotinoids tested, acetamiprid and imidacloprid are the most toxic to earthworms (Wang et al. 2012).
- Imidacloprid is toxic to earthworms at 2.30–3.48 ppm in dry soil (Zang et al. 2000; Wang et al. 2012).
- Spray applications of imidacloprid made to turfgrass at label rates reduced earthworm populations by 40–50%, though populations recovered in about 40 days (Kunkel et al. 1999).
- Following soil-injection of imidacloprid to control emerald ash borer, soil concentrations reached a maximum of 200 ppm, and average concentrations in a small radius around the injection site were 12–25 ppm (Kreutzweiser et al. 2008). Earthworms foraging in that area would be exposed to highly toxic concentrations of imidacloprid, reported to be 2.30–3.48 ppm in dry soil (Zang et al. 2000; Wang et al. 2012).
- A range of sublethal effects have been observed in earthworms after exposure to environmentally relevant levels of imidacloprid (0.33–0.66 ppm), including sperm deformities, changes in burrowing behavior, reduced body mass, and reduced cast production (Luo et al. 1999; Lal et al. 2001; Mostert et al. 2002; Capowiez et al. 2005, 2010; Dittbrenner et al. 2010, 2011). Such sublethal effects may be impacting the activity of earthworms and thus their beneficial contributions to soil health.

The direct effects of neonicotinoids on soil invertebrates other than earthworms have not been well studied, though what studies do exist suggest negative impacts on some nontarget invertebrates.

- Use of imidacloprid on turf at label rates for grub control for three consecutive growing seasons suppressed the abundance of collembola and adult beetles by 54–62%, though ants, fly larvae, beetle larvae, and soil mites were unaffected (Peck 2009a).

- Soil organic matter adsorbs to imidacloprid, and organic matter content may influence effects of the insecticide on soil invertebrates. Knoepp et al. (2012) found that numbers of collembola and mites were lower in soil with higher imidacloprid concentrations attributed to low organic matter.
- Soil-dwelling insects may be more susceptible to parasitic nematodes after exposure to neonicotinoids. For example, imidacloprid acts synergistically with nematodes that attack scarab beetle grubs (Koppenhöfer et al. 2002) and termites (Ramakrishnan et al. 1999), making these pests more susceptible to nematode infection. The same synergistic relationship is likely true of soil-dwelling nonpest/nontarget insects.

Both lethal and sublethal effects may be impacting the activity of soil invertebrates and thus their beneficial contributions to soil health. Declines of nontarget soil invertebrates may reduce rates of decomposition and nutrient cycling.

- Sublethal, field-realistic levels (0.1 and 0.5 ppm) of imidacloprid in the soil induced alterations to the burrowing behavior of earthworms (Capowiez and Bernard 2006) and these behavioral changes altered gas diffusion in soil (Capowiez et al. 2006).
- In a microcosm experiment, consumption of leaves from sugar maple trees treated with label doses of imidacloprid induced sublethal feeding inhibitions in litter-dwelling earthworms (*Dendrobaena octaedra*) (Kreutzweiser et al. 2009). The feeding inhibition significantly reduced the amount of leaves (treated or untreated) consumed by the worms, suggesting that dietary exposure to imidacloprid could significantly reduce the decomposition rate of leaves by earthworms (Kreutzweiser et al. 2009).
- Applied as a spray treatment to turf, clothianidin significantly reduced populations of earthworms, collembola, and oribatid mites, the predominant decomposers in cool season turf. Additionally, the decomposition of grass clippings was significantly delayed (Larson et al. 2012).

Knowledge gaps include the movement and retention of neonicotinoids in soil, effects of chronic neonicotinoid exposure on soil-dwelling organisms, and whether exposure in field settings alters decomposition and soil structure. Given the persistence of neonicotinoids in soil and the value of soil-dwelling invertebrates, these are important questions to answer.

5 Conclusions

Neonicotinoids are the most widely used class of insecticides (by acreage) in the United States, with several hundred registered uses for various ornamental plants, trees, crops, and structural pests as well as veterinary purposes. As a consequence, neonicotinoids are found across the country in every managed landscape: residential yards, gardens, schoolyards, and farms. In farmlands alone, millions of acres of neonicotinoid-treated seeds are planted every year, and countless other crops, including perennial fruit and nursery crops, are treated with foliar sprays or soil drenches. In addition to being widely used, these chemicals are also persistent. Neonicotinoids are known to remain in the soil for months or even years after a single application. Measurable residue levels have been found in unplanted corn and soybean fields three years after application and in woody plants up to six years after a single application.

Because of this widespread use and environmental persistence, neonicotinoids are a threat to a wide range of beneficial wildlife. Earlier research demonstrates that neonicotinoids pose a risk to bees, birds, and aquatic invertebrates. This report demonstrates that neonicotinoids also negatively impact other beneficial arthropods, including predatory and parasitoid species that provide biological control of crop pests and soil invertebrates that are critical to soil health.

Collectively, all of this research suggests that despite claims that neonicotinoids are a safer alternative to nontarget wildlife than older insecticides, use of neonicotinoids poses a threat to pollination services, to biological control, and potentially to soil health.

Prophylactic neonicotinoid use is widespread. Virtually all non-organic corn seed planted is now treated with neonicotinoids, and non-organic untreated seed is difficult to obtain. However, past and ongoing research demonstrates that preventative neonicotinoid seed treatments do not consistently result in successful management of key pests or crop yield benefits, which suggests that widespread use of treated seed is not warranted. Though seed treatment offers convenience for farmers, its use is not always supported by pest pressures or yield increases, and it may not be as cost effective as measures taken as part of an IPM program.

When balancing the need for food production with the conservation of biodiversity, there may always be some impacts on nontarget wildlife. However, too many tradeoffs at the expense of pollinators, beneficial insects, and soil invertebrates will threaten the ecosystem services upon which food production depends. We need to re-evaluate the usage of neonicotinoids, to fully account for the risks to the nontarget wildlife that contributes so much to farm and ecosystem health. Uses of neonicotinoids that result in little or no pest management benefit are counter-productive and pose an unacceptable risk to the health of land on which we all depend.

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